POLYCENTRIC URBAN DEVELOPMENT IN CHINA

by

MINGSHU WANG

(Under the Direction of Marguerite Madden)

ABSTRACT

Today, over 50% of the world's people live in urban areas, and the number is expected to keep growing. Understanding factors that influence urban growth through analysis of urban form is critical to urban planning towards optimizing efficiency and maximizing function. Recent attention has been paid to the polycentric urban development, which can be defined as the process of multiple independent urban centers of balanced sizes to be integrated by various forces. It has been highlighted in recent literature and adopted by policymakers as part of spatial development strategies around the world because the purported economic, social, and environmental benefits. Given there is limited empirical evidence supporting those speculated benefits and the emerging polycentric urban development in China, this investigation assessed the relationship between polycentric urban development and all the three pillars of outcomes (i.e., economic, social and environmental benefits) in Chinese cities. The results show that polycentric urban development at intra-urban scale is associated with higher carbon emission and less labor productivity, but higher quantity and diversity of urban amenities. Polycentric urban form at inter-urban scale and monocentric urban form at intra-urban scale are correlated with higher labor productivity. Also, there is synergy effect between polycentric urban development at intra-urban and inter-urban scales.

INDEX WORDS: Polycentricity, Urban Form, Sustainable Development, China

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

Over 50% of the world's population live in urban areas today, and the number is expected to keep increasing. Urban development is associated with a concentration of people living in cities, which brings opportunities and posts challenges to the society. One the one hand, urban development allows innovation and increases economic productivity. As of today, more than 80% of the world's Gross Domestic Product (GDP) is produced in cities (World Bank, 2018). On the other hand, it posts challenges to the society. Pollution and crime are just a couple of examples of negative externalities that are associated with urbanization. Furthermore, cities are vulnerable to climate change and disasters, as more than two-thirds of the world's population resides within 100-km of coastlines. Given the importance of urban development, scholars and policy-makers have devoted themselves to searching for sustainable paths of urban development. One type of urban development regimes, namely, polycentric urban development, has been on the radar of stakeholders, because of its purported economic, environmental, and social benefits.

WHAT IS POLYCENTRIC URBEN DEVELOPMENT?

Polycentric urban development refers to a suite of processes causing cities/regions consisting of multiple, independent, and proximately located urban centers with roughly equal importance (Figure 1-1). Polycentric urban development has been described by various terms, featured by polycentric, polycentricity, polynucleated, etc. For example, while Musterd and Kloosterman (2001) use the term of polycentric urban region, Scott (2001) argues that the city-regions of today are becoming increasingly polycentric or multi-clustered agglomerations (p. 18). When it comes to the Randstad, Lambooy (1998) articulates the word 'polynucleation' in illustrating its economic development; Kühn (2003) sticks to the term polycentric city-region. In general, Europe uses 'polycentric urban region' more often (e.g., Kloosterman and Lambregts (2001), Meijers and Romein (2003), and Parr (2004)); (polycentric) mega-regions are frequently mentioned in US-based studies (e.g., Florida et al. (2008) and Innes et al. (2010)). More recently, there is an emerging trend of polycentric urban development in China (e.g., Yang et al. (2015) with the term of 'megaregions', Liu and Wang (2016) and Liu et al. (2017) with the terms of polycentricity and polycentric urban regions).

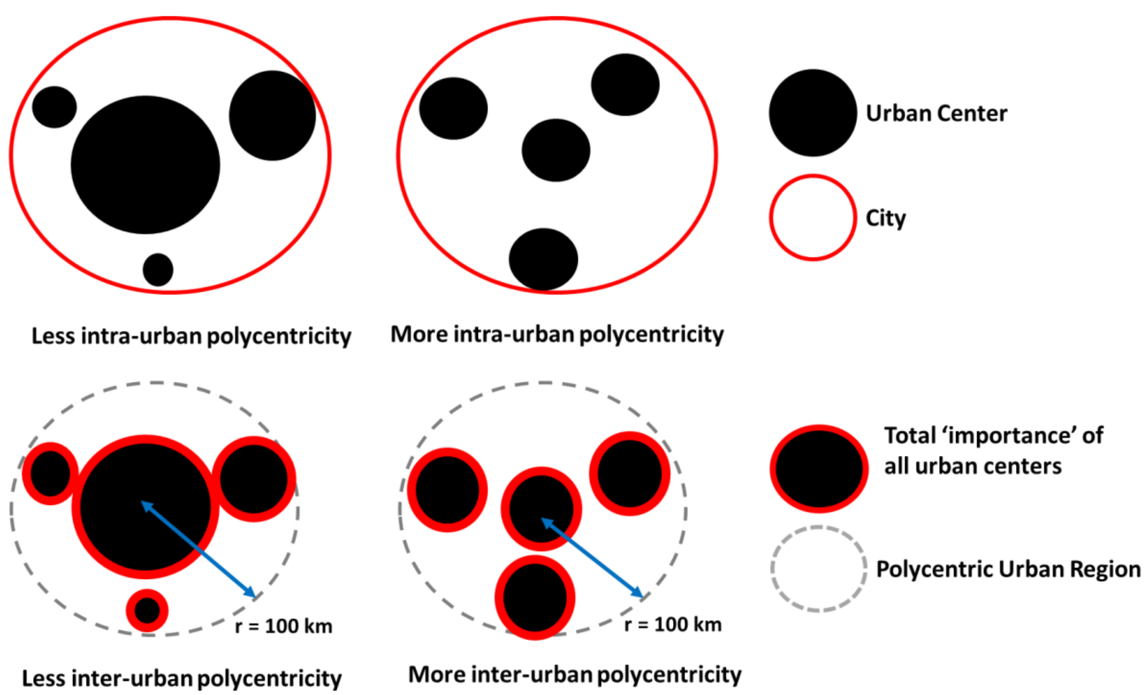

Figure 1-1. Diagram of polycentric urban development. The upper panel: each solid circle refers to an independent 'urban center' of a city; the relative size of the circle denotes the relative 'importance' of that center. The lower panel: each solid circle denotes the

summation of the ‘importance’ among all urban centers with a city; the relative size of the circle describes the relative ‘importance’ of that city within the polycentric urban region.

A precursor of polycentric urban development can be found in the concept of the ‘urban field’ (Friedmann and Miller, 1965; Pred, 1977). Castells (1989) argues that the essence of the emerging ‘new spatial logic’ is the creation of ‘multifunctional, multinuclear spatial structures’ in the informational city. More recently, ‘multi-city regionalism’ has been proposed in North America to embody both an emerging trend of growth coalitions and an appearing configuration of regional economic governance (Wachsmuth, 2017a, b).

Despite these different terms sometimes attempting to capture different processes and/or a specific dynamic, they have a shared essence: there are multiple urban centers in more or less proximity; there is a relative balance in the ‘importance’ of these various urban centers; we see this urban form popping up in different parts of the world, and the relative balance has a range of alleged advantages.

A BRIEF HISTORY OF POLYCENTRIC URBAN DEVELOPMENT

In retrospect, the rise of literature dating back to half century ago (Gottmann, 1957) regarding polycentric urban development is contingent upon both the empirical realities and normative dimensions. As a global phenomenon, empirical evidence concerning polycentric urban form can be dated back to several decades. Recently, Taubenböck and Wiesner (2015) have utilized satellite remote sensing data since 1970s to track the dynamics of five polycentric urban regions worldwide, including the Pearl River Delta (Asia), Southern California (North America), Amsterdam-Rotterdam, Ruhr-Cologne, Brussels-Antwerp and Lille (Europe), Sao Paulo- Rio de Janeiro (South America), and Nile Delta (Africa). Additionally, the area of Padua–Treviso–Venice in northern Italy, Kansai area in Japan (Batten, 1995), and central Scotland (Bailey and Turok, 2001) can be construed as polycentric urban regions. In the normative dimensions, polycentric urban regions have been imaginary entities, whose existence is long rooted and worth exploring and implementing. Individual countries in Europe have construed its polycentric urban regions, such as the Rhine-Ruhr in Germany, the Rhone-Alps in France, and the Randstad in Netherland. Later, the idea of polycentric urban regions has spread to the whole of Europe (Brezzi and Veneri, 2015) and integrated into European spatial development strategy and promoted by the European Spatial Development Perspective (Davoudi, 2003).

Importantly, the empirical realities and normative pursuits are often interrelated with each other, indicating complicated connotations of polycentric urban development. In the US, economic growth has historically been conducted at the individual city level, but now pursued through partnerships of polycentric city-regions. There are 171 partnerships of polycentric urban regions today in the US, compared to only 12 in 1973 (Wachsmuth, 2017a). In Russia, although Moscow is embedded as a polycentric megacity, the polycentric urban region of ‘New Moscow’—which is next to the ancient capital is marked by institution building of tightening central control (Argenbright, 2013). In China, the governance of polycentric urban regions can be interpreted as a state spatial selectivity to annex administrative power and prepare for the national spatial plan (Wu, 2017).

WHY AND HOW POLYCENTRIC URBAN DEVELOPMENT HAPPENED

Given the complex nature of polycentric urban development regarding why and how, the reasoning for polycentric space and space of polycentricity is of importance. To this end, a fundamental question is what makes polycentric urban regions as economically, politically, culturally and institutionally coherent spaces? Such quest can be understood by twofold analytics. First, the question of spaces of polycentricity refers to what spaces are consolidated to form these polycentric urban regions and how coherent are they as a single polycentric urban region space. For example, Dash Nelson and Rae (2016) use commuter flow data to partition polycentric megaregions in the US; Liu et al. (2017) apply gridded population data to extract centers within polycentric urban regions. An essential message here is that the spatial proximity of two cities is necessary but not sufficient to form a polycentric urban region. Second, the question of polycentric urban region space refers to examining differences spaces, places and communities across polycentric urban region space and producing nuanced knowledge about the regional identity and governance in that polycentric urban region space. Indeed, the geographical, socioeconomic and institutional processes across polycentric urban region spaces are unevenly distributed (Liu et al., 2017; Liu and Wang, 2016).

While there are some well-worn polycentric urban region examples around the world, it should be cautioned that such urban form should be taken for, neither is it the outcome of the singular set of processes. Instead, more attention should be paid to the context and underlying historical processes of polycentric urban regions. First, polycentric urban regions can be realized at very different scales even within the same economy. On one hand, a Chinese prefectural-level city can resemble an intra-city urban system, as it is usually composed of one core urban area and its surrounding regions (Liu and Wang, 2016). However, the heterogeneity of prefectural-level city composition in a Chinese context makes it sometimes regarded as a city-region in a Western context. For example, while most prefectural-level cities only contain districts, counties, and towns; some also include county-level cities and other sub-divisions. On the other hand, polycentric urban regions in China are perceived as city-regions and megaregions in a Western context (Liu et al., 2017; Yang et al., 2015). However, a single Chengdu-Chongqing polycentric urban region, consisting of 18 cities, covers over 2.6 million km^2, which is roughly equivalent to 60% of the whole EU areas. Therefore, theories and practices that have been envisioned and effectuated in European territorial development might also be applicable in polycentric urban development in China. Nevertheless, the point here is not to unify different terminologies delineating polycentric urban development in China but highlight that context matters. Additionally, rather than seeking for an ideal-type of polycentric urban development, much can be gained from explicitly exploring the diverse forms of polycentric urban forms.

Second, polycentric urban development can be observed by variable forms worldwide. For instance, the number of cities within each of the 22 identified Chinese PURs by Liu et al. (2017) range from three to eleven. Difference perspectives of the Randstad (in the central-western Netherlands) can include four (i.e., Amsterdam, Rotterdam, Hague, and Utrecht) or fourteen cities (Meijers, 2005). Third, polycentric urban development can be achieved in different settings, and some polycentric urban development outcomes are transnational. For example, in North America, the PUR of El Paso (TX, USA)— Las Cruces (NM, USA)—Ciudad Juarez (Mexico) (a.k.a. Paso del Norte) covers areas of two states in the US and the Ciudad Juarez metropolitan area in Mexico. This polycentric urban region ranks the most considerable bilingual and binational work force in the Western Hemisphere. In Europe, the Öresund PUR is transnational and anchored by Copenhagen, Denmark and Malmö, Sweden; the Dublin–Belfast Corridor encompasses the metropolitan of Dublin (Ireland) and Belfast (United Kingdom). Fourth, polycentric urban development is situated in different historical backgrounds. Although the 'desakota' phenomena in East Asia can be analogous to the polycentric urban development process in Europe for the past 150 years, where the polycentric network of towns and cities dating back to more than 500 years ago has promoted urban growth (Kloosterman and Lambregts, 2001), the underlying historical settings (e.g. who developed for whom) can be different. Polycentric urban development is not something entirely new in the more than hundreds of years' urban history (Schafran, 2015). Indeed, the developmental processes of polycentric urban form have some historical continuity and the trajectories of the development regime today is reflected and impacted by its localized histories. For example, the greater Paris (Ile-de-France) polycentric urban region (Figure 1-2), where one fifth of people in France reside, was formed in 19th century.The core of this region is distant from other major cities, despite the fact that Paris was connected to all roads and terminals for all trains. Relatedly, the developmental pathway of the Pearl River Delta can be dated back to 2000 years ago in Qin Empire—China's first centralized empire (Zhang, 2015).

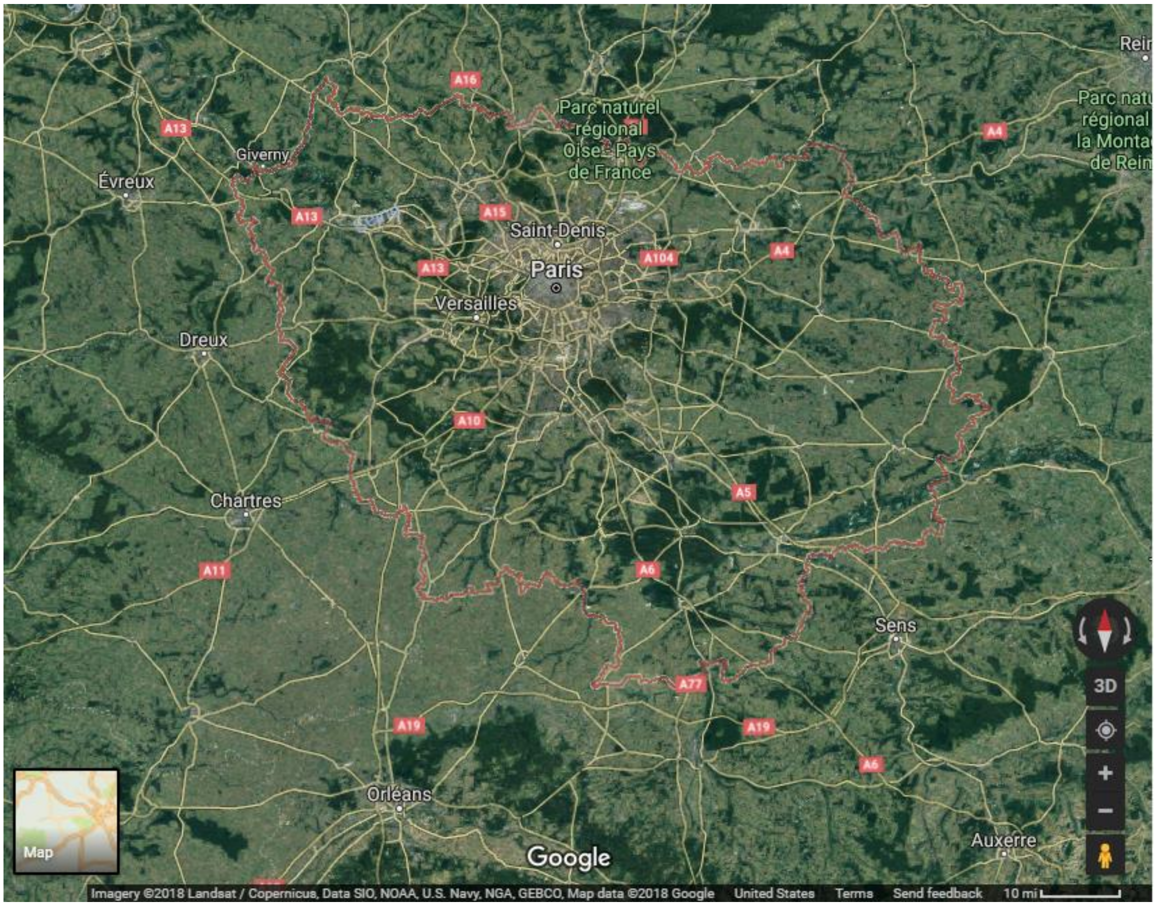

Figure 1-2. A Screenshot of the Ile-de-France polycentric urban region (Credit; Google). The area enclosed by red solid line is the Ile-de-France polycentric urban region.

Nevertheless, contemporary polycentric urban development is oftentimes deemed a desirable urban form, generating greater agglomeration externalities as well as facilitating the achievement of social, economic, and environmental goals (Parr, 2004). However, there are surprisingly very limited empirical studies to test those speculated benefits of polycentric urban development. Moreover, most of the existing studies are based on Western cities (i.e., in the US and Europe); there is a shortage of related studies in Chinese cities. Given such a development regime is emerging in current China and the complex nature of Chinese cities, my dissertation project aims to provide empirical evidence of the pros and cons of polycentric urban development in China.

OBJECTIVES AND HYPOTHESES

The general objective of this study is to improve our understanding of polycentric urban development in China, especially regarding the existence of environmental, economic, and social benefits. While GIScience methods are utilized to compute key indices from various geospatial data, econometrics are applied to unveil the effects of polycentric urban development on the benefits above. Specific objectives of my research include:

- Investigate the relationship between polycentric urban development and environmental response of carbon emissions;
- Inspect the economic benefits of polycentric urban development as proxied by non-agricultural labor productivity;
- Examine the social benefits of polycentric urban development regarding the quantity and variety of urban amenities.

Chapter 2 aims to explore the relationship between urban form and its environmental performance in Chinese cities. I focus on the measures of polycentric urban development (i.e., polycentricity) and urban land use compactness and consider the carbon emission as one example of environmental response. Specifically, I empirically test the following three hypotheses:

- More populous urban areas are more emission efficient than smaller cities due to economies of scale (size);
- More compact urban forms (compactness) are associated with less CO_2 emission;
- More polycentric urban regions (polycentricity) produce less emission.

Chapter 3 focuses on the economic benefits of polycentric urban development, measured by labor productivity. Specifically, I empirically test the following four hypotheses regarding the multiscalar nature of polycentric urban development:

- A higher degree of intra-city polycentricity is associated with higher labor productivity;
- A higher degree of inter-city polycentricity is associated with higher labor productivity;
- A small city may benefit more economically in a polycentric urban region;
- There is a positive interaction effect between intra-city polycentricity and inter-city polycentricity in terms of labor productivity.

Chapter 4 targets the social development aspect of polycentric urban development, where social development is reflected by the provision of urban amenities. Specifically, I empirically test the role of polycentric urban development in the quantity and diversity of urban amenities, which can be summarized as the following two hypotheses:

- A high degree of intra-urban polycentricity is associated with a larger quantity of urban amenities.
- A high degree of intra-urban polycentricity is correlated with greater diversity of urban amenities.

The dissertation concludes with a closing chapter (Chapter 5), which summarizes the main findings of this study. It also points out some directions for future research.

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CHAPTER 2

EXPLORING THE RELATIONSHIP BETWEEN URBAN FORMS AND CARBON DIOXIDE EMISSION IN 104 CHINESE CITIES[1]

[1] **Wang, M.**, Madden, M., & Liu, X. 2017. *Journal of Urban Planning and Development, 143*(4), 04017014.

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ABSTRACT

We explore the empirical relationship between city-level urban form and CO_2 emission in 104 Chinese prefectural level cities. While the analytical focus is on polycentric urban form, our analysis has also accounted for population size and land use compactness. CO_2 emission data are aggregated from the Fossil Fuel Data Assimilation System (FFDASv2) data portal. We find substantial economies of scale in CO_2 concerning total population. Further, despite a substantial wealth effect on CO_2 emission, cities with more centralized and compact urban form are associated with lesser emission, *ceteris paribus*. While existing analyses of CO_2 emission in Chinese cities are often limited to a handful of provincial capitals, our analysis covers a larger sample of cities. The paper concludes with spatial planning policy implications.

INTRODUCTION

Managing anthropogenic carbon emission posits a significant challenge to Chinese cities. Against the backdrop of various global greenhouse gas (GHG) reduction initiatives, China has become the largest emitter of CO_2 since 2007 (International Energy Agency, 2012). While existing GHG emission reduction strategies rely on technological solutions (e.g., renewable energy, and zero-carbon buildings) and market-based approaches (e.g., carbon trading), they are oftentimes unable to reach carbon reduction goals by themselves (Dodman, 2009, Ross Morrow, Gallagher, Collantes and Lee, 2010, Lee and Lee, 2014). Similarly, smart city initiatives call for an integrated approach to sustainability, emphasizing the idea that ‘technology is not enough’ (Angelidou, 2014). Indeed, a growing body of literature has identified urban form can be used as a supplementary emission reduction strategy and empirical analyses have been performed to explore urban form’s impacts on energy consumption and carbon emission (Anderson, Kanaroglou and Miller, 1996, Marshall, 2008, Poumanyvong and Kaneko, 2010, Futcher and Mills, 2013, Marins and Roméro, 2013). For example, aiming at contributing to the global emission reduction goals while sustaining the country’s economic development, the Chinese government has adopted advancing the development of low-carbon cities (Liu and Qin, 2016).

Since the late 1990s, research has highlighted urban forms including polycentric urban regions (PURs) to assess their role in fostering sustainable development. PURs have been pursued in recent years by cities across the world as both an ideal urban pattern and a development strategy. PURs emerge when previously proximate, but independent, urban settlements become functionally integrated (Parr, 2004, Hall and Pain, 2006). For example, polycentric urban development has been incorporated into normative development visions in both the United States and Europe (Vandermotten, Halbert, Roelandts, and Cornut, 2008, Harrison and Hoyler, 2014). The concept of PURs is associated with positive agglomeration externalities (Kloosterman and Lambregts, 2001, Burger, Van der Knaap and Wall, 2014), and PURs are considered to be able to reduce energy consumption and CO_2 emission by fostering mixed land use and shorter commuting trips, producing fewer heat island effects (Ewing and Rong, 2008, Lee and Lee, 2014), and enhance the receptivity of public transit (Veneri, 2010). Given the prevalence of polycentric urban development policies, surprisingly limited research has examined the association between polycentric cities and carbon dioxide (CO_2) emission. Therefore, this paper aims to assess such association for Chinese cities, controlling for socioeconomic variables and regional heterogeneities.

The Chinese central government has launched a national 'new form of urbanization' initiative, which features polycentric urban regions. The new initiative in China's the 12th Five-Year-Plan (2011—2015) aims to foster more sustainable urban patterns and target reducing 17% of CO_2 emissions per unit of Gross Domestic Product (GDP). More recently, in the 4th Central Government Urban Conference (2015), China's leadership reiterated the importance of the pursuit of compact, efficient and environmentally-friendly urban development (Liu and Wang, 2016).

With the increasingly important role of sustainable urban development in China's urbanization and GHG reduction strategies, an analysis of urban form and CO_2 emission is particularly relevant. First, China is still undergoing rapid urbanization (Bai, Shi and Liu, 2014, World Bank Group, 2015), leaving much room to shape its future urban forms (Dhakal, 2009, Liu, Song and Song, 2014). Second, China needs to carefully balance CO_2 emission and more generally environmental sustainability with other developmental objectives that could be affected by urban forms, such as economic opportunities, housing affordability, and social cohesion (Clark, 2013, Fragkias, Lobo, Strumsky and Seto, 2013). Third, given that the Chinese authority is incorporating compact city form and PURs into normative urban planning, a firm understanding of the relationship between these urban forms and GHG emissions is a prerequisite for sound policies and plans.

Existing research on the significance and magnitude of urban form effects on GHG emission is somewhat inconclusive (Makido, Dhakal and Yamagata, 2012, Clark, 2013, Lee and Lee, 2014). Although some scholars claim that carefully designed urban form potentially complements technology-based approaches (Marshall, 2008), others suspect the magnitude of the effects of urban form in emission reduction (Mindali, Raveh and Salomon, 2004, Gaigné, Riou and Thisse, 2012). Furthermore, most previous empirical studies of urban form and GHG emission have focused on cities in the United States and Europe, and existing analyses of Chinese cities are oftentimes limited to national and provincial capitals (Ou, Liu, Li and Chen, 2013, Liu, Song and Song, 2014, Fang, Wang and Li, 2015). In other words, there is a need for comprehensive examination of the impacts of urban form on CO_2 emission in China.

Therefore, this paper explored the relationship between polycentric urban form and aggregated CO_2 emission for 104 Chinese cities at the prefectural level and above, controlling for other urban spatial structures and socioeconomic variables. More specifically, we focus three types of urban form features, including population size, compactness, and polycentricity. Factors including in this study does not aim to exhaustive, as technological endowment and market institutions are excluded. The paper is organized as follows: The next section highlights gaps in existing research on urban form and GHG emission and identifies paths through which compact and polycentric urban development would contribute to emission reduction. The paper then elaborates on data sources and urban form metrics. The results and corresponding spatial planning implications are presented subsequently. The article concludes with several spatial planning policy implications, as well as a discussion of limitations and future studies.

LITERATURE REVIEW

The relationship between urban form and carbon emission

The relationship between urban form and CO_2 emissions has attracted attention from many scholarly fields. Notably previous studies on urban form and transport/building emission have highlighted the connection between vehicle mile traveled (VMT) and the built environment (Ewing and Cervero, 2010; Mohajeri et al., 2015). Nevertheless, these studies focus mainly on individual sectors and neighborhood-scale effects (Norman, MacLean and Kennedy, 2006, Cervero and Murakami, 2010, Ascione, De Masi, de Rossi, Fistola, Sasso and Vanoli, 2013, Ye, He, Song, Li, Zhang, Lin and Xiao, 2015). Such single-sector neighborhood-level analysis could miss potential tradeoffs among different sectors (e.g., transport, building, and production) that are induced by city-level urban spatial structures (Lee and Lee, 2014).

The polycentric urban form could affect household energy consumption and CO_2 emission through several paths, although there remain debates about the direction and size of impact (Lee and Lee, 2014). First, working in tandem with compact urban development, polycentric urban form often fosters shorter commuting trips and mixed land use, reducing overall travel and emission (Veneri, 2010; Lv and Sun, 2013). However, the contrary could also be true, as evidenced by Cervero and Wu, (1997); Schwanen et al., (2004); and Næss (2007). Second, scholars have conjectured that polycentric urban patterns could mitigate heat islands effects, by leaving more green spaces between subcenters (Ewing and Rong, 2008). Third, urban polycentricity could affect household emission through housing options, as relatively low housing prices in polycentric cities could induce larger houses and greater energy use (Zheng et al., 2010; Lee and Lee, 2014). Fourth, polycentric cities could have impacts on public transit. On the one hand, polycentricity could give rise to competitive public transit in densely populated subcenters (Susilo and Maat, 2007; Veneri, 2010). On the other hand, citing evidence from US cities, researchers (Cervero and Wu 1997; Lee and Lee 2014) suggest that the transformation towards polycentric cities may reduce public transit use. Overall, polycentric urban form tends to affect household transportation and heating more directly and exerts influence on household electricity and domestic fuel consumption in more indirect ways. Nevertheless, the evidence mentioned above is primarily based in Western countries, where the scope of the city in the US and Europe may not be the same as it is in China. Therefore, it should be cautious to infer the pathways how polycentric urban form impacts energy consumption and CO_2 emission in Chinese cities.

Other city-level spatial structures abate CO_2 emission in direct and indirect ways (Liu and Shen, 2011). First, referring to the 'Kleiber's law' in ecology, Bettencourt et al. (2007) argue for the existence of economies of scale in CO_2 emission concerning urban population. Nevertheless, empirical evidence suggests that larger cities are not necessarily emitting less CO_2 (Fragkias et al., 2013), and could have greater urban heat island effects (Arnfield, 2003).

Second, urban density is deemed essential in reducing commuting time and distances, alleviating heating/cooling needs of buildings, as well as enhancing the feasibility of public transit (Newman and Kenworthy, 1989; Ewing and Cervero, 2010). For example, lower residential density is often associated with greater household fuel consumption and longer VMT (Marshall, 2008). On the contrary, other scholars suggest that such connection between density and emission efficiency remains unclear (Mindali et al., 2004; Echenique et al., 2012). Still, Baur, Thess, Kleinschmit, and Creutzig (2014) found population density in European cities play a less important role in emission reduction, compared to household size and wealth.

Third and relatedly, compact city policies are often pursued as the panacea for urban sprawl and other urban problems (Marshall, 2008). In addition to socioeconomic benefits, compact cities are often deemed emission-efficient, through the preservation of open space, the promotion of more sustainable transportation and mixed land use, the abundance of multi-dwelling units, as well as the mitigation of urban heat island effects (Zhou et al., 2011; Debbage and Shepherd, 2015). There seems to be a consensus on the environmental effects of compact cities (however, see Echenique et al. 2012; Gaigné et al., 2012).

Taken together, existing empirical studies often show quite contrasting results, partly because previous studies adopt different urban form measures, focus on different analytical scale and sectors, and employ CO_2 emission estimated in different ways (Parshall et al., 2010). For example, ‘polycentric cities’ have been empirically defined and measured at essentially very different geographical scales (Veneri, 2010). Studies on the US and European cities often look at intercity polycentricity and focus on city-regions forged mainly by commuting trips among individual cities. Importantly, the concept of a city in the US and Europe may not be aligned with that in China. To ease understanding, we provide a brief introduction to Chinese urban system in next section. Nevertheless, (planned) city-regions in China often extend beyond commuting distance, contracting to the fact in western countries and polycentricity at intra-city scale might be more relevant for carbon emission studies in China.

CO_2 emission measurements

Data availability and method reliability are two major issues in carbon emission accounting (Marcotullio, Sarzynski, Albrecht, Schulz and Garcia, 2013). There are three broadly categorized methods for measuring CO_2 emissions in the urban context. The first type is direct measurement, which is recommended to secure the most accurate emission data (Gurney, Razlivanov, Song, Zhou, Benes and Abdul-Massih, 2012). However, as a bottom-up approach, it is usually resource and time to consume and often restricted to certain industries (Dhakal, 2009). The second method involves inventorying energy use and deriving total emission based on emission factors as identified by the Intergovernmental Panel on Climate Change (IPCC) (Liu, Song and Song, 2014). However, applying those emission factors directly to China can be problematic, because China uses a mixture of different fuels, for which it lacks the actual measurement of the emission coefficient (Liu, Guan, Wei, Davis, Ciais, Bai, Peng, Zhang, Hubacek, Marland, Andres, Crawford-Brown, Lin, Zhao, Hong, Boden, Feng, Peters, Xi, Liu, Li, Zhao, Zeng and He, 2015). The third type is the top-down approach, which downscales national CO_2 emission measurements based on distributions such as population and nightlight (Van Vuuren, Smith, and Riahi, 2010). Though easy to compute, this approach often undervalues emissions from energy and emission intensive plants (e.g., power stations; (Ghosh, Elvidge, Sutton, Baugh, Ziskin and Tuttle, 2010), as these plants are usually located in sparsely populated areas.

Alternatively, a hybrid method may serve the needs for measuring CO_2 emissions in China. For example, the latest Fossil Fuel Data Assimilation System (FFDAS) provides a global CO_2 emission at 0.1° × 0.1° (10 km × 10 km) spatial resolution from 1997 to 2010 (Rayner, Raupach, Paget, Peylin and Koffi, 2010, Asefi-Najafabady, Rayner, Gurney, McRobert, Song, Coltin, Huang, Elvidge and Baugh, 2014). The current FFDAS (a.k.a. FFDASv2) has an improved top-down approach by incorporating information from the bottom-up approach, such as global power plant emissions information. FFDASv2 products have been cross-validated with the Vulcan project, which is considered as the latest bottom-up approach to fossil fuel emissions in the United States (Gregg, Losey, Andres, Blasing and Marland, 2009). The comparison shows a strong correlation between FFDASv2 and Vulcan (i.e. a correlation coefficient of 0.86 at the scale of 0.1° and 0.99 at the scale of 4°) (Asefi-Najafabady, Rayner, Gurney, McRobert, Song, Coltin, Huang, Elvidge and Baugh, 2014), suggesting the applicability of FFDAS data for city-regional analysis.

DATA AND METHODS

Our analysis focuses on 104 Chinese cities at the prefectural level and above. A prefectural level city (including *di ji shi*, *zi zhi zhou*, *diqu*, and *meng*) usually comprises of core urban districts and their surrounding region which, in turn, contains districts, county-level cities, counties, towns, and/or other sub-divisions (Li, 2014). It is the second level unit (i.e., below province and above county-level city) in Chinese administrative system. Cities are further categorized for differences in energy consumption structure and climates (Figure 1). First, cities are classified into two Zones (i.e. North or South) based on China's Huai River Policy (Chen, Ebenstein, Greenstone and Li, 2013), by which cities in the North are covered by centralized home heating policy and cities in the South are not. Second, cities are classified into three Regions (i.e., Eastern, Central, and Western) based on Fan and Sun (2008), and from Eastern to West China, the climate changes from monsoon climate to continental climate. Although there are more than 300 administrative units at the prefectural level and above in China, we exclude those that lack accurate CO_2 emission estimates and auxiliary data. Nevertheless, our final sample has covered all provincial capital cities and is geographically well distributed (Figure 2-1).

Our empirical framework extends from the approaches adopted in Fragkias et al. (2013) and Liu et al. (2014). As the latest available FFDASv2 products were in 2010, we selected the year of 2010 for this analysis and collected all ancillary data in the same year. Boundaries of prefectural level cities are obtained from the open data repository of the National Bureau of Statistics of China (http://data.stats.gov.cn/). Data regarding population, GDP (including total, industrial sector, and tertiary sector), and the average number of public transit bus per 10,000 inhabitants (Bus) are secured from the Chinese City Statistical Yearbook. The ratio of GDP from the industrial sector to that from the tertiary sector was calculated as ST. The national land use map of 2010 is downloaded from the Data Center for Resources and Environmental Sciences of Chinese Academy of Sciences at a 1km by 1km spatial resolution.

CO_2 data are from FFDASv2 (http://hpcg.purdue.edu/FFDAS/) and are aggregated at the individual city level. As shown in Figure 1, the 104 cities selected for our analysis cover regions with highest CO_2 emission intensity in China. As a robustness check, the aggregated CO_2 emissions from FFDASv2 were cross-validated from a second source, which applied an inventory-based approach to estimate CO_2 emission (Zhang and Zou, 2013). Two sources of CO_2 yield a Pearson's r of 0.774.

The compactness and polycentricity measures of individual cities are characterized as follows. Compactness reflects the degree to which urban development is concentrated from a land use perspective. Built-up areas of individual cities are extracted from the land use map. Following Liu, Song, and Song (2014), we adopt the Compactness Ratio indicator, which characterizes the compactness of an urban area based on its minimum circumscribing circle. An illustration of the Compactness Ratio is shown in Figure 2-2. More specifically, for each city, we compute the average Compactness Ratio across a city as the compactness index for that city, based on the Equation 2-1:

$$Compactness = \frac{1}{n}\sum_{k=1}^{n}\frac{A_k}{A_k^c} \quad \text{(Equation 2-1)}$$

Where A_k refers to the area of the kth continuous built-up area within a city, and A_k^c refers to the corresponding minimum circumscribing circle of the kth continuous built-up area. The higher the compactness index is, the more compact the city is.

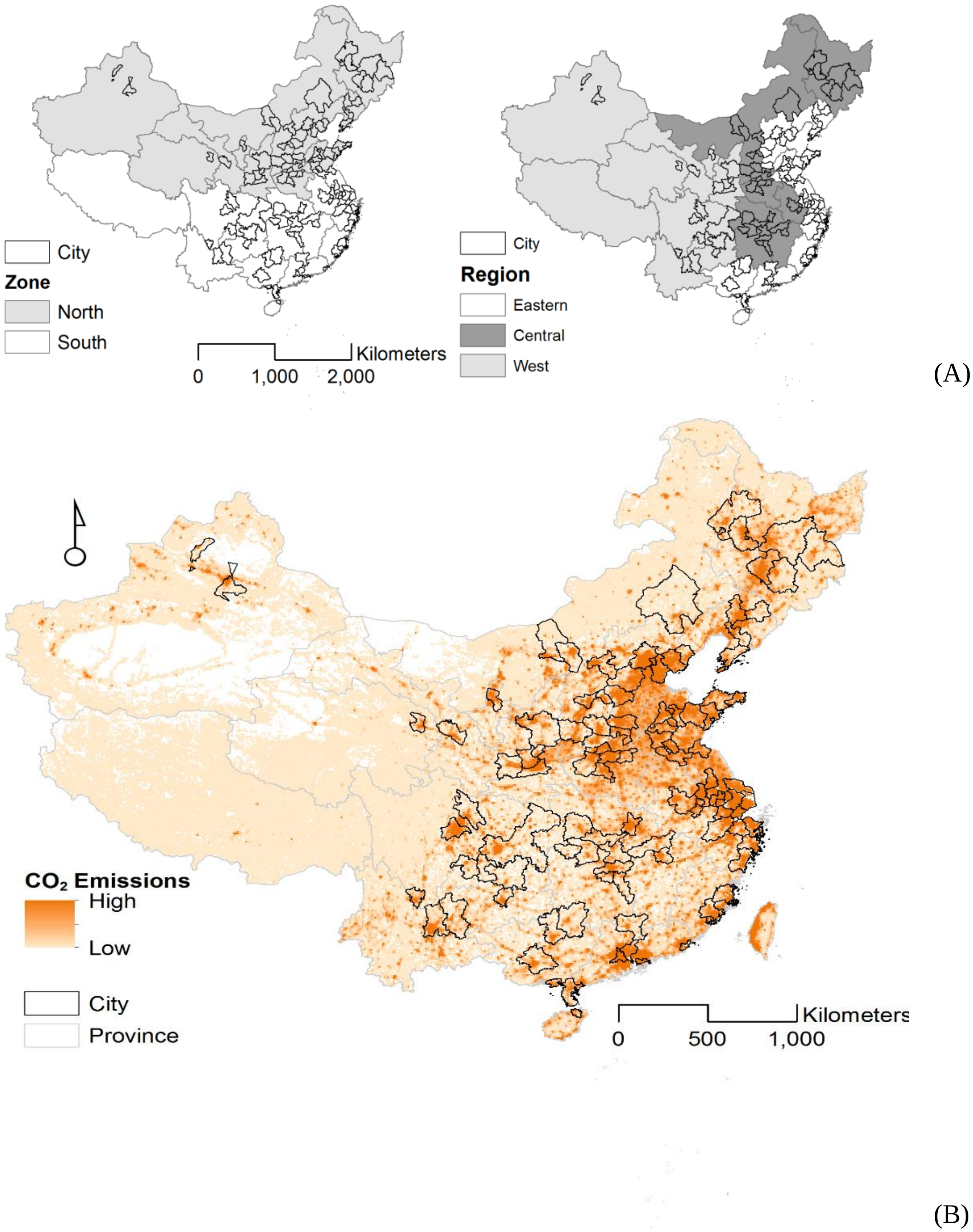
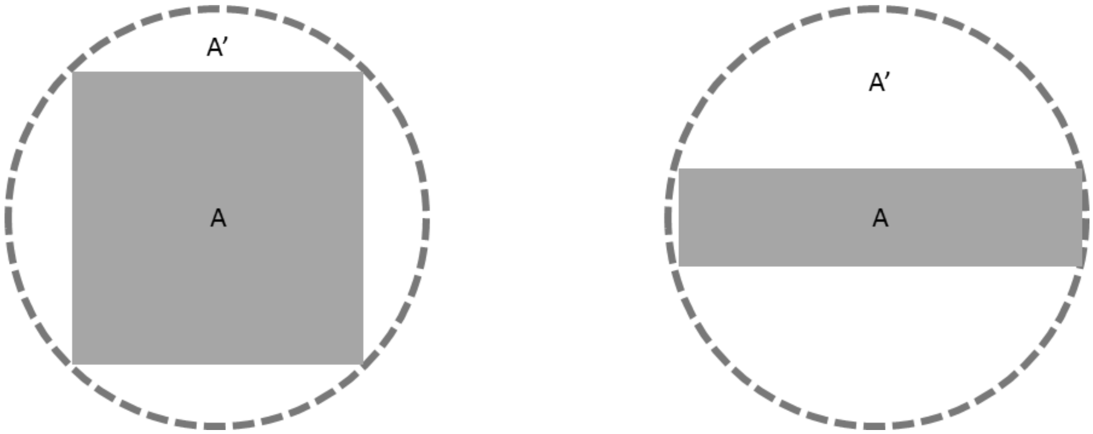


Figure 2-1. (A) The distribution of cities in this study; (B) CO2 emissions of cities in this study.



More compactness Less compactness

Figure 2-2. The conceptualization of Compactness Index. A refers to the area of the grey square (rectangle), A' refers to the area of the dotted circle. Structure in the left panel is more compact than that in the right panel, and thus has a higher value of Compactness Index.

Compare to the compactness index, which reflects urban spatial structures from a land perspective; the polycentricity measure emphasizes urban forms from a population perspective. A holistic view of both indices will provide more nuanced insight of a city's urban spatial structure. To measure polycentricity, we adopt a morphological definition of polycentricity, which has been widely applied and empirically examined in the polycentric urban development literature in the US (Meijers and Burger, 2010), Europe (Meijers, 2008) and Chinese cities (Liu and Wang, 2016). The morphological definition of polycentricity summarizes the relative balanced or hierarchical distribution of urban population within different sub-divisions of a city. Figure 3 conceptualizes morphological polycentricity that applied in this study. Although there are other definitions of polycentricity (e.g., relational or functional polycentricity), which provide additional insights, the morphological characterization is most pertinent to the aim of this paper—how urban forms relate to carbon emission. Additionally, functional characterization of polycentricity requires intra-city commuting records or information flows information such as telecommunication log (Liu, Derudder and Wu, 2016), which are less likely to be obtained for hundreds of cities in China.

Less polycentric More polycentric

Figure 2-3. The conceptualization of Polycentricity Index. Each solid circle refers to a sub-division of a city. The relative area of the circle denotes the relative population size of that sub-division. The urban system in the left panel is more hierarchical and less balanced than that in the right panel, and thus has a less value of Polycentricity Index.

We adapted the polycentricity index proposed by Meijers (2008) and Meijers and Burger (2010), and for each city, the degree of polycentricity is calculated based on the rank-size distribution of the second, third, and fourth most populated sub-divisions (including districts and counties). More specifically, the slope of the regression line that characterizes the rank-size distribution of the above-mentioned urban system is taken as the polycentricity index based on Equation 2-2:

$$Polycentricity = \frac{\sum_{i=2}^{4} \sum (x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=2}^{4} (x_i - \bar{x})^2} \text{ (Equation 2-2)}$$

Where for the i th largest sub-division, $x_i = \log_{10}(i + 0.5)$; y_i denotes the logarithm of the population with base 10; $\bar{x} = \frac{\sum_{i=2}^{4} x_i}{3}$; and $\bar{y} = \frac{\sum_{i=2}^{4} y_i}{3}$. The higher the polycentricity index of a city, the more evenly distributed is the population of the city. A few prefectural level cities composed of three or fewer sub-divisions are not included in our study. We also note that our measure characterizes polycentric urban development at the city level and does not aim to account for relationships between neighborhoods or localities, such as central business districts or subcenters.

Table 2-1 and Table 2-2 show descriptive statistics and correlation matrix, respectively. We take the natural logarithm of all variables (except for compactness and polycentricity) before applying an ordinary least square regression. CO_2 emission for individual cities is the dependent variable, and three urban form indicators mentioned above (population, compactness, and polycentricity) are included as explanatory variables. GDP per capita and overall population density are included as control variables. We conjecture the following relationships between spatial structures and CO_2 emission:

- More populous urban areas are more emission efficient than smaller ones due to economies of scale (size);
- More compact urban forms (compactness) are associated with less CO_2 emission;
- More polycentric urban regions (polycentricity) produce less emission.

Table 2-1 Descriptive statistics of variables.

Variable	**Unit**	**Min**	**Max**	**Mean**	**SD**
CO_2 emission	ton C	374413	50869700	10018070	8883415
Population size	ppl	391008	28846200	6003627	4217851
Compactness	N/A	0.648	0.915	0.784	0.059
Polycentricity	N/A	-3.442	-0.006	-0.595	0.552
GDP per capita	thousands CNY	210	2073	583	306
Population Density	ppl/sq. km	50.163	5572.867	670.004	727.359
Bus	/10000 ppl	2.050	103.110	10.853	10.259
STR	N/A	0.320	9.196	1.527	1.038

Number of observation = 104.

Table 2-2 Correlation matrix of variables (Number of observation = 104).

	Variable	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
(1)	*CO_2 emission*	-							
(2)	*Population size*	0.680***	-						
(3)	*Compactness*	-0.350***	-0.280**	-					
(4)	*Polycentricity*	0.140	0.200*	0.080	-				
(5)	*GDP per capita*	0.350***	0.090	-0.380***	-0.260**	-			
(6)	*Population Density*	0.440***	0.410***	-0.520***	-0.090	0.330***	-		
(7)	*Bus*	0.260**	0.200*	-0.150	-0.060	0.370***	0.660***	-	
(8)	*STR*	-0.210	-0.280**	-0.050	-0.230*	0.390***	-0.200*	-0.110	-

Significance level: 0.001 ‘***’, 0.01 ‘**’, 0.05 ‘*’, 0.1’ .’

RESULTS AND DISCUSSION

We employ a forward model selection strategy and test a series of nested models to include urban form and control variables progressively. In addition to the goodness of fit (Adjusted R^2), we report Akaike's Information Criterion (AIC) to assess the fit of individual models. Regression results are shown in Table 2-3.

Model 1 tries to explain total CO_2 emission with population size. Similar to Fragkias, Lobo, Strumsky, and Seto (2013), Model 1 suggests a sub-linear scaling relationship between total population and CO_2 emission at the city level. Because we have taken the logarithm of both sides of the regression, the estimated coefficients of urban form indicators can be interpreted as elasticity. For example, according to Model 1, a 1% increase in total population corresponds to a 0.901% increase in CO_2 emissions. Therefore, although our model suggests that more populated cities inevitably produce more CO_2 than smaller ones, the rate at which CO_2 is emitted increases less than that of the total population. This finding resonates with Bettencourt, Lobo, Helbing, Kühnert, and West (2007), where economies of scale in carbon emission concerning urban population at prefectural level cities in China. Nevertheless, Model 1 only explains about 43.9% of the variance in CO_2 emission across all cities.

Model 2 and Model 3 expands Model 1 by progressively adding compactness and polycentricity. The inclusion of compactness and polycentricity is supported by increased goodness of fit and a decreased AIC. Models 2 and 3 point to a significant and negative relationship between compactness and total emission; the higher the compactness, the lower the total emission, ceteris paribus. More specifically, conditioning on the overall population size, one unit increase of the compactness (measured by the Compactness Ratio) corresponds to approximately a 255.5% decrease in total CO_2 emission. The significance and magnitude of this effect is consistent with those reported in previous studies, such as Ewing and Rong (2008) and Liu, Song and Song (2014). Contrary to our conjecture (Veneri, 2010), when population size and compactness measures are held constant, one unit increase in the polycentricity index is associated with roughly a 24.9% increase in total CO_2 emission. When polycentricity is included, the partial coefficient of compactness decreased from -2.555 to -2.964, suggesting a potential trade-off between the effects of compact and polycentric urban patterns.

Model 4 aims to account for the 'wealth effect' identified in Fragkias, Lobo, Strumsky, and Seto (2013), which suggests that GDP per capita has a relatively large positive effect on CO_2 emission. When population size is held, 1% increase in GDP per capita is linked with a 0.611% increase in overall CO_2 emission, *ceteris paribus*. This finding corroborates with the broad literature on dynamics between wealth and CO_2 emissions (Kennedy, Steinberger, Gasson, Hansen, Hillman, Havranek, Pataki, Phdungsilp, Ramaswami and Villalba Mendez, 2009). The inclusion of GDP per capita also improves the overall model fit, raising Adjusted R^2 to 0.549. It also decreases AIC to 196.576.

Furthermore, Model 5 replicates the model specification reported in Liu, Song, and Song (2014), with a larger selection of cities. A joint interpretation of coefficient estimates (i.e., a negative compactness coefficient and a positive one for GDP per capita) suggests a positive correlation between urban compactness and CO_2 economic efficiency, with the latter defined as the ratio between GDP and CO_2 emission. This finding confirms previous observations on compactness, economic development, and carbon emission (Liu, Song and Song, 2014).

Model 6 extends Model 3 by adding the GDP per capita. The sign of all parameters included in previous models remains the same. Coefficients for total population, polycentricity and per capita GDP are statistically significant. Model 6 has achieved the highest goodness of fit and lowest AIC among all models above. Model 7 add population density to Model 6, thus introducing the effects of the absolute area size of individual cities. Finally, our full model, Model 8, has taken factors of the public transit system, industry structure and regional differences into consideration. Model 8 explains 62.5% variations in total CO_2emission and achieves the minimum AIC amongst all models. Coefficients of key explanatory variables are statistically significant, and the signs and magnitudes of all coefficients are consistent with previous models. Furthermore, the variance inflation factor (VIF) was calculated for all variables in our full model. As the largest VIF among all variables is 1.82, our full model is free from the problem of multicollinearity.

Table 2-3. The relationship between urban forms and FFDAS-estimated CO_2 emission.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Population size	0.901 ***	0.851 ***	0.759 ***	0.887 ***		0.765 ***	0.897 ***	0.888 ***
Compactness		-2.555 *	-2.964 *		-3.095 *	-1.072	-2.970 *	-3.525 *
Polycentricity			0.249 .			0.299 *	0.289 *	0.212 .
GDP per capita				0.611 ***	0.505 **	0.610 ***	0.638 ***	0.583 ***
Population density							-0.239 *	-0.168
Bus								0.038
STR								-0.120
Zone (South)								-0.396 **
Region (Eastern)								-0.175
Region (West)								-0.243
Adjusted R^2	0.439	0.461	0.477	0.549	0.142	0.564	0.581	0.625
F-statistic	81.49	44.97	32.01	62.40	9.50	34.35	29.53	18.20
AIC	217.181	214.013	212.247	196.576	262.319	193.733	190.667	183.499

Note: Significance level: 0.001 '***', 0.01 '**', 0.05 '*', 0.1' .'

Discussion and urban policy implications

In this session, we will first elaborate potential synergistic effects between compact urban form and population density. Second, the potential trade-off effect between compact city and PURs is discussed. Third, implications of right-sizing cities for carbon emission are introduced.

First, to further test the relationship between compactness and population density, we experimented by adding an interaction term as *compactness* * *population density* to Model 8. However, in this trial model, the coefficients of both compactness and population density become statistically insignificant, although the interaction term is significant with a beta of -1.563. The addition of interaction term has slightly improved the overall model fit with an Adjusted R^2 of 0.633. This finding implies there might be a synergistic effect between compact urban form and population density. With respective to emission efficiency, it seems the denser and more compact the better. Indeed, as China's urban population growth has surpassed urban land over the past decade (World Bank Group, 2015), sustainable low-carbon development requires a dynamic view what coordinates the development of both land (i.e., compactness) and people (i.e., population density).

Moreover, although our finding reveals that CO_2 emission efficiency is positively correlated with urban compactness and population density—compact urban development policies may have positive effects on reducing carbon emission in China, it should be noted that compact development could incur social and economic costs. For example, dense city increases land price (Glaeser, Kolko and Saiz, 2001), wage premium (Wheaton and Lewis, 2002), unaffordable housing (Clark, 2013), and crime (Zhang, 2015). Although the world's densest cities—such as New York (2011) and London (2013)—have pursued explicitly for even higher densities, our analysis suggests that policymakers in China should carefully balance trade-offs between carbon reduction and other consequences of urban spatial structures.

Second, Models 3, Model 7 and Model 8 have pointed to the potential trade-off effects between urban compactness and polycentricity. This observation could be because our polycentricity measure focuses on population distribution at the city-level and does not reflect subcenters within the built-up area (Lee and Lee, 2014). For many Chinese cities, a more polycentric urban pattern at the city-level often means a relatively small and thus less dense central urban district. This highlights the positive effects of a compact and dense urban center, confirming the economy of scale in emission reduction.

Third, our analysis suggests that the effects of population size and GDP per capita often trump those of other urban spatial structures included in our study. This finding highlights the importance of city-size distributions and the overall size of urban systems in addressing emission issues (Fragkias, Lobo, Strumsky and Seto, 2013). Relatedly, there is a recent call for the right-sizing city in the US urban planning circle to avoid the trap of growth-oriented planning (Hollander, Pallagst, Schwarz and Popper, 2009, Hackworth, 2015). By favoring the compatibility between a city's infrastructure and its population, right-sizing cities aims to provide positive externalities (Schilling and Logan, 2008, Heckert and Mennis, 2012). Therefore, while it is desirable to promote compact and polycentric urban development strategies, as China continues to urbanize and expand, stakeholders need to take into consideration the concept of right-sizing city and urban size effects on CO_2 emission.

CONCLUSIONS

The sustainable urban form is increasingly deemed a supplementary emission reduction strategy, and substantive empirical analyses have been performed to explore the relationship between urban form and CO_2 emission. Nevertheless, existing empirical insights are largely derived from experiences in the United States and Europe, and analyses of Chinese cities are often restricted to a handful of cities. Filling this void, this paper characterizes the relationship between urban form and urban CO_2 emission in 104 prefectural level cities of China. A series of regression models are constructed to link total emission with three urban form features (population size, compactness, and polycentricity). Our results reveal significant economies of scale with urban population size and CO_2 emission in China. Also, more compact and centralized cities are associated with lesser carbon emission, *ceteris paribus*. While most observations are consistent with previous analyses of European and North American cities, our study also suggests that polycentric urban development, measured at the metropolitan level, does not offer additional advantages in reducing carbon emission. Moreover, there also exists substantial wealth effects (GDP per capita) on CO_2 emission.

This study suffers from several limitations, which also sheds lights on future research. Firstly, as the full model (Model 8) of this study only explains 62.5% of the variations in CO_2 emission across prefectural level cities in China, our findings indirectly highlights the importance of technological development and market institutions in carbon reduction (Futcher and Mills, 2013). A holistic examination that includes urban form, technology endowment and market is required to understand mechanisms of carbon emission reduction. Secondly, due to data availability issue, this study only contains cross-sectional data circa 2010, and thus can just focus on correlations between variables. Future research should incorporate longitudinal data to identify channels through which individual urban spatial structure influence urban carbon emission. Third, our current measure of polycentricity focuses on population distribution at the city-level, and future analysis could examine polycentric urban patterns through different variables (e.g., jobs and business establishment) at multiple geographical scales (e.g., within built-up areas and at inter-city level). Fourth and relatedly, when more detailed national data is available, a multi-scale analysis spanning from district to regional levels could be conducted, where we expect our conjectured relationships between urban form and CO_2 emission continues to hold.

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CHAPTER 3

POLYCENTRIC URBAN DEVELOPMENT AND ECONOMIC PRODUCTIVITY IN CHINA: A MULTISCALAR ANALYSIS[2]

[2] **Wang, M.** To be submitted to *Environment and Planning A: Economy and Space*

ABSTRACT

'Urban polycentricity' has become both an empirical reality and a normative policy objective. This rising interest has resulted in blossoming scientific literature, but very few studies have examined if and how urban polycentricity unfolding at different geographical scales affects the urban economy. Taking up this empirical challenge, in this paper we systematically examine how intra-urban and inter-urban polycentricity is related to economic productivity in Chinese cities. We use an extension of the Cobb-Douglas function to evaluate urban-economic performance based on labor productivity in individual cities, while fine-grained population data are used to measure intra-urban and inter-urban polycentricity. We find that intra-urban monocentricity and inter-urban polycentricity tend to be associated with higher levels of labor productivity. Additionally, there is a positive interaction effect between intra-urban polycentricity and inter-urban polycentricity on labor productivity. We also find that there are some agglomeration spillover effects where smaller cities tend to benefit more than larger cities. The paper concludes with an overview of possible policy implications and possible avenues for future research.

INTRODUCTION

‘Polycentricity’ has become a key term in urban studies and planning, both as a conceptual framework that helps to capture emerging empirical realities as well as part of normative visions and goals in spatial development policies. Although van Meeteren et al. (2016) have identified ‘polycentricity’ as a concept that is particularly prone to conceptual stretching, in urban and regional studies, the term is most commonly used to refer to the presence of multiple proximate ‘centers’ of roughly similar ‘importance’ in an area (Kloosterman and Musterd, 2001; Meijers and Lambregts, 2009). In the scientific literature and policy frameworks alike, ‘polycentric urban development’ is often associated with more competitive urban economies in that ‘the polycentric system’ is deemed more than the sum of its parts (cf. Meijers, 2005). Put differently, the combined agglomeration effects of a range of nearby centers is posited to be equal to, and perhaps even exceeding that of an undifferentiated ‘large’ center.

While the debate on the relationship between urban polycentricity and economic performance is still inconclusive (Meijers and Burger, 2010; Zhang et al., 2017), it is further complicated by the fact that polycentricity has been conceived and pursued at multiple spatial scales. For example, the European Spatial Development Perspective has interpreted and pursued polycentricity at intra-city, inter-city, and inter-regional scales (Davoudi, 2003; Brezzi and Veneri, 2015). Meanwhile, in US planning circles, polycentricity has been debated at both intra-urban (e.g., the discussion on edge cities; Garreau 1991; Lee, 2007) and inter-urban scales (e.g., the debate on ‘megaregions’, see Harrison and Hoyler, 2015).

Most relevant to our purpose here, the concept has also become very popular as a planning tool in post-reform China (Cheng and Shaw, 2017). Cases in point are the two new towns near Beijing that are currently being developed. Within the city of Beijing, the satellite town of Tongzhou was designated as a ‘vice administrative center’ in 2015, with the hope of relocating the city government of Beijing and its supporting sectors away from the city center which is thought to collapse under urbanization diseconomies (Liu et al., 2017). Meanwhile, approximately 150 km south of Beijing, an entirely new city, the Xiong’an new district, has been planned and constructed since early 2017. One of the goals of developing this new district is to achieve a more ‘balanced’ spatial economic pattern in the broader Beijing-Tianjin-Hebei region.

Against this background, this paper aims to empirically analyze if and how urban polycentricity at different spatial scales in China is indeed associated with urban economic performance. Measures of non-agricultural labor productivity will approximate this 'performance'. We extend the production functions proposed by Ciccone and Hall (1996) and Meijers and Burger (2010) by including both intra-urban and inter-urban polycentricity measures. The remainder of this paper is organized as follows. In the next section, we provide definitions of key terms and elaborate our conceptual framework, which culminates in a set of testable hypotheses. We will then discuss the empirical research design, present and discuss our empirical results with robustness checks, and finally conclude with an overview of policy implications and avenues for future research.

LITERATURE REVIEW

Multiscalar polycentric urban development

In the context of an overall lack of focus in dealing with polycentric urban phenomena (Kloosterman and Musterd, 2001, p. 624), a major source of confusion and debate is the scale at which polycentric urban development unfolds (cf. van Meeteren et al., 2016). The academic literature dealing with 'urban polycentricity' commonly distinguishes between: (1) intra-urban and (2) inter-urban patterns of clustering of the population and economic activity. The former literature is exemplified by the debate in urban economics over whether a polycentric version should replace the monocentric Alonso-Muth-Mills land value model. Questions surrounding the 'optimal' number and the location of employment centers in US cities would be an archetypical example of this line of research (Giuliano and Small, 1991; McDonald and McMillen, 2000; Wei and Knox, 2015). Meanwhile, the literature on inter-urban clustering is exemplified by research on 'polycentric urban regions' (PURs). Here, analyses of the presence of urban synergies in a region such as the Dutch Randstad would be representative for this line of research (e.g., Meijers, 2005; Van Oort et al., 2010). Broad-scale regions in China such as the Yangtze and Pearl River Deltas are increasingly examined through the PUR lens, as these megaregions are often characterized by more or less proximate cities (Li and Phelps, 2016, 2017; Zhang et al., 2017).

Such a neat distinction between intra-urban and inter-urban polycentricity does not do justice to empirical complexities and nuances in scientific writings. Hall and Pain (2006) rightly note that an analysis of, say, 'polycentricity in Southeast England' is circumscribed by the territorial definitions of 'London' and 'the Southeast', the functional processes being captured, and the scales at which these processes unfold. Put simply: what may seem a monocentric phenomenon at one geographic scale/for one function can be part of a polycentric phenomenon at another scale/for another function (see also Burger et al., 2014). Furthermore, what is often considered to be a ‘city’ in the Chinese context is often similar to a ‘metropolitan region’ in the US (Liu and Wang, 2016). Consequently, empirical evidence regarding the effects of polycentricity in different studies are often difficult to compare as they sometimes relate to different spatial scales (Van Houtum and Lagendijk, 2001). Liu et al. (2016, 2017) have recently begun analyzing urban polycentricity at various scales in a single framework, acknowledging that there can be interactions between polycentricity at multiple scales (cf. Davoudi, 2003).

Kloosterman and Musterd (2001) offer some rules of thumb on how to differentiate between intra- and inter-urban polycentricity. Intra-urban polycentricity appears to be the apt framework when ‘centers’ are: (1) organized around a common public transport infrastructure; (2) under the same administrative unit; (3) part of a generic and functional economic system; and (4) share the same cultural and historical identities. The lack of integrated transport infrastructure, the presence of multiple social-cultural identities, as well as the lack of political authority can be seen as a sign that the inter-urban polycentricity language needs to be adopted. In reality, however, there is a scalar continuum of polycentricity that makes a nice scalar distinction perforce a difficult proposition. Nonetheless, it is possible to use the distinction as a useful heuristic in that it does have some analytical purchase. In the US context, for example, the distinction would imply that population and employment centers within individual metropolitan areas are to be interpreted through the lens of intra-urban polycentricity, while ‘megaregions’ that usually consist of multiple metropolitan areas are to be interpreted through the lens of inter-urban polycentricity.

Urban spatial structure and economic performance at the intra-city scale

The link between urban spatial structure and economic performance of cities has long been debated. Explanations are often interpreted regarding the relative balance between agglomeration economies and diseconomies. On the one hand, the clustering of people and economic activities in cities may facilitate input sharing, labor pooling, and knowledge spillovers, thus generating 'agglomeration economies' and improving economic productivity (Duranton and Puga, 2004). On the other hand, as cities become larger, agglomeration diseconomies may arise, for example, because of congestion and pollution. The effect of city size has therefore been extensively explored. For instance, Capello and Camagni (2000) argue that smaller cities have a higher capacity to keep social, economic, and environmental costs under control. By contrast, recent work by Helsley and Strange (2014) suggests that the size of cities may not necessarily be conducive to economic agglomeration. Furthermore, Frick and Rodríguez-Pose (2016) examined cities from 114 countries and found no universal positive relationship between city size and economic growth from 1960 to 2010.

It is often believed that a polycentric urban structure can help achieve 'optimal' urban performance, in that the negative impacts of urban concentration can be mitigated while agglomeration economies are preserved (Krugman, 1991; Fujita and Thisse, 2002). The emergence of information and communication technologies, as well as declining transport costs, have facilitated the development of, and interactions between, (sub)centers in a city. The possible synergies arising from the interaction between individual (sub)centers can then produce agglomeration economies that are observed in a single urban core of a roughly similar size. Meanwhile, Parr (2002) suggests that agglomeration diseconomies are often contained in individual (sub)centers. As a corollary, cities with a more balanced system of (sub)centers are theoretically expected to provide more productive and efficient environs. An analysis by Meijers and Burger (2010) associates a higher level of intra-city polycentricity with higher labor productivity in US metropolitan areas. Similarly, Veneri and Burgalassi (2012) suggest a positive link between urban polycentricity and economic productivity in Italy. However, we do notice that empirical evidence sometimes points in other directions. For instance, Lee and Gordon (2007) do not find evidence for an 'efficient' urban spatial structure when it comes to employment and population growth in US metropolitan areas. Given the positive relationship found in the European context, our first hypothesis is that a more polycentric urban structure at intra-city scale is associated with higher urban economic performance.

Urban spatial structure and economic performance at the inter-city scale

Although the effects of agglomeration and external economies were initially deemed to be mainly 'local', the geographical scale at which agglomeration effects unfold seems to be expanding (Phelps, 2004). For example, Parr (2002) regards economies of agglomeration at the intra-city scale to be conventional 'agglomeration externalities' and considers economies of agglomeration at inter-city scale to be 'regional externalities'. The assumed benefits of 'polycentric urban regions' can be associated with Alonso's (1973) notion of 'borrowed size' (cf. Burger and Meijers, 2015). The 'borrowed size' thesis argues that a group of functionally integrated small cities can exhibit some of the characteristics of a larger city. This is also consistent with Capello's (2000) notion of 'urban network externalities', which argues that cities situated in a functional network will enjoy additional benefits through synergies and complementarities between cities. The presence of polycentric urban regions can be deemed as one of the possible outcomes of such 'urban network externalities' (Burger and Meijers, 2010). Our second hypothesis, therefore, seeks to explore whether a more polycentric urban structure at inter-city level is associated with higher economic productivity.

It is often assumed that smaller cities may benefit from spillovers and synergy from nearby cities, as the interactions and synergetic effects between cities may generate something greater than the sum of parts (Meijer, 2005). Still, smaller cities may benefit even when they locate nearby a large city. For example, Partridge et al. (2007) find that a small city's proximity to a higher-tier urban center is positively related to its population growth. However, agglomeration diseconomies may also appear at the scale of a polycentric urban region. For example, the 'agglomeration shadow' thesis (Krugman, 1993) suggests that large cities in a city-region may 'suck' all resources and wealth from smaller cities and inhibit their growth potential. In other words, the growth of larger cities may be boosted at the expense of that of smaller ones. A recent study by Burger et al. (2015) finds that larger cities take advantage of their support base from smaller neighboring cities, leading to agglomeration shadows for those smaller cities Our third hypothesis, therefore, concerns whether smaller cities benefit from locating in a polycentric urban region.

The literature on the interaction between inter-city and intra-city polycentricity is, however, patchy and difficult to understand. While previous studies often treat intra-city and inter-city polycentricity as two spheres, scholars have identified potential interactions between polycentricities at different scales (Davoudi, 2003). For example, although the development of capital cities in Eastern European countries contributes to the emergence of a more polycentric urban patterns at the inter-regional scale, it cements the dominance of these capital cities in their respective countries thus producing a more monocentric urban system at the national level. Similarly, Liu et al. (2017) suggest that there is a moderate positive relationship between polycentricity at different scales in China. Therefore, the fourth hypothesis will explore whether there is a positive interaction effect between intra-city and inter-city polycentric spatial structure on urban economic performance.

Hypotheses

As discussed above, the multiscalar nature of polycentric urban development has propelled us to develop refutable hypotheses from intra-city and inter-city perspectives. Based on this necessarily brief discussion, we propose the following working hypotheses to organize our empirical analysis:

- *H1: A higher degree of intra-city polycentricity is associated with higher labor productivity.*
- *H2: A higher degree of inter-city polycentricity is associated with higher labor productivity.*
- *H3: A small city may benefit more in a polycentric urban region.*
- *H4: There is a positive interaction effect between intra-city polycentricity and inter-city polycentricity on labor productivity.*

DATA AND METHODS

Study area

Our analysis focuses on cities at the prefectural level and above in China (Li, 2014). A prefectural-level division (including *di ji shi*, *zi zhi zhou*, *diqu*, and *meng*) ranks below a provincial-level unit, but above county-level units. There are also four municipalities under the direct control of the central government (i.e., Beijing, Tianjin, Shanghai, and Chongqing), which have the same administrative ranks as provinces.

The geographical analysis of prefectural-level cities in China qualifies as Kloosterman and Musterd's (2001) reading of polycentricity at the intra-city scale for the following reasons. First, a Chinese prefectural-level city is, in principle, a self-contained urban system consisting of a core urban area as well as associated towns, counties, and districts. The political authority over these urban centers is often consolidated in the hands of the municipal government, which *inter alia* oversees taxation, budgeting, and planning of all sub-units (Li, 2014). The remote centers rely on the core urban areas for higher-level goods and services. Second, the (sub)centers within a prefectural level city are usually well connected with local roads and public transit. Third, the administrative boundaries of individual cities often match quite well with local cultural regions. In sum, in our study, the intra-urban analysis will focus on multiple centers within prefectural-level cities, while the inter-urban analyses deal with regional clusters of neighboring prefectural-level cities.

We employ the LandScanTM High-Resolution Global Population Dataset (Dobson, et al., 2000) to measure both intra- and inter-urban polycentricity. The LandScan dataset provides the fine-grained global population of 1 km-by-1 km grids and has been applied as 'ground truth' measures for understanding population distributions (Bhaduri et al., 2007). Importantly, the gridded population data are ideal for a coherent multiscalar analysis. In this paper, LandScan data were obtained for the year 2010. Accordingly, other socioeconomic data were gathered from the China Statistical Yearbook for the same year. Due to data availability issues, our final sample included 281 out of 364 cities at the prefectural level and above (approximately 77%) (Figure 3-1). Missing samples are mainly located in Western China.

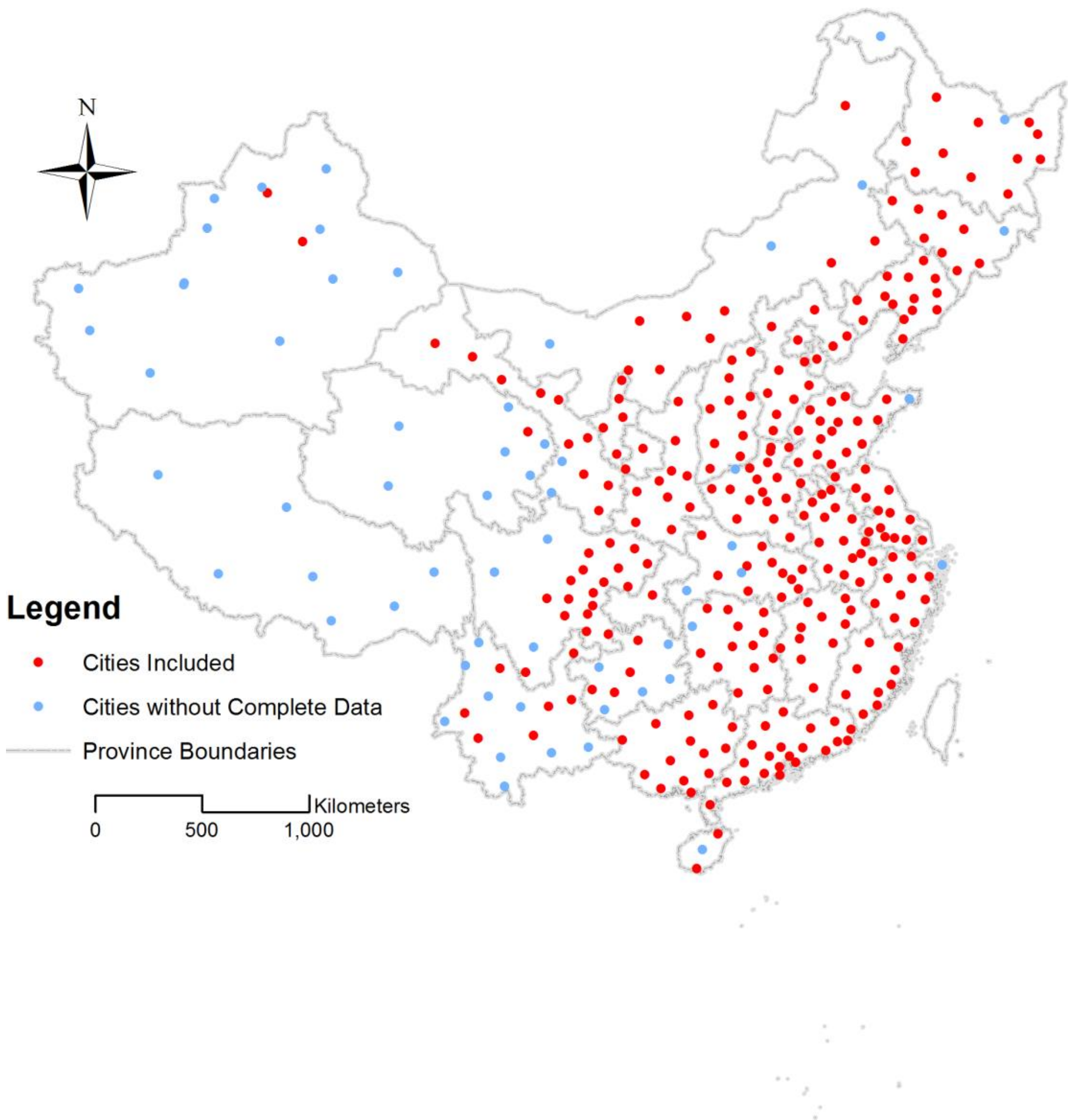

Figure 3-1. Cities included in this study (N = 281).

The focus on population distribution entails a morphological approach to studying polycentricity. In other words, we focus on the morphological aspects (e.g., size) of individual settlements rather than the functional interactions between these settlements. Our choice for this morphological approach rests on two main arguments, which have been spelled out in more detail in Liu and Wang (2016). First, empirical evidence has suggested a positive association between morphological and functional ways of defining polycentricity (Burger and Meijers, 2012; Vasanen, 2012). Second, gridded population data can be used to identify polycentric patterns at multiple spatial scales (Liu et al., 2017) and enable consistent comparisons.

As our study focuses on the spatial distribution of population, it should be considered as one particular measure of polycentricity: population centers do not necessarily overlap with other types of urban centers, such as employment hotspots. As a result, other analyses based on different types of urban centers may or may not arrive at the same conclusions. However, following Liu et al. (2017), we believe a focus on population centers is relevant in the Chinese context. For example, shaping the spatial distribution of the population is still a major planning goal, as evidenced by the earlier-mentioned Tongzhou 'vice administrative center' case. For example, planning targets are again set based on per capita standards (of built-up land and public service).

Measuring inter- and intra-urban polycentricity

As mentioned, the intra-city analysis examines the spatial structure of population centers within a Chinese city, while the analysis at the inter-city scale focuses on the spatial distribution of population across nearby cities. A schematic diagram of our approach is shown in Figure 3-2.

More polycentricity is characterized by a relatively more balanced distribution of urban centers, while a lower degree of polycentricity points to a more hierarchical distribution of urban centers. Our method of measuring polycentricity extends from Liu and Wang (2016), and Liu et al. (2017), which consists of three consecutive steps.

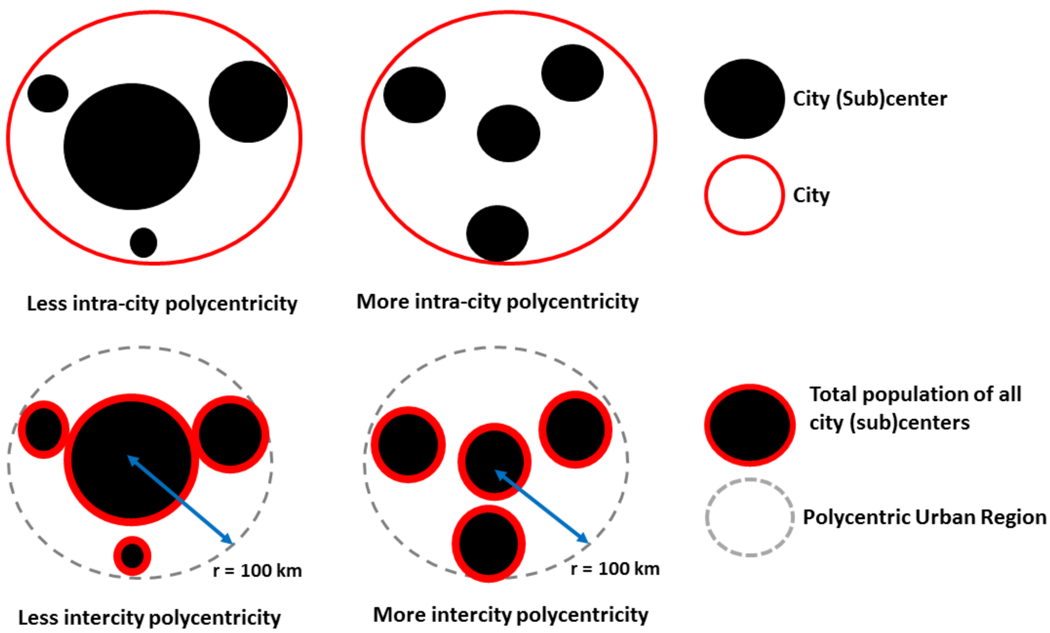

Figure 3-2. A conceptual diagram of polycentricity measures in this study (relatively larger size of the solid circle indicates a more substantial number of people in the population center (upper panel) or more substantial number of total people in all population centers within a city (lower panel)).

<u>Identifying population centers</u>

A first step is to determine the population centers within individual cities. We define population centers as a cluster of population grids that have significantly higher population than surrounding grids. The identification of intra-city population centers adapted from Liu and Wang (2016) can be summarized as follows. For individual cities, we begin by identifying densely populated LandScan grids. The 5% most densely populated grids in a city are selected for subsequent analysis. Once defined, significantly dense population grids that are adjacent to each other (i.e., rook contiguity) are combined to form candidate centers. Finally, candidates covering at least 2 km^2 (i.e., two grids) are selected as population centers.

Measuring intra-urban polycentricity

Polycentricity is about the balance in the 'importance' of urban places. The more evenly distributed the population centers are, the more polycentric the city is (Figure 3-2). The rank-size distribution based on the size of population centers provides information about such hierarchies and is, therefore, a reasonable measure of the degree of polycentricity (Parr, 2004; Meijers and Burger, 2010; Burget et al., 2014; Meijers, 2008). Therefore, we adopt this method and calculate the slope of the regression line that best fits a rank-size distribution of population centers within a city. Following Meijers and Burger (2010), we construct three scenarios where the largest two, three, and four centers are included in rank-size distributions. The slope for each scenario is then calculated (Eq. 3-1).

$$IntraSlope(k) = \frac{\sum_{i=1}^{k}\sum(x_i-\bar{x})(y_i-\bar{y})}{\sum_{i=1}^{k}(x_i-\bar{x})^2} \qquad \text{(Eq. 3-1)}$$

Where for the $i\ th$ largest population center, $x_i = \log_{10}(i)$; y_i denotes the logarithm of the total population of the $i\ th$ largest population center with base 10; $\bar{x} = \frac{\sum_{i=1}^{k} x_i}{k}$, $\bar{y} = \frac{\sum_{i=k}^{k} y_i}{k}$; k = 2, 3, 4.

A flatter slope of a rank-size distribution suggests a more balanced distribution amongst different centers, and thus points to a more polycentric system. Finally, the measure of intra-city polycentricity (*IntraPoly*) is constructed as per Eq. 3-2, in which a higher value indicates greater intra-city polycentricity.

$$IntraPoly = \frac{1}{3}\sum_{i=2}^{4} \left| \frac{1}{IntraSlope(i)} \right| \qquad \text{(Eq. 3-2)}$$

<u>*Measuring inter-urban polycentricity*</u>

Inter-city polycentricity is calculated similarly, but focuses on the size distribution among neighboring cities. The more evenly distributed the cities are, the more polycentric the region (Figure 2). For each city, the calculation of inter-city polycentricity started with constructing its ‘region’, which includes the following two categories of cities: (1) all cities that share borders with a given city are included; and (2) following Patridge et al. (2007), other cities within the 100-km radius of that city (but do not share borders with the city). Second, the total population in the intra-city centers identified previously is calculated. Third, we consider the rank-size distribution of the largest 2, 3 and 4 cities within a city’s region. Like the measure of intra-city polycentricity, we calculate the slope in each scenario as in (Eq. 3-3):

$$InterSlope(k) = \frac{\sum_{i=1}^{k}\sum(x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{k}(x_i - \bar{x})^2} \qquad \text{(Eq. 3-3)}$$

Where for the $i\ th$ largest city in a city’s ‘neighborhood’, $x_i = \log_{10}(i)$; y_i denotes the logarithm of the summation of population in all population centers of the $i\ th$ largest city with base 10; $\bar{x} = \frac{\sum_{i=1}^{k} x_i}{k}$, $\bar{y} = \frac{\sum_{i=k}^{k} y_i}{k}$; k = 2, 3, 4.

The intercity polycentricity (*InterPoly*) is computed as per Eq. 3-4, in which a higher value indicates a more pronounced inter-city polycentricity.

$$InterPoly = \frac{1}{3}\sum_{i=2}^{4} \left| \frac{1}{InterSlope(i)} \right| \qquad \text{(Eq. 3-4)}$$

Model formulation

Following Ciccone and Hall (1996) and Meijers and Burger (2010), we extend the Cobb-Douglas production function to evaluate labor productivity. Thus, our model starts with the following linear equation (Eq. 3-5):

$$\ln(LP) \sim \ln(CLR) + \ln(LLR) + \ln(HCLR) + \ln(GOV) + \ln(POP) + \ln(PUD) \qquad \text{(Eq. 3-5)}$$

Where LP denotes labor productivity, CLR denotes capital-labor ratio, LLR denotes land-labor ratio, $HCLR$ denotes human capital-labor ratio, and PUD represents the effects of polycentric urban development as elaborates in the previous section of this study, including the direct impact of intra-city polycentricity (*H1*), inter-city polycentricity (*H2*), the interaction effects between intra-city and intercity polycentricity (*H3*), and the role of city size (*H4*).

For each city, the effects of polycentric urban development (PUD) are measured in terms of intra-city polycentricity ($IntraPoly$) and inter-city polycentricity ($InterPoly$). The dependent variable, labor productivity (LP) is operationalized by Gross Domestic Product (GDP) in the secondary and tertiary sectors. Capital-labor ratio (CLR) is calculated as the ratio of total capital of all scale firms over the total labor of those firms. Land-labor ratio (LLR) is computed as the average built-up urban area per worker. Human capital-labor ratio ($HCLR$) is approximated by the average years of education per worker. The total population (POP; including both those in and out of the workforce) of individual cities is included. In light of the recent debates on variegated capitalism in China, local governments exert institutional power and adopt different market intervention strategies (Peck and Zhang, 2013; Zhang and Peck, 2016). Therefore, governmental intervention (GOV) is derived as the fiscal expenditure divided by GDP in each city, in order to control for the heterogeneity of governments' role on labor productivity (Sun and Li, 2016). Whenever possible, these independent variables are gathered from the China City Statistical Yearbooks for the year of 2010.

Robustness checks

We estimate Eq. 3-5 using an ordinary least square (OLS) estimator. We start by benchmarking our model with the standard Cobb-Douglas production function. Both adjusted R-squared and the Akaike Information Criterion (AIC) are used to evaluate model fit. For an OLS estimator, it is consistent only when the regressors are exogenous to the model. Further, OLS is the best linear unbiased estimator when the errors are independently distributed and homoscedastic. Therefore, before reporting our OLS results, we perform a series of robustness checks regarding the possible presence of endogeneity, multicollinearity, autocorrelation, and heteroscedasticity in the model.

Endogeneity

Although the specification in Eq. 3-5 implies that polycentricity affects labor productivity, the actual causality may work both ways. More specifically, while economies of agglomeration suggest polycentricity could lead to higher labor productivity, the reverse can also be true. For example, areas with higher labor productivity may attract more firms and provide more employment opportunities, which in turn lead to the creation of multiple population and employment centers. Put differently, the presence of multiple population centers can be both the cause and consequence of labor productivity. If endogeneity is an issue, OLS estimators are no longer consistent.

Therefore, we apply two-stage least square (2SLS) estimator with instrumental variables (IVs) to control for endogeneity. According to Wooldridge (2010), IVs are ideally related with endogenous variables (i.e., *IntraPoly* and *InterPoly*) but simultaneously unrelated to the dependent variable (i.e., *LP*). Based on Liu and Wang (2016), the topography is associated with the degree of polycentricity, as geomorphological constraints such as mountains and waterways play a significant role in shaping land use patterns and inevitably affect the development of polycentric urban areas (Zhang et al., 2017). Meanwhile, such topographical features are unlikely to associate with the level of labor productivity. Consequently, we use the standard deviation of curvature (the second-order derivative of a digital elevation model, DEM) within a city (*IntraCurvature*) as the instrumental variable for the degree of intra-city polycentricity (*IntraPoly*). Similarly, the instrumental variable for the degree of inter-city polycentricity (*InterPoly*) is constructed as the standard deviation of landform curvature across neighboring cities (*InterCurvature*). DEM data are acquired from the United States Geological Survey (https://lta.cr.usgs.gov/GTOPO30). Weak instrument tests are applied to examine if the specification of each IV is valid. Given the validity of all IVs, Wu–Hausman test is further applied to test if 2SLS is a more consistent and efficient estimator, compared to OLS. If regressors can be treated as exogenous variables, OLS should be preferred over 2SLS (Wooldridge, 2010).

Multicollinearity of regressors

A concern in any multivariate regression model is the potential of multicollinearity, where two or more exogenous variables are highly correlated so that one variable can be reasonably linearly predicted from other variables. Although the presence of multicollinearity does neither affect the reliability nor adversely impact the predictive power of a model, it may not produce a valid result about individual exogenous variables. Therefore, the variance inflation factor (VIF) for each additive independent variable is reported. Empirically, a VIF of 5 and above indicates the presence of multicollinearity (O'Brien, 2007) and a VIF over 10 suggests severe multicollinearity problems (Kutner et al., 2004).

Autocorrelation and heteroscedasticity of the errors

OLS is producing 'optimal' results also relies on the errors being independently distributed and homoscedastic. Therefore, a Durbin–Watson statistic is applied to detect the presence of autocorrelation in the errors and Breusch-Pagan test is used to test if the variance of errors is constant (i.e., homoscedastic). In case of the presence of heteroscedasticity, the OLS is still unbiased, but it becomes inefficient as the coefficients associated with regressors may be either underestimated or overestimated.

RESULTS AND DISCUSSIONS

Robustness tests

Descriptive statistics are reported in Table 3-1. Our discussion of estimation results begins with a benchmarking of the standard Cobb-Douglas production by only including the exogenous factors of capital-labor ratio (*CLR*), labor land ratio (*LLR*) and human capital-labor ratio (*HCLR*) in

Model 1. We then add population size (*POP*) and level of governmental intervention (*GOV*) in Model 2 as the baseline for estimating the effects of polycentric urban development. Model 3 focuses on the main effects of polycentricity and allows testing *H1* and *H2*. Subsequently, the full Model 4 was developed to test the roles of the interaction between polycentricity and the moderating effects of population size on labor productivity (*H3* and *H4*). Results are shown in Table 3-2.

Table 3-1. Descriptive statistics of variables (N = 281)

Variable *	**Min**	**Max**	**Mean**	**S.D.**
LP	9.667	12.802	11.137	0.535
CLR	10.377	14.933	12.463	0.592
LLR	2.649	6.243	4.111	0.647
HCLR	1.879	2.460	2.189	0.090
GOV	-3.096	0.396	-1.884	0.460
IntraPoly	-2.195	3.740	-0.167	0.628
InterPoly	-1.883	4.599	0.581	0.814
POP	12.354	17.177	15.067	0.690

* All variables were log-transformed.

In Table 3-2, the gradual increment in Adjusted R^2 along with a decrease in AIC as we move from Model 1 to Model 4 indicates that our main effect model (Model 3) and full model (Model 4) improve the explanatory power. None of four models leads to significant concerns of heteroscedasticity (Breusch-Pagan tests, $p>0.1$), autocorrelation (Durbin-Watson tests, $p>0.1$), while adding variables does not raise issues of multicollinearity (VIF<5). Furthermore, the curvature of topographical profile as instrument variables are valid at both scales ($p<0.05$), while the Wu-Hausman test reveals endogeneity is neither a concern in Model 3 ($p=0.989$) nor in Model 4 ($p=0.707$). A detailed overview of endogeneity tests for our full model (Model 4) is shown in Table 3-3. Therefore, the OLS provides consistent and efficient estimates for both Model 3 and Model 4.

Labor productivity and polycentricity at multiple scales

As suggested by Model 1, the impacts of land, capital, and human resources on productivity in Chinese cities are significant and positive. Most notably, one standard deviation increase in the average years of education increases labor productivity by about three units of standard deviation, everything else being equal. Model 2 suggests government spending tends to affect urban productivity negatively. A unit of standard deviation increases of governmental expenditure would decrease labor productivity by 0.542 units of standard deviation. The negative impacts of government spending have two potential explanations. On the one hand, economically lagging cities with low productivity tend to rely on transfer payment from the central government, and fiscal expenditure, therefore, accounts for a substantive portion of local GDP. More specifically, most cities with large GOV values in our sample locate in China's mountainous inland. On the other hand, a high percentage of GDP in governmental fiscal expenditure may imply a strong local state in managing the economy. State involvement in the economy is often linked with unnecessary institutional costs and therefore may lead to stagnating urban economies (Huang, 2008).

The effects of polycentricity are highlighted in Models 3 and 4. As discussed in Liu et al. (2017), polycentric urban development in China resembles the interplay among (fragmented) geographies, uneven economic development, and state intervention. We will discuss our results along these lines. First, according to Model 3, when other covariates are held constant, one standard deviation increase of *IntraPoly* is associated with a 0.064 decrease of the standard deviation of labor productivity. In other words, a lower degree of polycentricity at the intra-city scale is associated with a higher level of labor productivity. Our first hypothesis (*H1*) is therefore rejected. This observation can be ascribed to the fact that the polycentricity measure used in this study (Meijer and Burger, 2010) tends to pick up cities with fragmented and mountainous internal geographies. Again, such cities are more commonly seen in the economically lagging regions. Relatedly, this result may also be interpreted in the context of the literature on infrastructure sharing and agglomeration. In the Chinese context, since the foundation of modern China in 1949, most urban construction was concentrated in the central part of a city. Consequently, the central part of a city serves most urban functions and usually this is the densest area in a city and many outlying (new) towns, and districts have yet to fully grow into functional centers. In other words, a larger city center may produce more agglomeration effects, but entail a more hierarchical intra-city urban system. This is in line with the significant agglomeration effects of city centers found in the American and European context (Agarwal et al., 2012; Arauzo-Carod and Viladecans-Marsal, 2009; Rosenthal and Strange, 2003; Van Soest et al., 2006).

As for the effects of polycentricity at the inter-city level, one standard deviation increase of *InterPoly* is associated with a 0.055 increase of the standard deviation of labor productivity, everything else being equal. Put differently, a higher level of polycentricity at the inter-city scale is associated with a higher level of labor productivity, so that *H2* is accepted. In a recent study of Chinese city-regions, Liu et al. (2017) find that the most developed city-regions in China – the Pearl River Delta, the Yangtze River Delta, and Beijing-Tianjin-Hebei – are among the most polycentric ones. While these polycentric urban regions are often seen as the product of intensive economic decentralization, rapid marketization, and high economic productivity (Zhao et al., 2017), our results suggest that there is also a positive effect the other way around. This can be related to the concepts such as regional externalities (Parr, 2002) and regional innovation systems (Asheim and Isakeen, 2002). With the development of information and communication technologies and falling transportation costs, the scope and scale of agglomeration effects can be expanded (Renski, 2011; Partridge et al., 2007). For example, Fu (2008) has observed that regional innovation and technological capabilities have contributed further to regional economic growth in China's coastal regions, but not in the inland regions.

In Model 4, the positive sign and the significance ($p<0.1$) of the coefficient associated with *IntraPoly * InterPoly* suggest a positive interaction effect of polycentricity at the two scales (*H4* is accepted). This result can be interpreted in two ways, considering the other three hypotheses. On the one hand, our results imply that if a city is situated in a less polycentric region, increasing its intra-city monocentricity may lead to increased economic productivity. Cities in the mountainous western and central China are often polycentric at the intra-city level, but are less so at the inter-city level (Liu et al., 2017). City-regions in these areas are often dominated by one leading city, and therefore suffer from a ‘primate regional urban system’ syndrome (Henderson, 2002). While theoretically speaking a primary city could serve as the growth pole and generate spillovers effects (Richardson, 1976), the leading cities usually capture more growth potential with their relatively better endowment in transport, telecommunication, and other infrastructures. On the other hand, if a city is located in a more polycentric region, a balanced intra-city urban system may benefit the city more. This is again consistent with Liu et al.’s (2017) observation that Chines city-regions along the eastern seaboards is found to be polycentric at both intra-city and inter-city levels. Due to the emergence of town and village enterprises in the 1980s, the 'fever' of establishing development/enterprising zones in the 1990s, and new town development in the 2000s, cities in the more developed coastal areas are usually polycentric at the intra-city level (Lin, 2002; Hsing, 2010; Wu and Phelps, 2011). Our results imply that there could be synergetic effects between polycentricity and economic development at the regional level.

The negative sign and significance ($p<0.1$) of the coefficient associated with *POP * InterPoly* suggests that a small city may benefit from in a more polycentric urban region (*H3* is accepted). In more polycentric urban regions, smaller cities can probably enjoy the positive spillovers and are less likely to become the 'victims' of the 'agglomeration shadows', where smaller cities are exploited by larger cities nearby effect (See Dobkins and Loannides (2001) and Burger et al. (2015)). This is also consistent with our previous observation that the non-leading cities in a less polycentric urban region may suffer from the 'primate regional urban system' syndrome in the Chinese context.

Table 3-2. OLS regression results of labor productivity (*LP*) in 2010 (all variables are standardized).

	H	Model 1			Model 2			Model 3			Model 4	
		Estimates	S.E.	VIF	Estimates	S.E.	VIF	Estimates	S.E.	VIF	Estimates	S.E.
(Intercept)		58.031 ***	6.313		23.729 ***	6.367		22.840 ***	6.281		22.601 ***	6.278
CLR		0.121 **	0.038	1.127	0.191 ***	0.033	1.226	0.194 ***	0.032	1.229	0.193 ***	0.032
LLR		0.236 ***	0.042	1.658	0.294 ***	0.041	2.310	0.295 ***	0.041	2.315	0.292 ***	0.041
HCLR		3.001 ***	0.288	1.507	1.357 ***	0.298	2.358	1.311 ***	0.294	2.377	1.305 ***	0.294
GOV					-0.520 ***	0.046	1.462	-0.542 ***	0.046	1.511	-0.546 **	0.046
POP					0.006	0.032	1.620	0.010	0.032	1.648	-0.004	0.035
IntraPoly	*H1*							-0.064 *	0.028	1.066	-0.372	0.280
InterPoly	*H2*							0.055 *	0.021	1.008	-0.408	0.248
IntraPoly * InterPoly	*H3*										0.055 .	0.032
POP * IntraPoly											-0.044	0.041
POP * InterPoly	*H4*										-0.068 .	0.037
Adjusted R^2		0.562			0.699			0.710			0.713	
ΔR^2		N/A			0.137			0.011			0.003	
F-statistic		120.8***			131.200***			98.68***			70.68***	
Breusch-Pagan (χ^2)		0.670			0.583			0.254			0.057	
Durbin–Watson		2.087			1.977			1.981			1.966	
AIC		220.080			116.417			108.652			107.760	
Δ *AIC*		N/A			-103.663			-7.765			-0.892	

Significant codes: '***' p<0.001; '**' p<0.01; '*' p<0.05; '.' p<0.1. The higher the value of *IntraPoly*, the greater degree of polycentricity at intra-city scale; the higher the value of *InterPoly*, the greater degree of polycentricity at inter-city scale.

Table 3-3. Endogeneity tests for multiscalar polycentricity measures in Model 3-4.

	Weak Instruments	Wu-Hausman	p-value	
IntraPoly	3.229		0.008	**
InterPoly	3.753		0.003	**
POP * IntraPoly	3.216		0.008	**
POP * InterPoly	3.846		0.002	.
IntraPoly * InterPoly	2.077		0.068	**
2SLS		0.591	0.707	

Significant codes: '***' p<0.001; '**' p<0.01; '*' p<0.05; '.' p< 0.1.

CONCLUDING REMARKS

The concept of 'urban polycentricity' has attracted sizable interest in both academic and policy circles. It has been used not only as an ideal-typical theoretical construct to characterize the emerging urban landscape, but also used normatively to set goals and visions in spatial plans. Indeed, polycentricity has been conceived and pursued at different geographical scales. The lack of a comprehensive framework to discuss the identification, theorization, and analysis of polycentricity at various spatial scales has thus led to literature that is wide-ranging and blossoming, but also sometimes assumption-rich, disjointed and lacking analytical depth. Against this backdrop, the purpose of this paper has been to understand how polycentricity affects economic performance (expressed by labor productivity) at multiple scales. Using fine-grained population data from LandScan, we have characterized polycentric urban patterns at both intra-city and inter-city scales for 281 Chinese cities in 2010. By extending the Cobbs-Douglas production function, we could evaluate the effects of polycentricity on labor productivity at multiple scales.

Our results suggest that cities with a lower degree of intra-city polycentricity show higher labor productivity. Meanwhile, cities with a higher degree of inter-city polycentricity demonstrate greater labor productivity. Additionally, a less polycentric city is better off in a less polycentric region, and a more polycentric city is better off in a more polycentric region. Moreover, smaller cities tend to benefit more from regional agglomeration. To sum up, different effects of intra-city polycentricity and inter-city polycentricity on labor productivity not only reconfirm the multiscalar nature of polycentricity, but also emphasize the necessity to understand the scales at which agglomeration economies are achieved.

Some of the limitations of our research work pave the path for future research. First, our study only examines morphological polycentricity. As discussed, understanding polycentricity from a functional perspective may contribute to more nuanced understandings of the relationship between polycentric urban development and economic performance. Second and relatedly, using fine-grained datasets detailing employment (or other types of urban centrality) could lead to more nuanced and diverse analyses. And third, this paper is confined to labor productivity as a proxy for urban-economic performance. Future work can test the polycentric urban development's role in other dimensions of economic performance, such as wage and housing price. And finally, it would be interesting to explore the relationship between polycentricity and economic performance in a dynamic view by having a longitudinal study.

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CHAPTER 4

HOW ATTRACTIVE IS POLYCENTRICITY? EVIDENCE FROM URBAN AMENITIES IN CHINESE CITIES[3]

[3] **Wang, M.** To be submitted to *Journal of Economic Geography*

ABSTRACT

The recent literature of ‘consumer city’ and the ‘love of variety’ argues the provision of urban amenities (such as goods and services) makes a city more attractive to people. Meanwhile, polycentric urban development is favored by academia and policymakers, although its purported benefits need to be further tested. Against this background, this paper explores the correlation between intra-urban polycentricity and both the quantity and the diversity of urban amenities in 309 Chinese cities. We found a higher level of intra-urban polycentricity is associated with both higher number and a larger variety of urban amenities. The finding is backed up by several robustness checks. A possible explanation of such relationship is speculated from both the production and consumption sides of urban amenities through revisiting the Central Place Theory.

INTRODUCTION

Why are some cities better and more attractive than others? Economic geographers and urban economists have long been focusing on the producer side of cities, where the production structure and agglomeration economies are the causes of population growth and economic development (Rosenthal and Strange, 2004). Recently, the ‘consumer city’ thesis (Glaeser et al., 2001) has driven an impetus of understanding cities from the perspective of people, i.e., the consumers. Grounded on earlier theories on urban amenities (e.g., Roback (1982) and Graves (1983)), cities that attract more consumers to live will be better than others, where the attractiveness is defined not only by urban agglomeration economies, but also urban amenities. Stylized facts have been found in the US (Glaeser and Gottlieb, 2009; Partridge, 2010; Rust and Chung, 2006) and Europe (Garretsen and Marlet, 2017) that amenity-rich cities are more attractive and enjoy greater urban growth.

A concept related to consumer city is the ‘love of variety’ (Dixit and Stiglitz, 1977; Krugman, 1993). Cities are attractive because they provide to consumers a large variety of goods and services. More recent work in economic geography and urban economics provide empirical evidence that consumption amenities, mainly local and nontradable goods, are a significant driving force for people to live in US cities (Chen and Rosenthal, 2008; Glaeser, 2011; Lee, 2010). Importantly, goods and service providers in cities may face less direct price competition by differentiating their products (Mazzeo, 2002), which consequently increase the product variety in a city.

In urban studies and planning scholarship, sustainable urban development has been extensively studied through the lens of urban quality of life and competitiveness (Myers, 1988; Robert, 1999; Tweed and Sutherland, 2007). Recently, polycentricity has become an essential term both as an analytical framework and part of normative spatial development policies around the world. While a recent meta-analysis reveals that polycentricity is a multi-scalar and multi-faceted construct (van Meeteren et al., 2016), it usually refers to a more balanced urban system where there are multiple independent urban 'centers' with a similar degree of 'importance' (Kloosterman and Musterd, 2001). The favoritism of polycentricity by the academic and policy-makers is largely associated with its purported benefits of economic productivity (e.g., Meijers and Burger (2010) in US and Li and Liu (2018) in China) and environmental consequences (e.g., Veneri (2010) in Europe and Wang et al. (2017) in China), where the agglomeration economies are better achieved in a more balanced urban system (i.e., a more polycentric urban form) rather than a hierarchical urban system (i.e., a less polycentric urban form). While these studies explain the advantages of polycentricity from the production side, there is a shortage of relevant studies on the consumer side— e.g., are polycentric cities more attractive? Do they provide more quantities of urban consumption amenities? Do they render a greater variety of urban consumption amenities?

To the best of our knowledge, the only two empirical studies exploring the relationship between polycentricity and urban amenities are based on the city-regions of The Netherlands (Burger et al., 2014; Meijers, 2008). While Meijers (2008) finds that polycentric urban regions are correlated with fewer advanced and rare high-level urban amenities, their association with the number of retail facilities depends on the dispersion of the city-region (Burger et al., 2014). Given the uniqueness of a Dutch city (Garretsen and Marlet, 2017) and the fact that polycentric urban regions represent only one subject of polycentricity at inter-urban level (van Meeteren et al., 2016), such finding may not hold in other contexts, for example, in the US or China.

Towards the end of the last century, the concept of polycentricity was introduced to China (Cheng and Shaw, 2017), where some Chinese cities have adopted polycentric urban development strategy as part of their master plans. Against this background, we aim to empirically analyze whether polycentric cities are more attractive in China regarding the quantity and the variety of urban amenities. 'Urban amenities' information was obtained from Dianping.com (China's Yelp), the most extensive geo-tagged user-generated content website of city living guide in China, which provides merchant information of catering, retail, entertainment, lodging, etc.

Our work builds on the polycentricity literature where polycentric urban form has been envisioned and observed in the US (Arribas-Bel and Sanz-Gracia, 2014), Europe (Hall and Pain, 2006), and China (Cheng and Shaw, 2017). More recently, Liu and Wang (2016) quantified the degree of polycentricity of 318 Chinese cities, where they found over half of Chinese cities have developed a polycentric urban system, with at least two urban centers. Later, Liu et al. (2017) expanded the framework to measure inter-urban polycentricity at 22 Chinese city-regions.

Our work also builds on the consumer city and the 'love of variety' literature which focuses on the emerging consumption choices in cities (Dixit and Stiglitz, 1977; Glaeser et al., 2001; Handbury and Weinstein, 2015). The emergence of multiple urban centers (of people and activities) in polycentric urban development has created purchasing power from the city center. People in (or nearby) different urban centers will be more likely to dine out, have fun, and purchase goods and services in the (or to the closest) urban center. Most recently, Zheng et al. (2017) demonstrated that the industrial parks in urban periphery cause the emergence of suburban "consumer city" in China.

The rest of the paper is organized as follows. Section 2 presents the literature review and theoretical framework. In Section 3 we introduce research design, data, and empirical strategies. Section 4 demonstrates the results of our main findings and robustness checks, respectively. Lastly, we discuss our findings and conclude in Section 5.

LITERATURE REVIEW AND THEORETICAL FRAMEWORK

Despite the stretched concept of polycentricity, there has been observed priorities in intra-urban polycentricity research and its relation to urban economic geography literature (van Meeteren et al., 2016). Our literature review and theoretical framework depart from a brief introduction of intra-urban polycentricity in China and its relationship with the Central Place Theory. We examine the rationale of co-location of urban amenities from producer and consumer sides, before formulating two refutable hypotheses.

Intra-urban polycentricity in Chinese cities and the Central Place Theory

Intra-urban polycentricity in China usually refer to the polycentric urban form in a prefectural level city and above. The 'above' here explicitly refers to the four municipalities under the direct control of the central government (i.e., Beijing, Tianjin, Shanghai, and Chongqing). In the Chinese administrative division system, a prefectural-level city (*di ji shi*) ranks below a provincial-level unit, but above county-level units. A prefectural level city is usually comprised of core urban districts and their surrounding region, which in turn contains districts, county-level cities, counties, towns, and other sub-divisions. In other words, A Chinese city is often like a 'metropolitan region' in the US (Liu and Wang, 2016), which is different from a functional polycentric urban region in the European context (See Meijers (2008) and Burger et al. (2014) as examples). Based on Liu and Wang (2016) and Wang et al. (2017), the degree of intra-urban polycentricity can be conceptualized as how balanced the population is distributed amongst different subdivisions of a city (i.e., urban centers). If the population distribution is more hierarchical in various urban centers within a city, the level of intra-urban polycentricity of that city is lower (Figure 4-1a). Conversely, a higher degree of intra-urban polycentricity corresponds to a more balanced distribution of population among urban centers (Figure 4-1b).

(a) Less intra-urban polycentricity (b) More intra-urban polycentricity

Figure 4-1. Conceptualization of intra-urban polycentricity (adapted from Wang et al. (2017)). Each solid circle refers to an urban center of a city; the relative size of the ring denotes the relative population size of that subdivision.

The highlight of ‘urban center’ in intra-urban polycentricity is particularly relevant to the iconic Central Place Theory (Christaller, 1966), which describes the possible relations between population distribution and the provision of goods and services (central functions). Christaller demonstrates the theory in two phases. The first phase discusses population distribution, the supply of central functions, and the central places accommodating such relationships (Christaller, [1933] 1966, pp. 27–58). The second phase hypothesized there is a hierarchical pattern of central places (Christaller [1933] 1966, pp. 58–80). Despite the Central Place Theory being constantly revisited and reconstructed (e.g., Buursink (1975) and more recently van Meeteren and Poorthuis (2018)), there are two critical notations related to this study.

First, a central place is not a ‘city’. In fact, it can be “any economic geographical pattern based on central-place notions” (Christaller [1933] 1966, pp. 16–17, 139, 198). The Central Place Theory addresses the location of central functions, a partial theory of settlement structure (Carol, 1960). An ‘urban center’ is defined as a cluster of places where the population density is significantly higher than their surroundings (Liu and Wang, 2016), which provides demands for different urban amenities and opportunities for the supply of goods and services. Put differently, an 'urban center' can be conceptualized as a 'central place'.

Second, the premise of a hierarchical pattern of central places can be relaxed. Part of the reason is that Christaller assumed "central places of a higher order also contain all the central functions of the lower orders" for the simplification of operationalization (Christaller [1933] [1966], p. 64), Christaller ([1933] 1966, pp. 43, 50) was explicit that in reality, people engage in multipurpose shopping and thus not always frequent the nearest center. Furthermore, a recent study completed by van Meeteren and Poorthuis (2018) with similar volunteered geographical information data relaxed the assumption that customers frequent the nearest urban center as well. To sum up, on the one hand, the emergence of multiple independent urban (population) centers constitutes the intra-urban polycentricity; on the other hand, such emerging reality contributes to some 'central places' in Chinese cities.

The co-location of urban amenities in urban centers: The producer side

Why firms are clustered is summarized by Ahlfeldt and Wendland (2012) regarding two forms of agglomeration economies from the production side, namely the first nature of geography and the second nature of geography. While the first nature of geography is more relevant to explain the natural comparative advantages of some locations for cities to emerge and subsequently for firms to cluster in the first place (Ellison and Glaeser, 1999), the externalities from the second nature of geography, where intense interactions between firms and consumers at the same location are more pertinent to this study. The individual urban centers are arenas for such ‘interactions’, and thus serve the function of central places.

First, co-location of firms within the same industry reduces transport costs through Marshallian externalities regarding resource sharing, labor pooling, and knowledge spillover in labor market, which have been empirically tested (Ellison et al., 2010). Urban amenities relating to the service sector, such as restaurants, retail stores, entertainment establishments, hotels, and professional services can save shipping costs when locating near each other. Urban centers provide not only a vast customer base, but also a large labor pool for firms in tertiary industries. Urban centers also create opportunities for intellectual spillovers from one firm to another firm.

Second, co-location of firms in different industry promotes innovation and more attractive cities through urban diversity, or Jacobs externalities (Jacobs, 1969). Many inventions of urban amenities are interdisciplinary, due to the stimulation of “ideas” in heterogeneous surroundings in cities. For example, the emerging urban spaces of urban café, the food court in shopping complex are just a couple of examples of these interdisciplinary innovations.

In theory, the externalities that one firm receives from the spatial closeness to others in a city can be found in any urban structure (regardless of the degree of intra-city polycentricity), based on the 'locational potential function' by Fujita and Ogawa (1982). However, Helsley and Strange (1990) revealed that agglomeration economies are strongest within the central business district and decline with distance. Duranton and Overman (2005) further confirmed that such agglomeration effects are very localized at the zip code level in US. Therefore, the presence of multiple urban centers facilitates the emergence of central places, where those localized agglomeration economies can be achieved in individual urban centers.

The co-location of urban amenities in urban centers: The consumer side

Urban amenities are location-sensitive, partly because of the nature of face-to-face transactions, for example, dining out, shopping in a mall, watching a show, and visiting a place. From a consumer's perspective, the heterogeneous consumption demands are more likely to be realized in urban centers, where there are stores of various types and sizes. Urban centers are areas with significantly denser population, which can increase the consumption variety by spatially aggregating demand (Schiff, 2015).

First, consumers like the co-location of firms in the same industry. For example, people like to dine out on a food street or the food court in a shopping complex, because it gives customers a variety of choices for catering. Importantly, the severe competition of co-locating restaurants benefits consumers because it ensures these restaurants provide quality food and services at affordable prices. Similarly, Larsson and Öner (2014) analyzed the co-location phenomenon of retail stores, in which urban centers are often occupied by either a cluster of small-scale stores or a large shopping center with nested shops.

Second, consumers like the co-location of firms in different industries. Since Christaller himself, it has been long documented people prefer multi-purpose shopping trips where they procure different types of goods and services (O'Kelly, 1981). An apparent reason is that a multi-purpose shopping trip reduces the costs of time and travel. For example, in a typical weekend, friends may have brunch together in the morning, go shopping in retail stores in the afternoon, and have a drink in a bar in the evening, etc. People will strategically select places that can satisfy the demand for multi-purpose trips, i.e., where firms in different industry co-locate.

In a nutshell, the location-sensitive spatial demand of urban amenities favors urban centers, as central places, with co-location of firms both in the same and different industry. These central places also attract consumers in the surrounding areas.

Hypotheses

To summarize, urban centers are central places, which provide goods and services to people in and proximate to those centers through urban amenities (2.1). From producers' perspective, firms benefit from co-location in urban centers, regardless of co-locating with other firms in the same industry (Marshallian externalities) or those in a different industry (Jacob externalities) (2.2). From the consumers' perspective, the spatially aggregating demand requires firms co-locating with other firms both in the same and different industry (2.3). Given urban amenities are location-sensitive, we formulate the following two hypotheses:

- *H1: A higher degree of intra-urban polycentricity is associated with a larger quantity of urban amenities.*
- *H2: A high degree of intra-urban polycentricity is correlated with greater diversity of urban amenities.*

RESEARCH DESIGN

We utilize multiple regression models to empirically test the relationship between intra-urban polycentricity and the provision of urban amenities (i.e., restaurants, retail stores, entertainment, tourist spots, hotels, and professional services) regarding their quantity of diversity in Chinese cities. In these models, the dependent variables are the total establishments of urban amenities (i.e., the quantity) and a suite of indices representing the extent of a variety of urban amenities (i.e., the diversity). The primary explanatory variable of interest is the degree of intra-city polycentricity, which is adapted from Liu and Wang (2016) and Wang et al. (2017).

Measures

First, we need to measure the *quantity* and *diversity* of urban amenities of each city, respectively. The *quantity* is a straightforward measure which calculates the totality of establishments of restaurants, retail, entertainment, tourist spots, hotels, and professional services. Regarding the *diversity*, we have utilized a suite of widely used concentration or inequality indices, including Herfindahl-Hirschman index (*HHI*), Gini coefficient (*GINI*), and Theil index (*THEIL*).

The Herfindahl-Hirschman index (*HHI*) is computationally simple, and can be defined as the sum of all squared relative shares of urban amenities (Eq. 4-1):

$$HHI = \sum_{i=1}^{n} \left(\frac{UA_i}{\sum_{i=1}^{n} UA_i}\right)^2 \text{ (Eq. 4-1)}$$

Where for a city with n categories of urban amenities, UA_i denotes the sum of establishments of the ith category of urban amenities. *HHI* ranges from 0 to 1, where increases in the *HHI* indicate a decrease of diversity, where are decreases suggest the opposite.

Gini coefficient (*GINI*) is the most commonly used measure of inequality. When it comes to the measure of urban amenity diversity, *GINI* can theoretically range from 0 (complete diversity where all categories of urban amenities have the same share) to 1 (perfect monopoly where a single category of urban amenity occupies the whole city). Noting that a city with n categories of urban amenities, UA_i denotes the sum of establishments of the ith category of urban amenities. The index can be calculated as in (Eq. 4-2)

$$GINI = \frac{n+1}{n} - 2\sum_{i=1}^{n} \frac{n+1-i}{n} \left(\frac{UA_i}{\sum_{i=1}^{n} UA_i}\right) \text{ (Eq. 4-2)}$$

Theil index (*THEIL*) is widely used to quantify income inequality and racial segregation. Derived from information theory, it measures an entropic "distance" the urban amenity is away from the state of all types of amenities having the same level of share. *THEIL* is regarding negative entropy so that a higher number indicates more concentration that is further away from the diversity of urban amenities. Given a city with n categories of urban amenities, UA_i denotes the sum of establishments of the ith category of urban amenities. The index can be calculated as in (Eq. 4-3)

$$THEIL = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{UA_i}{\frac{\sum_{i=1}^{n} UA_i}{n}} ln\left(\frac{UA_i}{\frac{\sum_{i=1}^{n} UA_i}{n}}\right) \text{(Eq. 4-3)}$$

Second, we measure of intra-urban polycentricity, inspired by Wang et al. (2017). The degree of intra-urban polycentricity (*POLY*) is modified from Meijers and Burger (2010) and Wang et al. (2017), which computes the marginal effect of the rank-size distribution of the population in different urban centers within a city (Eq. 4-4):

$$POLY = \frac{\sum_{i=1}^{n}\sum(x_i-\bar{x})(y_i-\bar{y})}{\sum_{i=1}^{n}(x_i-\bar{x})^2} \text{(Eq. 4-4)}$$

Where in a city with n urban centers, for the ith largest urban center, x_i = $\log_{10}(i+0.5)$; y_i denotes the logarithm of the population with base 10; $\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$; and $\bar{y} = \frac{\sum_{i=1}^{n} y_i}{n}$. The higher *POLY* is, the higher degree of intra-urban polycentricity the city is.

As a robustness check, another polycentricity index (*POLY**) presented by Liu and Wang (2016) is also adopted. Such intra-urban polycentricity metric was originated by Green (2007), which examines the standard deviation of the size of urban centers (Eq. 4-5):

$$POLY^{*} = 1 - \frac{\sigma_{UC}}{\sigma_{\max\_UC}} \text{ (Eq. 4-5)}$$

Where σ_{UC} denotes the standard deviation of population amongst all urban centers in a given city, $\sigma_{\max\_UC}$ denotes the standard deviation of population in urban centers of a hypothetical two-center city where one center has ‘no population’ and the other one has the ‘maximum’ observed population in all urban centers of that city. *POLY** ranges from 0 to 1, with a value of zero denoting a total lack of intra-urban polycentricity within the corresponding city and one suggesting that city consisted of several urban centers of the same size. Like *POLY*, the higher *POLY** is, the higher degree of intra-urban polycentricity the city is.

Third, the following explanatory variables are included as control variables in the multiple regression, namely population, population density, wage, and human capital. Population (*POPULATION*) is measured by resident population, which includes locals and seasonal immigrants. The inclusion of population is highlighted by recent advancement of New Economic Geography (Ottaviano and Puga, 1998; Scott and Storper, 2003), in which agglomeration economies pivot on the population-development interactions. The consideration of ‘seasonal immigrants’ is inspired by Puga (1999), which considers migration of labor forces as an important factor of the self-reinforcing process of economic development. Furthermore, recent empirical work has shown the industrial composition, and product diversity varies systematically with population size (e.g., Mori et al. (2008) and Schiff (2015)). Population density (*DENSITY*) is measured by the resident population per square kilometer. In the ‘consumer city’ article, Glaeser et al. (2001) speculate that higher population density may increase consumers’ access to a variety of goods and services. Recently, Couture (2013) utilized Google Places and household travel survey data to reveal that increased population density enables consumers to realize gains from variety. More recently, Schiff (2015) found that population size and population density have a substantial effect on the amount of product variety in a city. Wage level (*WAGE*) is measured by the average wage in a city. A growing number of firms spur competition, which increases the demand for labor and raises wage (Krugman, 1999). Human capital (*HC*) is measured by the number of people with a bachelor and above degree. A high concentration of skilled workers provides knowledge spillover, which is an essential influencing factor of agglomeration economies (Fu, 2007). Relatedly, Florida (2002) found human capital distribution, which he phrased it as the ‘creative class’ (Florida, 2014) , is closely associated with urban amenities.

Data and study area

We obtain urban amenities information from Dianping.com, the most extensive geo-tagged user-generated content website of city living guide in China, which provides merchant information of catering, retail, entertainment, lodging, etc. A Python program was written to scrape the listing of establishments of urban amenities of all Chinese cities in Mid-2015. The measurements of intra-urban polycentricity are based on LandScan^{TM}, which provides an estimation of the rasterized population at a 1-km spatial resolution. The identification of urban centers is obtained from Liu and Wang (2016). All control variables are populated from China City Statistical Yearbook.

Our analysis starts with all 364 Mainland Chinese cities at the prefectural level and above. Despite there are 46 cities without urban centers with ‘significant dense population’ (Liu and Wang, 2016), nine cities without complete socioeconomic profiles to construct the set of control variables are further excluded. Our final dataset covers 309 Chinese cities, which includes all 22 provinces in Mainland China, five Autonomous Regions, and the four municipalities directly under the Central Government (Fig. 4-2).

Estimation strategies

The provision of urban amenities in Chinese cities is empirically tested through multiple regression models in regards of intra-urban polycentricity based on the following set of linear models:

$QUANTITY = POLY + \log(POPULATION) + \log(DENSITY) + \log(WAGE) + \log(HC)$ (Model 4-1)

$DIVERSITY = POLY + \log(POPULATION) + \log(DENSITY) + \log(WAGE) + \log(HC)$ (Model 4-2)

In Model 4-1, the dependent variable—the totality of urban amenities—is a count variable. Therefore, the relationship between intra-urban polycentricity and urban amenities is examined using negative binomial regression model. Additionally, Model 4-1 is re-run by taking $\log(QUANTITY)$ as the dependent variable to fit an ordinary least square model (OLS) as one robustness check.

In Model 4-2, $DIVERSITY$ is proxied by HHI to fit an OLS estimator as our main model. Similarly, Model 4-2 is re-run through replacing HHI with $GINI$ and then $THEIL$, respectively for robustness check.

A critical concern of regression model is the endogeneity problem, which often results from mis-specification and a loop of causality between an explanatory variable and dependent variables. We adopted three strategies to handle such potential issue. First, we took a two-year lag of data to construct all explanatory variables to partly address the reverse direction of causality. In other words, in Model 4-1 and Model 4-2, we regressed the provision of urban amenities in Mid-2015 with the intra-urban polycentricity and other controlling factors in 2012. Second, we checked the if multicollinearity exists in both models, given it is a common source of misspecification. The variance inflation factor (VIF) is commonly reported to reflect the severity of multicollinearity, where a VIF over 5 indicates the presence of multicollinearity (O'brien, 2007). Third, we applied two-stage least square (2SLS) regressions to Model 4-1 and Model 4-2, to further test and control for potential endogeneity. For each city, we utilized the average slope of the landscape (*AVGS*) as the instrument for its intra-urban polycentricity. *AVGS* is the first-order derivative of a digital elevation model (DEM), where global DEM data is available from the United States Geological Survey (https://lta.cr.usgs.gov/GTOPO30). Natural landscape matters in determining intra-urban polycentricity, because mountains, waterways, and coastal lines delineate urban land use patterns. However, topographical features are unlikely to be correlated with the provision of urban amenities. Therefore, *AVGS* meets the requirement of an instrument, according to Wooldridge (2010). In the presence of endogeneity, OLS is biased and inconsistent; therefore, 2SLS should be preferred over OLS. Conversely, OLS is more efficient, which should be preferred.

Lastly but not the least, we conducted an additional round of robustness check by replacing *POLY* with *POLY** as the degree of intra-urban polycentricity and re-ran Model 4-1 and Model 4-2 to reflect the nuances of different measures. We present the descriptive statistics of all the variable in Table 4-1 and report regression results along with robustness checks in the next section.

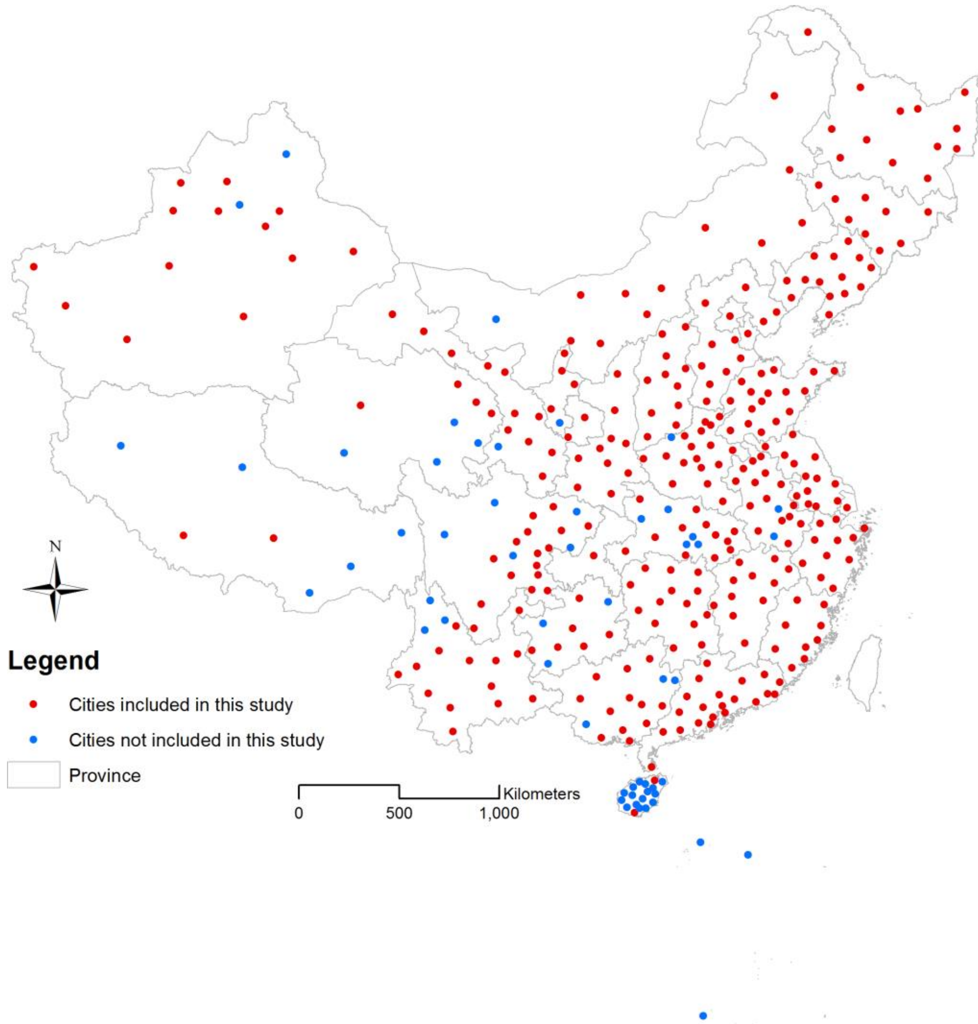

Figure 4-2. Mainland Chinese cities.

Table 4-1. Descriptive statistics of variables (N = 309).

Variable	Minimum	Maximum	Mean	Standard deviation
QUANTITY	2072.000	714172.000	59123.960	79820.810
HHI	0.068	0.203	0.145	0.021
GINI	0.328	0.538	0.464	0.031
THEIL	0.195	0.525	0.396	0.053
POLY	-4.000[#]	-0.032	-2.237	1.541
*POLY**	0.000	0.965	0.225	0.246
Log (POPULATION)	3.153	7.775	5.782	0.746
Log (DENSITY)	0.416	8.572	5.502	1.244
Log (WAGE)	10.100	11.359	10.594	0.197
Log (HC)	-0.546	5.940	2.049	1.040
AVGS	0.016	10.323	2.214	1.829

[#] We assigned a *POLY* value of -4 to cities with only one urban center, given the lowest number value of *POLY* is -3.29.

EMPIRICAL RESULTS

Intra-urban polycentricity and the quantity of urban amenities

Table 4-2 shows the results of the negative binomial estimation of intra-urban polycentricity (*POLY*) on the number of urban amenities in a city, controlling for other city-specific features (Model 4-1). Likelihood ratio test was performed, resulting a significant chi-sq. value ($p < 2.2e-16$). Therefore, the negative binomial specification is better than a Poisson counterpart, due to a presence of over-dispersion (See also the histogram of *QUANTITY* in Figure 4-3). We also fitted Model 4-1 with an OLS estimator and its 2SLS counterpart, where *POLY* is instrumented by *AVGS*. The weak instrument test was significant (14.967, $p < 0.001$), indicating *AVGS* is a valid instrument variable for *POLY*. However, the Wu-Hausman test is insignificant (0.013, $p > 0.910$), suggesting OLS is consistent, and endogeneity may not be a big problem. Therefore, we report the results of OLS in Table 4-2. Furthermore, the VIF test indicates none of the explanatory variable has a VIF value greater than 5, indicating multicollinearity is not an issue in Model 4-1.

In Table 4-2, it is clear that the higher degree of intra-urban polycentricity has a positive effect on the quantity of urban amenities, conditioning on other covariates, which is consistent with our proposition. Meanwhile, the negative binomial estimator and OLS produce similar estimation results. If a city increases its intra-urban polycentricity degree by one point, the difference in the logs of expected quantity of urban amenities would be expected to increase by 0.023 unit, while holding the other covariates constant. In contrast, the log-level OLS regression is easier to comprehend: if a city increases its degree of intra-urban polycentricity by one unit, we would expect the number of urban amenities of that city to increase by 2.2%.

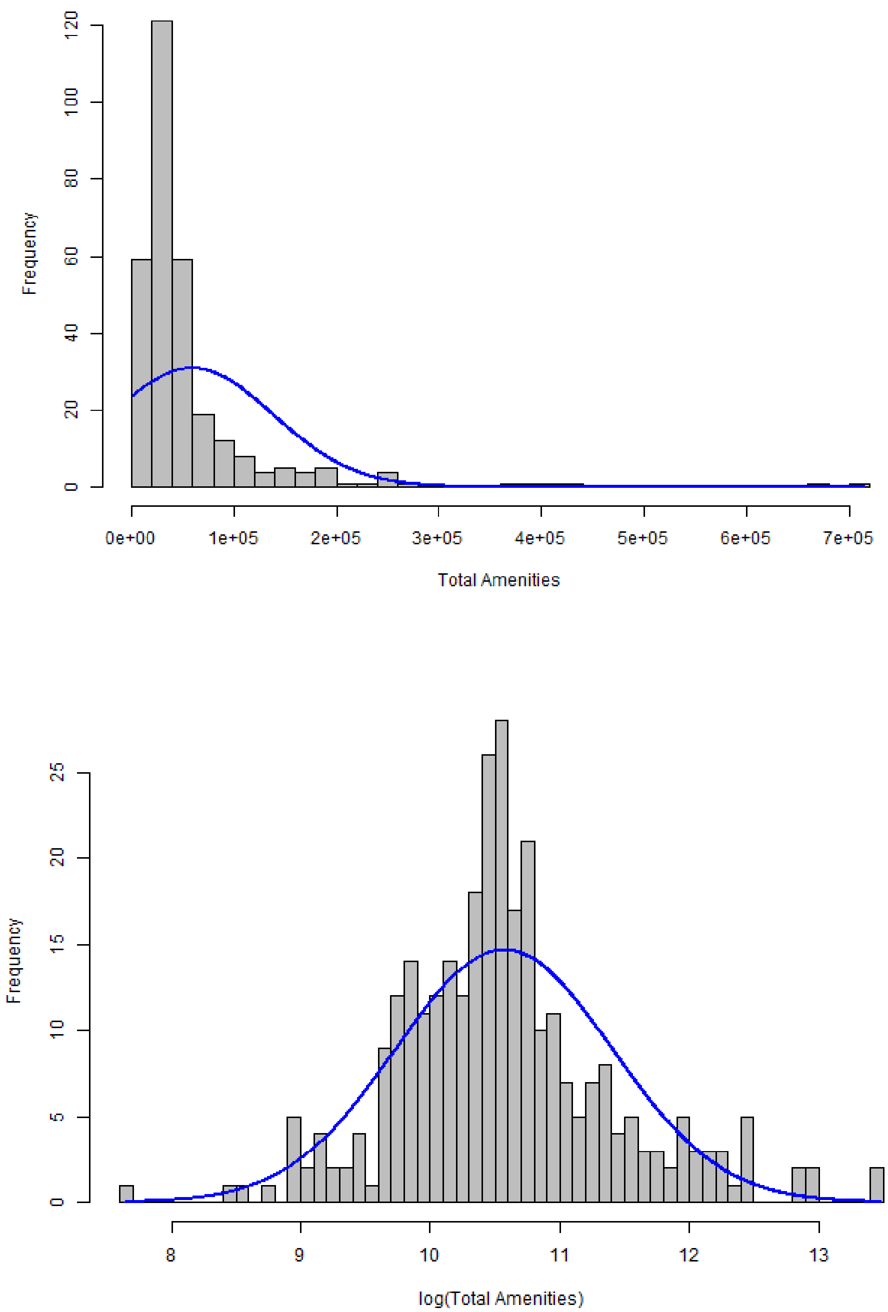

Figure 4-3. The histograms of the number of urban amenities (*QUANTITY*) in different cities.

Table 4-2. Estimation of the quantity of urban amenities (Model 4-1)

	Negative Binomial			OLS		
Dependent Variable	*QUANTITY*			*Log (QUANTITY)*		
	Estimate	SE		Estimate	SE	
(Intercept)	4.406	1.133	***	4.631	1.137	***
Log (POPULATION)	0.208	0.043	***	0.208	0.045	***
Log (DENSITY)	0.087	0.016	***	0.091	0.017	***
Log (WAGE)	0.327	0.096	***	0.299	0.098	**
Log (HC)	0.538	0.030	***	0.547	0.031	***
POLY	0.023	0.010	*	0.022	0.011	*
-2* log-likelihood	6571.877			*N/A*		
Adjusted R2	*N/A*			0.901		

SE = White-Huber standard errors (heteroskedasticity robust standard errors)
Significant codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1

Intra-urban polycentricity and the diversity of urban amenities

Table 4-3 shows the results of the OLS and 2SLS estimation of intra-urban polycentricity (*POLY*) on the diversity of urban amenities in a city, measured by *HHI*. The weak instrument test was significant (14.970, p< 0.001), indicating *AVGS* is a valid instrument variable for *POLY*. Furthermore, the Wu-Hausman test is significant (22.36, p< 0.001), suggesting the existence of endogeneity. Therefore, OLS is no longer consistent. Hence, 2SLS estimator is preferred over OLS.

In Table 4-3, it is obvious that after instrumentation, a higher degree of intra-urban polycentricity has a positive effect on the diversity of urban amenities, when other variables are constant, which is consistent with our proposition. After instrumentation, if we increase the degree of intra-urban polycentricity of a city by one point, we would expect the diversity of its urban amenities increases by 0.0168 unit (a decrease of *HHI* indicates an increase of diversity).

Table 4-3. Estimation of the diversity of urban amenities (Model 4-2)

Dependent Variable: *HHI*	OLS			2SLS#		
	Estimate	SE		Estimate	SE	
(Intercept)	0.1102	0.0840		-0.1416	0.1599	
Log (POPULATION)	0.0087	0.0031	**	0.0257	0.0078	**
Log (DENSITY)	0.0019	0.0013		-0.0032	0.0025	
Log (WAGE)	-0.0006	0.0075		0.0137	0.0125	
Log (HC)	-0.0094	0.0019	***	-0.0131	0.0036	***
POLY	0.0001	0.0008		-0.0168	0.0060	**
Adjusted R^2	0.074			N/A		
Weak instruments	N/A			14.970		***
Wu-Hausman	N/A			22.36		***

# The instrument of *AVGS* was used in the first stage of the regression for the endogenous variable *POLY*.
SE = White-Huber standard errors (heteroskedasticity robust standard errors)
Significant codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1

Robustness checks

First, we re-ran the negative binomial specification of Model 4-1 by replacing *POLY* with *POLY**, an alternative measure of intra-urban polycentricity. Similarly, the likelihood ratio test with a significant chi-sq. value (p< 2.2e-16) indicates the negative binomial specification is better than a Poisson counterpart due to the over-dispersed distribution of *QUANTITY*. The estimation results are consistent with Table 4-2, where a city increases the degree of its intra-urban polycentricity as defined by Liu and Wang (2016) by one unit, the difference in the logs of expected quantity of urban amenities would be expected to increase by 0.116 unit while holding the other explanatory variables constant. The detailed estimation results are presented in Table 4-4.

Table 4-4. Negative binomial estimation of the quantity of urban amenities with an alternative intra-urban polycentricity measure.

Dependent Variable	*QUANTITY*		
	Estimate	SE	
(Intercept)	4.177	1.128	***
Log (POPULATION)	0.215	0.044	***
Log (DENSITY)	0.085	0.016	***
Log (WAGE)	0.339	0.096	***
Log (HC)	0.540	0.031	***
*POLY**	0.116	0.069	.
-2* log-likelihood	6573.574		

SE = White-Huber standard errors (heteroskedasticity robust standard errors)
Significant codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1

Second, we re-ran Model 4-2 with both OLS and 2SLS estimators by replacing the diversity measure of urban amenities *HHI* with *GINI* and *THEIL*, respectively. The significant weak instruments and Wu-Hausman tests ($p<0.001$) indicate the preference of 2SLS over OLS for both estimations. Table 4-5 reports the 2SLS estimation results. The findings are consistent with Table 4-3, where an increase of intra-urban polycentricity is associated with a higher level of diversity of urban amenities in a city, measured by both *GINI* and *THEIL*. Furthermore, we re-ran Model 4-2 by replacing *POLY* with *POLY** with both OLS and 2SLS, with all three urban amenity diversity measures as dependent variables (Table 4-6). The findings are consistent with Table 4-3 and Table 4-5.

Table 4-5. 2SLS estimation of the diversity of urban amenities with alternative measures of diversity.

Dependent Variable[#]	*GINI*			*THEIL*		
	Estimate	SE		Estimate	SE	
(Intercept)	0.001	0.249		-0.516	0.437	
Log (POPULATION)	0.041	0.012	***	0.080	0.022	***
Log (DENSITY)	-0.006	0.004		-0.012	0.007	.
Log (WAGE)	0.022	0.019		0.046	0.034	
Log (HC)	-0.019	0.006	***	-0.041	0.010	***
POLY	-0.026	0.009	**	-0.050	0.017	**
Weak instruments	14.970		***	14.970		***
Wu-Hausman	22.38		***	27.91		***

[#] The instrument of *AVGS* was used in the first stage of the regression for the endogenous variable. SE = White-Huber standard errors (heteroskedasticity robust standard errors)
Significant codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1

Table 4-6. 2SLS estimation of the diversity of urban amenities with an alternative intra-urban polycentricity measure.

Dependent Variable[#]	*HHI*			*GINI*			*THEIL*		
	Estimate	SE		Estimate	SE		Estimate	SE	
(Intercept)	-0.010	0.143		0.206	0.221		-0.126	0.396	
Log (POPULATION)	0.023	0.007	***	0.038	0.011	***	0.073	0.019	***
Log (DENSITY)	-0.003	0.002		-0.005	0.004		-0.011	0.007	
Log (WAGE)	0.009	0.012		0.014	0.019		0.031	0.034	
Log (HC)	-0.016	0.004	***	-0.023	0.006	***	-0.049	0.011	***
*POLY**	-0.106	0.038	**	-0.165	0.060	**	-0.315	0.106	**
Weak instruments	13.320		***	13.320		***	13.320		***
Wu-Hausman	21.080		***	20.990		***	27.080		***

[#] The instrument of *AVGS* was used in the first stage of the regression for the endogenous variable. SE = White-Huber standard errors (heteroskedasticity robust standard errors)
Significant codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1

CONCLUSION AND DISCUSSIONS

We have explored the relationship between intra-urban polycentricity and the provision of urban amenities in 309 Chinese cities. It is found that a higher level of intra-urban polycentricity is associated with more quantity and diversity of urban amenities. Such finding is robust to: (1) different estimation strategies; (2) different indices of intra-urban polycentricity; and (3) different measures of the diversity of urban amenities. The findings have the following implications for literature and urban development strategies.

First, the ultimate goal of sustainable urban development is to increase the quality of life of its citizens. Urban amenities play a critical role in attracting consumers to live and work. Put differently; cities can benefit from the richness of urban amenities for their growth (Garretsen and Marlet, 2017; Glaeser and Gottlieb, 2009; Partridge, 2010; Rust and Chung, 2006). Our finding suggests polycentricity is attractive due to its positive correlation with both the quantity and the diversity of urban amenities at the city level in China. We have provided the micro-foundations for the speculation of such relationship: Firstly, the essence of intra-urban polycentricity is the emergence of multiple independent urban centers in a city. Secondly, we re-interpreted the classic Central Place Theory and conceptualized those ‘urban centers’ as ‘central places’, which provide goods and services (i.e., central functions) through urban amenities. Second, the co-location of firms (urban amenities) in and close to those ‘urban centers’ has been jointly explained by agglomeration economies from the producer side and spatial clustered demands from the consumer side. While a firm co-locates with other firms in different industries increases the diversity of urban amenities, the co-location of firms regardless of the industry which they belong to contributes to higher quantity of urban amenities.

Second, our finding contributes to both fields of economic geography and urban economics regarding the 'consumer city' (Glaeser, 2011; Glaeser et al., 2001) and the 'love of variety'' literature (Dixit and Stiglitz, 1977; Krugman, 1993). While most previous studies are based on US cities (Chen and Rosenthal, 2008; Glaeser, 2011; Lee, 2010), our work contributes to the strand of literature by providing empirical evidence in Chinese cities. Meanwhile, we also contribute to the polycentric urban development literature, which traditionally attributes the benefits of polycentric urban development to the facilitation of agglomeration economies from the side of production (Parr, 2004). Through the lens of urban amenities, we have expanded its potential benefits from both production and consumption perspectives, evident by a Chinese case.

Third, in addition to intra-urban polycentricity, the stock of human capital is also positively correlated with both the quantity of diversity of urban amenities. Such finding is supported by the 'creative class' argument (Florida, 2002, 2014), where urban amenities rather than agglomeration economies attract creative people. Similarly, entrepreneurs in the creative industry consider urban amenities to be more critical than agglomeration economies for their location decision (Wenting et al., 2011). Relatedly, the population size is positively associated with the quantity but negatively associated with the diversity of urban amenities. As the quality of life at least contains the quantity and diversity aspects of urban amenities, one policy implication is that population itself is not enough; and how multiple urban centers are distributed in city matters.

Lastly but not the least, some limitations of this work also set paths for future research. Firstly, although this study has relaxed the assumption of a hierarchical pattern of central places in Central Place Theory for operationalization purpose, it will be worth to explore the role of polycentricity in different hierarchies of the central functions of urban amenities. Secondly, this study has only investigated intra-urban polycentricity. As polycentric urban development is multiscalar and multifaceted (van Meeteren et al., 2016), future research can be done at an inter-urban scale (e.g., Meijers (2008) and Burger et al. (2014)). Comparative studies of polycentric urban development in various scales and in different settings will provide a holistic view of the relationship between polycentricity and urban amenities.

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CHAPTER 5

CONCLUSIONS

This research aims to empirically test the purported benefits of polycentric urban development, to answer whether it is a sustainable development regime. This study empirically examines the effects of polycentricity on the environmental, economic, and social performances of Chinese cities.

In Chapter 2, we explored the environmental performance through the lens of carbon emission in Chinese cities. We find intra-urban polycentricity is associated with higher carbon emission, while compact land use pattern is associated with less emission. Additionally, there are economies of scale in CO_2 concerning total population and a substantial wealth effect on CO_2 emission.

In Chapter 3, we systematically investigated how intra-urban and inter-urban polycentricity is related to economic productivity in Chinese cities. We extend the Cobb-Douglas production function to evaluate urban-economic performance based on labor productivity in individual cities. We find that intra-urban monocentricity and inter-urban polycentricity tend to be associated with higher levels of labor productivity. Additionally, there is a positive interaction effect between intra-urban polycentricity and inter-urban polycentricity on labor productivity. We also find that there are some agglomeration spillover effects where smaller cities tend to benefit more than larger cities.

In Chapter 4, we examined how intra-urban polycentricity is associated with the provision of urban amenities regarding the quantity and the diversity in Chinese cities. We find a higher level of intra-urban polycentricity is associated with both higher number and a more extensive variety of urban amenities. We also provide a possible explanation from both the production and consumption sides of urban amenities through revisiting the Central Place Theory.

As polycentric urban development is at the core of blossoming literature and adopted by policy-makers around the world as part of spatial development strategies, it is essential to understanding this issue from a holistic perspective. Some limitations that this study suffers from may also shed light on future research.

First, due to Chinese data availability issues, this study only contains cross-sectional data, and thus can just focus on correlations between polycentricity and the outcomes. Future research should incorporate longitudinal data. Second, we have adopted the morphological definition of polycentricity and implemented it with population data. Future analyses could examine polycentricity through different facets (e.g., the relational, functional, and political dimension) and/or implement the morphological concept with varying measures of the 'importance' (e.g., employment, business establishment). Third, we attempted to deconstruct polycentric urban development regarding intra-urban and inter-urban scales. The multiscalar nature of polycentricity can range from neighborhood to continent level continuously. A holistic value of polycentricity needs to consider such a continuum. Fourth, our measures of city performances can be enriched. For example, the environmental performance of polycentric urban development can be tested against urban heat/dry island effects, air pollution, urban flooding, and the loss of biodiversity; the economic performance can be proxied by wage and housing price; the social performance of the provision of urban amenities can be refined given the hierarchy and quality of urban amenities. Finally, any comparative studies of polycentric urban development in different settings or countries will provide nuanced knowledge about the 'health' of the global economies and environements.