Land Use Policy 115 (2022) 106005

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

Do compact cities have higher efficiencies of agglomeration economies? A dynamic panel model with compactness indicators

Yongling Yao [a], Haozhi Pan [b,*], Xiaoyu Cui [a], Zhen Wang [c,d,**]

[a] School of Applied Economics, Remin University of China, China
[b] School of International and Public Affairs, China Institute for Urban Governance, Shanghai Jiao Tong University, 800 Dongchuan Rd., Shanghai 200240, China
[c] College of Resources & Environment, Huazhong Agricultural University, Wuhan 430072, China
[d] Interdisciplinary Research Center for Territorial Spatial Governance and Green Development, Huazhong Agricultural University, Wuhan 430070, China

ARTICLE INFO

Keywords:
Compact city
Urban sprawl
Land efficiency
Agglomeration economies
Population density
Land management

ABSTRACT

Compact development is proposed to preserve land resources as well as promote agglomeration economies. This paper adopts a multi-indicator system of compact cities, including population density, boundary limitation, and road density, to examine the relationship between the compact city and urban efficiency through agglomeration economies. We empirically examine the relationships between compact city indicators and comprehensive/technical efficiency measures of the cities through GMM regression with panel data of 226 prefectural and upper-level cities in China during 2001–2015. We find the answers heterogeneous for each indicator-efficiency pair for each city type. Higher population density and compact urban form are beneficial to the urban economic efficiencies of large cities, but not for the technical efficiency of small cities. Road density is conducive efficiencies for small and medium cities, but not technical efficiencies for large cities. We confer that the heterogeneity may be explained by the economic structure compositions of cities of different sizes. Based on our findings, we propose tailor-made policy suggestions regarding urban compactness and economic efficiencies for cities of different sizes.

1. Introduction

Urbanization processes consume a large quantity of essential but limited natural land resources around the world (Liu, 2018; Yang et al., 2018), which lead to negative consequences such as land and ecosystem degradation (Liu et a, 2014, 2018a; Zhang et al., 2020), loss of fertile agricultural resources, and arising food security issues (Gao et al., 2019; Salvati, 2014). Urban sprawl—low-density urban land growth and expansion—has been recognized as the main causal chain of negative byproducts of urbanization (Sorensen, 1999). To accommodate the growing population while limiting consumption of natural resources, "compact city" is proposed worldwide as one of the potential solutions (Johnson, 2001; Chen et al., 2016).

Improving land efficiency through improvements of resource efficiency and reduction of travel demand (Liu et al., 2014) is at the core of compact city's conceptualization. Land efficiency is a compound construct while identified as a key indicator set for the policy-making and management of the sustainable environment and the socio-economy (Meng et al., 2008). The indicator set includes floor-area ratio (Liu et al., 2018b), per area industrial output (Huang et al., 2016), per capita built-up area (Nguyen et al., 2002), and environmental or ecosystem-based matrices (Kwak and Deal, 2021; Pan et al., 2021b). In the context of the compact city (or "smart growth" in the U.S.), land efficiency indexes often relate to environmental factors such as green-space impacts (Tian et al., 2014), energy consumption (Yamagata and Seya, 2013), and carbon emissions (Liu et al., 2014; Gudipudi et al., 2016), and other on social factors including housing and accessibility (Wu et al., 2017). The compact city concept can provide twofold contributions to higher land efficiency (Shi et al., 2016; Lee and Lim, 2018; Jun, 2020): it reduces low-efficiency consumption of land resources; at the same time, it can promote agglomeration economies by encouraging high-density development. Thus, promoting agglomeration economies while avoiding negative externalities of high density, should be incorporated into land efficiency and compact city evaluations.

The theory of agglomeration economies proposes that firms prefer positive externalities from the spatial concentration of economic

* Corresponding author.
** Corresponding author at: College of Resources & Environment, Huazhong Agricultural University, Wuhan 430072, China.
E-mail addresses: yaoyongling@ruc.edu.cn (Y. Yao), panhaozhi@sjtu.edu.cn (H. Pan), 1527741915@qq.com (X. Cui), sinoo@mail.hzau.edu.cn (Z. Wang).

https://doi.org/10.1016/j.landusepol.2022.106005
Received 20 November 2020; Received in revised form 26 November 2021; Accepted 23 January 2022
Available online 29 January 2022

activities. According to the urban economic theory, these positive externalities can arise from either spatial concentration of similar or diverse/related economic activities (Melo et al., 2009; Andersson et al., 2016). Natural byproducts of compact city principals can be linked to the concept of agglomeration economies in the aspects of geographical proximity of human capital (Abel et al., 2012; Ciccone and Hall, 1996; Squicciarini and Voigtländer, 2015), firms (Accetturo et al., 2018), market access (Zheng and Du, 2020), and purchasing power (Sato et al., 2012). However, compactness may also generate dis-economies of agglomeration, such as higher crime rates, traffic congestions, housing shortages, resource shortages, "heat island" effects, noise, and pollution (Chen et al., 2016; Mouratidis, 2017, 2019). Therefore, the linkage between agglomeration economy and compactness is highly complex. Previous studies have examined the potential linking mechanism including: (1) human capital and market access concentration in driving entrepreneurship (Zheng and Du, 2020); (2) transportation and accessibility that support inter-city social interactions (Zheng and Du, 2020); (3) denser firm locations that increase productivity (Pan et al., 2020; Yang et al., 2019); 4) and knowledge spillovers that promote local innovation (Capello and Faggian, 2005; Huber, 2012). However, previous literature does not pay much attention to: (1) differentiated agglomeration effects for cities of different sizes; (2) and different mechanisms of how compactness can improve land efficiency through agglomeration economies.

To examine the relationship between compactness and urban economic efficiency through agglomeration economies, this paper puts forward a theoretical framework that links city compactness with agglomeration economies. Three indicators—population density, boundary limitation, and road density—are measured against key land efficiency measures—comprehensive and technical (knowledge spillover) efficiency. Specifically, we classify the 226 prefectural and upper-level cities in China into three groups as follows: the first group (large city) includes cities with a population larger than 3 million; the second group (medium-sized city) refers to cities with a population between 1 and 3 million; and cities with a population less than one million (small city). We adopt GMM regression model to analyze the panel data of these cities during 2001–2015.

This study contributes to the existing literature of compact city and agglomeration economies with a theoretical framework as well as clear evidence that demonstrates the relationship between compact city indicators and measures of economy efficiency. Specifically, we focus on how "compactness" affects economy efficiency through the promotion of knowledge spillover and economy of scale. The theoretical framework has two merits: (1) we derive comprehensive and technical efficiency for each city from controlled return to scale and the city size simultaneously. Thus, the effects of compactness on urban efficiency can be measured and distinguished by the increasing population size, population density, and the increasing knowledge spillovers or expertize sharing (technical efficiency); (2) the model is applied to cities of different sizes (small, medium, and large cities), and can test whether effects of compactness are monotonic increasing or shifting at some certain city sizes, thus has implications for cities in different size.

Practically, this paper addresses the policy perspective of urbanization and intensification of existing urban land development persisting in China's land use policy platform from the late 1990 s (Tan et al., 2008). Due to the scarcity of per capita arable land resources in China, strict growth control and intensive urban land use have been the key themes of land use policy in China (Lin and Ho, 2003). The central government even stopped approving any application for the non-agricultural occupation of arable land across the country from 1997 to 2004 according to the National General Land Use Plan (1997–2010) in 1997 (or 1997 National Plan) (Zhong et al., 2018). Such policy incentives raise many questions, such as: can population densification and land intensification lead to higher economic efficiency when land use growth is constrained? Is the effect of densification and intensification similar to cities in different sizes? To what extent do the return of densification and intensification become negative? How do intensification of population, land development, and transportation infrastructure interplay? Examination of urban compactness and efficiency measures in this paper can shed light on these questions.

The paper begins with a literature review and theoretical framework proposal of land efficiency of compact cities through agglomeration economies promotion. The following section presents the methodological framework. Section 4 discusses the empirical analyses of 226 prefectural and upper-level cities. Section 5 concludes with theoretical and practical implications.

2. Literature review and theoretical framework

2.1. Relationship between urban compactness and agglomeration economy efficiencies

Compact city refers to the arrangement of dense population and industry in limited urban space to improve the efficiency of urban land use (Westerink et al., 2013). Efficiency benefits of compact cities are both proposed in terms of environmental efficiency (saving resources) and economic efficiency (promoting agglomeration economies). Research shows that the proximity of various factors, including human capital, market access, and transportation network, promotes the agglomeration effect, thereby improving urban economic efficiency (Zheng and Du, 2020). As a counterpart to compact city, expansion and sprawl of built-up land increases land inputs and thus reduce land efficiency. However, previous studies have shown mixed evidence of the relationship between compactness and urban efficiency (Liu et al., 2014; Wang et al., 2019; Deilmann, 2018). For example, Wang et al.'s (2019) panel model for cities in Pearl River Delta, China from 1990 to 2013 indicates that building compact cities help to improve CO_2 efficiency. Liu et al. (2014) find more complicated results that compactness correlates positively with CO_2 economic efficiency but negatively with CO_2 social efficiency for 30 China cities. Deilmann et al. (2018) focus on cities and towns in Germany and show that compactness is no guarantee of efficiency and medium-sized cities make the most efficient use of land. Tan and Lu (2019) use a vector autoregression model for compactness and sustainable development in Nanjing China from 2005 to 2015 and show that compactness shock (population and economy) receive responses of decline in social development and slightly upward trend in the ecological environment. These studies mostly directly measure the correlation between urban compactness and environment, or between land and economy outcomes, but how the economic efficiency is realized through agglomeration economies is rarely mentioned.

Efficient use of land resources is one of the major arguments for the compact city. Therefore, measures used in land efficiency evaluation can shed light on the urban efficiency measure for compactness. Previous literature focused on environmental and resource aspects of land use efficiency (Zhang et al., 2020; You et al., 2020). Recently, causal and dynamic space-time relationship between land use efficiency and other indicators has been also investigated. For example, Zhang et al. (2020) construct a land efficiency measure for 13 cities in Jiangsu Province able to test causal relationships between indicators and disparities between cities. Gao et al. (2019) develop a total factor urban land use efficiency for counties in the Wuhan Metropolitan region to identify spatial autocorrelation with clustering patterns. Other investigations into spatial-temporal variation and influencing factors of urban land use efficiency include locations, policies, and industrial structure (Chen et al., 2016; Liu et al., 2018). An important application of these indicators is to better understand the mechanisms of specific urban forms and policies in promoting land efficiency. One of such mechanisms is to promote agglomeration economies through compactness in improving land efficiency.

Principals of compact cities in nature correspond to the agglomeration economies of cities (Bardhan et al., 2015) by emphasizing the development mode of high density, mixed functions, and social and cultural diversity. Agglomeration effects of density, externality, scale economy, market access, and transportation connectivity have been well-studied in literature. Regarding population density and concentration of human capital, Andersson et al. (2016) confirm a city-wide employment density–wage elasticity and an economically significant density–wage elasticity at the neighborhood level using geocoded high-resolution data. Melo et al. (2017) find productivity gains from urban agglomeration by employment density measures for a sample of the largest metropolitan areas in the United States. Zheng and Du (2020) document strong positive entrepreneurial effects of local human capital resources and market size for nearly 300 prefecture-level cities in China, and the agglomeration effects are more robust in mega urban agglomerations. The concentration of human capital is also recorded by other studies as the most fundamental factor for the urban innovation ecosystem as human capitals prefer to stay in close proximity to each other in order to enjoy positive knowledge spillovers (Accetturo et al., 2018). Melo et al. (2009) undertake a quantitative review of the empirical literature on agglomeration through a meta-analysis of 729 elasticities taken from 34 different studies, and find out labor quality can give rise to differences in the results of agglomeration economies. Abel et al. (2012) find out that doubling density in metropolitan areas yields productivity benefits that are about twice the average by estimating a model of urban productivity. Faggian et al. (2017) find that human capital—measured by educational attainment—is considerably more conducive to employment growth than the share of creative occupations in rural and urban United States counties.

In terms of transportation connectivity, Holl (2004) uses municipality-level data to study firm birth in Portugal from 1986 to 1997 with motorway expansion and finds out the increased attractiveness of locations close to the new infrastructure for most sectors. Graham (2007) also shows that there are positive externalities from the provision of transportation infrastructure. However, counter-evidence is proposed by De Bok and van Oort (2011) in a case study of the Dutch province of South Holland with micro-level data. They confirm that own-sector and generalized external economies are more important for a firm's location choices than proximity to transport infrastructures. Besides job connectivity, transportation connectivity can also promote agglomeration economies by connecting people to quality-of-life amenities and thus attracting human capital concentration. Yang et al. (2019) find out that, in Chicago, accessibility to quality-of-life amenities is critical for agglomeration economies as it has the highest weight in location choices for urban residents and workers. Patil and Sharma (2020) develop an Urban Quality of Life (UQoL) score to measure the relationships between urban quality-of-life, economic development, and transportation access.

In general, literature on agglomeration economies has not reflected, to our best knowledge, how and whether compact city indicators link with agglomeration economies outcomes. Though the linkage between the principles of compact city and agglomeration economies is intuitive, empirical evidence of whether and how they are related is still lacking. Moreover, an examination with multi-level city sizes is necessary, since compactness may not monotonically create agglomeration benefits as negative externalities could arise with excessively high density and large scale. Furthermore, previous analyses have not distinguished whether the effects of density on productivity are derived from improvement of return to scale or knowledge spillovers from a denser concentration of human capital.

2.2. Theoretical framework

In this paper, we set up indicators of urban compactness, including population density, boundary limitation, and road density, to evaluate the relationship between the compact city and urban economic efficiency. The aim of this paper is to explore the impact of different aspects of urban spatial patterns on economic efficiency through agglomeration effectiveness, as well as to find the ways that different agglomeration effectiveness has on urban growth. We demonstrate our framework in Fig. 1.

In our analytic framework, urban compactness is identified by population density, boundary limitations, and road density, which are identified as key indicators for urban compactness by previous literature (Mouratidis, 2019). The urban economic efficiency outcomes, including comprehensive and technical efficiencies, are to be measured to

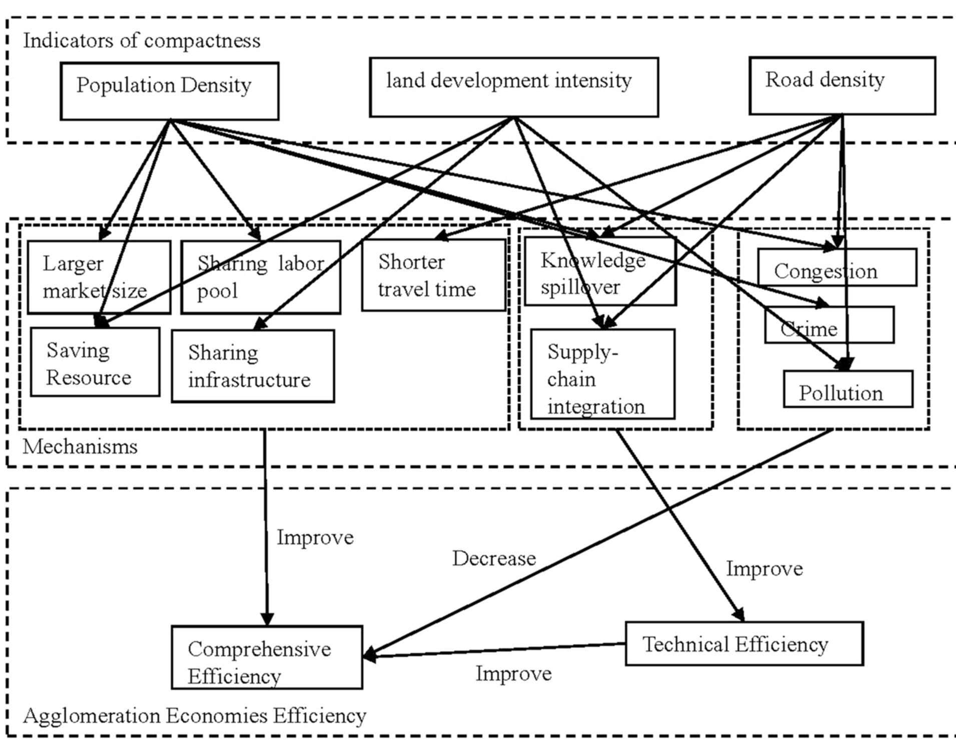

Fig. 1. Framework of urban compactness and agglomeration effects.

understand how they relate to these urban compactness indicators.

Comprehensive efficiency measures whether a city is operating at an optimal efficiency of production with regard to input factors such as land, labor, and capital. According to the literature, compactness can promote sharing of labor pool, public infrastructure (Eberts and McMillen, 1999; Zheng and Du, 2020), saving land resources, shortening travel time (Graham, 2007; De Bok and Van Oort, 2011), increasing market opportunities (Billings & Johnson, 2016), and thus promoting comprehensive efficiency of cities. Particularly, technical efficiency improvement is a key channel for compact cities to achieve higher comprehensive efficiency. Technical efficiency is an efficiency measure that compares a city only to other cities of similar scale while ignoring the impact of scale size (Mitra, 1999; Ouyang et al., 2019). In compact cities, higher density and spatial proximity development patterns can facilitate technical efficiency improvement through knowledge spillovers and sharing of technical expertize, among other mechanisms such as increased personal contacts and business vibrancy (Pan et al., 2021b). On the other hand, high density can also cause negative externalities that could compromise technical efficiency in compact cities, such as higher crime rates, traffic congestions, infectious diseases (Chen et al., 2021b), housing shortages, resource shortages, "heat island" effects, noise, and pollution (Kwak et al., 2020).

To examine the relationship between city compactness and comprehensive efficiency, the analytic framework of this paper is developed on the basis of four hypotheses, as follows:

Hypothesis 1. Urbanization with higher population density can lead to optimal comprehensive efficiency through potential mechanisms such as market opportunities and labor pool sharing, as well as stronger knowledge spillovers (measured by technical efficiency).

Hypothesis 2. Urbanization with more available land resources within the boundary leads to optimal city size and density (measured by comprehensive efficiency) with potential mechanisms such as sharing public infrastructure, as well as higher production per unit of land (measured by technical efficiency).

Hypothesis 3. Urbanization with higher road density can lead to optimal city size and density (measured by comprehensive efficiency) with potential mechanisms such as improved transport connectivity and reduced travel time, as well as higher industry production efficiency (such as improved supply chain integration and knowledge communication).

Hypothesis 4. Compact indicators (population density, boundary limitation, road density) cannot monotonically improve urban efficiency (measured by comprehensive efficiency and technical efficiency) due to negative externalities with over-compactness, such as traffic congestions, housing shortages, and pollution. Thus, model results for cities of different sizes (small, medium, and large cities) will vary.

Note that there could be endogeneity among the compactness indicators and urban efficiency measures. For example, higher comprehensive and technical efficiency may further spur agglomeration and contribute to higher population density in the highly developed central-business district (CBD). To address this issue, we use a multi-year dynamic panel with GMM (Generalized Method of Moments) estimations that control for the lag term of comprehensive and technical efficiency measures, to avoid reversed effects of comprehensive and technical efficiency on urban agglomeration.

3. Methodological framework

3.1. Compactness indicators

In this paper, three indicators are calculated to identify the compactness of each city, including population density, boundary limitation, and road density. Population density is calculated by the number of residents per unit area of the total municipal area. The total municipal area represents all the areas within the city's administrative boundary. Boundary limitation is the calculated ratio of built-up area to total municipal area, which represents the extent of urbanization and urban boundary's effects on urban economic efficiency as examined in previous studies (Chen et al., 2016; Anas and Rhee, 2006; Gennaio et al., 2009). Road density is calculated by the average length of paved roads per unit of urban area for each city. Though there is strong evidence that public transit is conducive to urban agglomeration economies (Chatman and Noland, 2014), some public transit services (such as metro) are not available in small or even medium cities, and data for such services may not be comparable across cities in different sizes. Thus, this study only incorporates road length in the calculation as it is the most comparable transportation infrastructure indicator across cities. Whether this is a key limitation to the empirical analysis subjects to further studies.

3.2. Urban economy efficiency (scale and technical efficiency) measures

Economic efficiency refers to the consequences of output and input of production factors. Based on the production function, input factors are indicated by capital, human resource, and land; output is usually represented by GDP. Data Envelopment Analysis (DEA) is often used to analyze the efficiency of the input-output ratio (Chen et al., 2016). This paper uses the asset-output ratio method to calculate the total capital value. Firstly, we calculate the average value of output coefficients of current and fixed assets in various sectors, and then calculate the current and fixed assets of the second and tertiary industries, respectively, by using the ratio of the value added of industrial sectors within the total municipal area to the value added of the second and third industries. Finally, we obtain the total amount of capital investment in each municipal area by adding up the total amount of current and fixed assets. Notably, this method covers land in depreciable capital, since the urban land resource is one of the most important inputs factors of urban economic growth. The detailed motivation and reason for the process can be found in Supplementary Materials S1.

The calculation of economic efficiency needs various input factors of production function and considers the comparability between cities of different sizes. Data Envelopment Analysis (DEA) model is used to derive the comprehensive and technical efficiency of each city. In DEA analysis, the relative effectiveness of a decision-making unit (DMU) is measured by comparing the degree of deviation of DMU from the combination of the optimal inputs. The original model of DEA is set up by Charnes, Cooper, and Rhodes (1978) (DEA-CCR), and the formula is the followings:

$$maxh_{j0} = \frac{\sum_{r=1}^{s} u_r y_{rj0}}{\sum_{i=1}^{m} v_i x_{ij0}} \quad (1)$$

$$\frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1, j = 1, 2, \ldots, n \quad (2)$$

$$u \geq 0, v \geq 0$$

Where, x_{ij} refers to the input amount of the j unit to the input of type i. in this paper, there are three kinds of inputs: land, capital and labor; y_{ij} refers to the output of type r in the j unit. In this paper, there is only one kind of output, namely GDP. v_i is the weight coefficient of type i input; u_r is the weight coefficient of the output measure; i = 1, 2; m ; r = 1, 2, …, s ; j = 1, 2,…, n. h_{j0} ($0 \leq h_{j0} 0 \leq 1$) is the efficiency index of the j city. The closer the value of h_{j0} to 1, the higher the urban efficiency is; the vice versa. The DEA-CCR model takes the efficiency index of j_0 unit as the objective, and takes the efficiency index of all units as the constraint, which can offset the different impacts by the boundaries of frontier trend surface with different sized cities. This makes the results comparable among the included samples. Thus, the CCR model is used to calculate the comprehensive efficiency of cities with constant scale returns.

We use an updated version of DEA to decompose combined efficiency into technical efficiency. Banker, Charnes, and Cooper (1984) established DEA-BCC to account for the changeable of scale return of cities. In DEA-BCC, the efficiencies can be decomposed into technical efficiency and scale efficiency. Technical efficiency refers to the distance between DMU and DEA frontier when the return to scale is variable. The technique efficiency is denoted by setting the non-archimedean infinitesimal in DEA-BCC model as the following formula:

$$\begin{aligned} & min\theta = h_{j0} \\ & \sum_{j=1}^{n} x_{ij}\lambda_j \leq \theta x_{i0}, \qquad i = 1 \\ & \sum_{i=1}^{n} y_{rj}\lambda_j \geq \theta x_{i0}, \qquad r = 1 \\ & \lambda_j \geq 0, \quad j = 1, \quad \ldots, n \end{aligned} \tag{3}$$

While, λ_j is a weight variable, h_{j0} ($0 \leq h_{j0} \leq 1$) is the effect index of city j. The effective DEA-BCC is from $h_{j0} = 1$, and the constrain condition parameter $\sum_{i=1}^{n}\lambda_j = 1$. This efficiency reflects the combination and use level of input factors by output, and reflects the innovation ability of the city. Technical efficiency represents knowledge spillover through learning, sharing, and matching. In the urban economy, agglomeration can generate benefits by increasing investment scale and reducing costs, which reflects the low-cost strategy of the agglomeration effect.

4. Empirical analysis

In this paper, panel regression models are constructed for 226 China prefectural and upper-level cities between 2001 and 2015 to investigate the relationship between urban compactness and economic efficiencies. Urban economic efficiencies (comprehensive and technical efficiency) are taken as dependent variables; indicators of urban compactness (population density, boundary limitation, road density) are taken as core independent variables. The list of variables is shown in Table 1.

Urban economic efficiencies may be affected by other factors that cannot be captured by the compactness indicators. To address this issue, our model controls these covariates to better measure the marginal contributions of compactness indicators. Previous studies have highlighted the impacts of economic structure on urban agglomeration economies and growth (Cohen and Paul, 2005; Drucker and Feser, 2012; Yang et al., 2019), so this paper also takes economy structure as a control factor to capture the structural factors of urban economy sectors (characterized as "localization agglomeration economies" by (Baldwin et al., 2008) and Fracasso and Marzetti, 2018). The industrial structure is calculated by the ratio of manufacturing output to the service output of a city. The variable is based on the evidence that shift from manufacturing to service sectors improves urban economy productivity (Bosma et al., 2011; Meliciani, and Savona, 2015). R&D activities and innovation capacity are found to be important drivers for agglomeration economies (especially in terms of technical efficiency), and public R&D investment positively correlates with locational choices of private R&D investment (Siedschlag et al., 2013; Becker, 2015). In this study, government investment refers to the R&D investment share of total government investment of a city; innovation capacity is calculated by human capital indicators—the number of university students per 10,000 capita of each city.

Since our Hypothesis 4 concerns the non-monotonic effects of compactness on urban economy efficiency, we separate city size into 3 groups: (1) small cities (total population less than 1 million, with 110 such cities in our sample); (2) medium cities (total population ranging between 1 million to 3 million, with 94 cities in our samples); and (3) large cities (total population larger than 3 million, with 22 cities in our samples). The classification of city sizes corresponds to the official city classification of China statistical outlet (Gov.cn, 2014), but we disregard metropolis (population ranging between 5 and 10 million) and megapolis (population over 10 million) since the data points of these cities are too scarce for regression analysis. We plan to investigate how the effects of compactness would vary with urban size due to density-related urban issues.

Table 1
Abbreviations and descriptions of variables.

Abbreviation	Description
Dependent variables: urban economic efficiencies	
Veff	Technical efficiency (0–1)
Ceff	Comprehensive efficiency (0–1)
Independent variables: urban compactness indicators	
Popud	Population density within the total municipal area (person/km^2)
Road	Road density measured by road area per unit of the urban area (%)
Spa	Limitation of growth boundary (built-up urban area/ total municipal area) (%)
Other covariates	
Ind	Industrial structure measured by the ratio of manufacturing to service sectors (%)
Res	The ratio of investment in R&D to total investment by government (%)
Human	Human capital measured by college students per 10,000 capita
Size	Population in the total municipal area (10,000 persons)

4.1. Study area and data

The study area contains 226 China prefectural and upper-level cities. The total population of these cities increased by 85% from 1997 to 2015, but the total urban construction area increased by 110% over the same period and accordingly the population density dropped from 684 to 608 persons per square kilometer. Specifically, the built-up area in China increased by 2 times, which far exceeded the speed of population growth. Choosing China for the empirical analysis is because its cities have different urbanization levels and environmental conditions, with comparable data from official national statistical outlets. Thus, using cities of large numbers and geographical outreach of China makes a good social experimental setting. The empirical analysis also has important practical implications as rapid urbanization and expansion of Chinese cities. Thus, understanding economic efficiency for compact city policies is important to gauge losses of urban sprawl and useful in designing policies to promote sustainable development.

4.2. Indicators and variables

All data are from China City Statistic Year Book (2001–2015). Table 1 presents variable descriptions and abbreviations. Table 2 contains natural logarithms for all independent variables and summary statistics. Some general patterns can be observed in Table 2: (1) comprehensive and technical efficiency both increase, indicating that megacities have the best knowledge spillovers due to large market size and diverse economic activities; (2) large cities have the highest population density and road density, while medium cities are similar to small cities in density measures. This indicates that megacities tend to be more compact in terms of density; (3) small cities have the highest boundary limitation pressure while large cities have the lowest pressure. This indicates that large cities still have the most undeveloped lands within the total municipal boundary in comparison to existing developed, while small cities in China are mostly highly urbanized within their boundaries.

Schwartz information criterion is used to conduct the unit root test for the stationarity of the data time series to conform to the basic assumption of GMM. The results indicate stationarity and fitness of the GMM regression (unit root test results are recorded in Supplementary

Table 2
Statistics of variables.

		Veff	Ceff	popud	Road	Spa	Ind	Res	Human	Size
Large Cities	**Obs**	330	330	330	330	330	330	330	330	330
	Mean	0.692	0.425	7.270	7.189	0.180	3.894	4.688	6.096	15.281
	S.D.	0.204	0.159	0.461	0.685	0.033	0.186	1.058	0.934	0.601
	Min	0.226	0.146	6.363	4.959	0.119	3.124	2.573	2.796	13.905
	Max	1.000	1.000	8.668	8.772	0.296	4.238	6.673	7.521	16.699
Medium Cities	**Obs**	1410	1410	1410	1410	1410	1410	1410	1410	1410
	Mean	0.449	0.415	6.841	6.495	0.233	4.062	4.299	5.320	14.103
	S.D.	0.186	0.173	0.704	1.052	0.055	0.178	1.036	1.341	0.416
	Min	0.118	0.103	4.990	3.159	0.134	3.061	0.782	0.000	11.646
	Max	1.000	1.000	9.551	9.877	0.671	4.379	7.154	8.611	15.336
Small Cities	**Obs**	1650	1650	1650	1650	1650	1650	1650	1650	1650
	Mean	0.397	0.352	6.453	6.130	0.287	4.076	4.108	4.851	13.235
	S.D.	0.204	0.160	1.074	1.303	0.109	0.200	0.886	1.823	0.400
	Min	0.071	0.070	2.565	0.686	0.157	2.944	0.293	0.000	11.362
	Max	1.000	1.000	9.093	9.496	1.193	4.516	7.269	7.986	15.049

Materials Table S1). Another potential issue is that the panel mismatches the advantages of dynamic panel GMM regressions, which could make the estimation biased. Bond test (Bond et al., 2001), therefore, is applied to test the validity of the results. The result indicates that all the estimated coefficients of the first-order lagged term for the interpreted variables from one-step system GMM fall in the range of validity (detailed test results are documented in Supplementary Materials Table S2).

4.3. Panel data GMM regression

Note: Veff is Technical efficiency, Ceff is Comprehensive efficiency, Popud is Population density within the total municipal area, Road is Population density within the total municipal area, Spa is Limitation of growth boundary, Ind is Industrial structure measured by the ratio of manufacturing to service sectors, Res is Ratio of investment in R&D to total investment by government, Human is Human capital, Size is Population in the total municipal area.

This paper adopts a dynamic panel data model and generalized matrix estimation to avoid potential endogeneity and omitted variable biases. The main advantage of this method is that the effect of unobserved variables is controlled by variable difference or instrumental variable. Meanwhile, explanatory variables and lagged explanatory are also used as instrumental variables to alleviate the endogeneity problem. One-step estimations for GMM, including differential GMM and system GMM, of the dynamic panel are adopted. Since system GMM uses more information from the sample, it is generally more effective than differential GMM. Thus, we use the system GMM method and assess the robustness of the results by comparing the results to the estimations of the differential GMM. Additionally, to reduce the risk of deviation caused by over-fitting, one-stage lag values of explanatory variables are used as instrumental variables for the first-order difference variables.

The validity of GMM parameter estimation depends on the validity of the instrument variables. In this way, we use two methods to identify the validity of the instrument variable model. First, Sargan or Hansen test is used to identify the validity of instrument variables. If zero hypothesis is accepted, we have evidence that the instrument variables are chosen properly. Then, we use AR (2) to test the residual term *epsilon I*. If there is a second-order autocorrelation in the differential residual term, the original residual sequence is assessed autocorrelation and follows a moving average process at least one order.

Among the variables mentioned above, urban size is a gross indicator for urban development, which determines almost all the characteristics of the city and affects urban efficiency as an external environment. Thus, including the current and lagged level of urban size into the regression model can help to alleviate the endogeneity problem due to missing variables. As a result, we define the SYS-GMM model for estimating the impact of compact cities on urban efficiency as follows:

$$\mathrm{eff}_{i,t} = \beta_0 + \beta_1 \mathrm{eff}_{i,t-1} + \beta_2 popud_{i,t} + \beta_3 road_{i,t} + \beta_4 spa_{i,t} + \beta_5 ratio_{i,t} + \beta_6 res_{i,t} + \beta_7 human_{i,t} + \beta_8 \mathrm{size}_{i,t} + \beta_9 \mathrm{size}_{i,t-1} + \varepsilon_{i,t} \tag{3}$$

Where *eff* is the urban economic efficiencies (comprehensive or technical efficiencies) of city i at time t; $\varepsilon_{i,t}$ is the error term; other terms use the abbreviations as in Table 1.

5. Results and discussions

5.1. GMM results

The SYS-GMM (selected model) estimation results are shown in Table 3 for relationship identification between urban compactness indicators and economic efficiency. DIF-GMM only estimates the difference equation ; SYS-GMM estimates both the horizontal and the difference equation, and takes the lag term of the difference variable as the instrumental variable of the horizontal equation and the lag term of the horizontal variable as the instrumental variable of the difference equation. SYS-GMM contains more sample information. The alternative model (DIF-GMM) results are shown in the Supplementary Materials Tables S3 and S4 for robustness check. The two tables show that, the significance levels for each same variable are the same and the coefficients' values for each same variable are similar. They indicate that, the estimated results of the system GMM and the differential GMM are consistent in the direction and statistically significant, indicating that the regression results are robust. In addition, the test results of second-order sequence correlation AR (2) support the original hypothesis that the error term of the estimation equation does not exist in second-order sequence correlation. The Hansen's over-recognition test results also show that the zero hypothesis of the validity of tool variables is not rejected (p values are significantly greater than 0.1), which shows that the rationality of the regression model and tool variables are effective. In view of the superiority of the system GMM, the results of this model are valid to describe the basis.

The effects of the three indicators of compact cities on two types of urban efficiencies are quite different. First, population density has negative effects on both comprehensive and technical efficiencies for small cities, while the effects become positive for large cities. This means that compactness, measured by population density, is only beneficial for the efficiencies of large cities and not for smaller ones. Second, boundary limitation has a negative impact on the technical efficiency of small cities and the comprehensive efficiency of medium cities. This means that lacking land resources has the most negative impacts on the development of smaller cities. On the other hand, boundary limitations have positive effects on the technical efficiency of large cities. This suggests that consumption of land resources in large cities still has a

Table 3
Estimation results with GMM-SYS efficiency as the dependent variable.

	Large Cities		Medium Cities		Small Cities	
	Comp'Efficiency	Technical Efficiency	Comp' Efficiency	Technical Efficiency	Comp' Efficiency	Technical Efficiency
l.Veff	0.7096***	0.6436***	0.3251***	0.3386***	0.3888***	0.4701***
	(6.65)	(7.07)	(7.56)	(9.94)	(8.99)	(9.25)
Size	0.0523**	0.0896***	0.1445***	0.1468***	0.1097***	0.1045***
	(1.57)	(2.82)	(3.60)	(3.86)	(3.32)	(2.62)
l.size	0.0046	-0.0702**	0.017	0.0166	0.0102	0.0353
	(0.21)	(−2.42)	(0.78)	(0.68)	(0.44)	(1.41)
Popud	-0.0006	-0.0458**	-0.0510**	-0.0497**	-0.0724***	-0.0873***
	(−0.03)	(−2.62)	(−2.60)	(−2.56)	(−4.26)	(−3.97)
Road	0.0505	0.0205	0.0513***	0.0506***	0.0491***	0.0637***
	(1.33)	(0.66)	(3.21)	(3.00)	(3.23)	(3.25)
Spa	-1.0149*	-0.0016	-0.2951*	-0.2301	-0.0771	-0.2794**
	(−3.37)	(0.00)	(1.76)	(1.29)	(0.74)	(2.45)
Ind	0.1198	0.1249**	0.2040***	0.1858***	0.0881	0.0329
	(1.67)	(2.16)	(3.65)	(3.54)	(1.79)	(0.45)
Res	0.0127	0.0341***	0.0229***	0.0217***	0.0332***	0.0362***
	(1.36)	(3.48)	(4.40)	(4.03)	(5.95)	(4.38)
Human	-0.0056	-0.0137	-0.0093*	-0.0132**	-0.0029	-0.0136*
	(−0.39)	(−0.67)	(−1.73)	(−2.12)	(−0.62)	(−1.79)
_cons	-1.6964*	-0.5041	-2.9221***	-2.8237***	-1.7043**	-1.7574**
	(−1.86)	(−0.67)	(−4.59)	(−4.47)	(−2.55)	(−2.20)
AR(2)	0.224	0.793	0.328	0.436	0454	0.980
P_ Hansen	0.206	0.175	0.798	0.801	0.378	0.382
Num_IVs	25	25	115	115	115	115
Num_Groups	22	22	94	94	110	110
Num_Obs	308	308	1316	1316	1540	1540

Notes: All estimates have been done with software Stata 12.0 and "xtabond2" program (Roodman, 2006). * ,* * and * ** indicates significant at 10%, 5% and 1% levels, respectively. The T statistics are in parentheses. AR (2) and Hansen test give P values corresponding to statistics. Since GMM estimation is suitable for large samples, we adjust the covariance matrix with small samples. The t statistic is the robust t statistic consistent with heteroscedasticity and autocorrelation. The same as below. Veff is Technical efficiency; Ceff is Comprehensive efficiency; Popud is Population density within the total municipal area; Road is Population density within the total municipal area; Spa; is Limitation of growth boundary; Ind is Industrial structure measured by the ratio of manufacturing to service sectors; Res is Ratio of investment in R&D to total investment by government; Human is Human capital; Size is Population in the total municipal area.

positive return to scale regarding knowledge spillovers. Third, road density has a significant positive impact on almost all efficiency measures of cities in different sizes, except for the technical efficiency of large cities. In other words, road density is important for urban efficiencies in general, but there is a caveat that it could decrease knowledge spillovers for large cities. Moreover, the regression coefficient shows that for all types of cities and efficiency measures, the pre-efficiency has a significant positive effect on the current efficiency, indicating that urban efficiency has cumulative characteristics.

For the control variables, the share of the manufacturing sector has positive impacts on the technical efficiency of small cities, as well as the comprehensive and technical efficiency of medium cities. Investment in R&D has positive effects on all efficiency measures, while human capital does not show any significant and positive influence. Population size has significant effects on all efficiencies except the technical efficiency of small cities. This indicates that the size of the urban population is still the fundamental condition for urban economic efficiency. We summarize the results for all the regressions (see Table 4).

6. Discussion

Our findings indicate 2 different dynamics of agglomeration economies in China, which demonstrate different efficiency impacts from urban compactness indicators. The 2 types are: (1) manufacturing agglomeration and land-resource-based development in small and medium cities (Jiang et al., 2017; Chen et al., 2020); and (2) service and innovation agglomeration with market-size based development in large cities. The most important indicator for urban compactness—population density—significantly improves comprehensive efficiencies for large and medium cities, which indicate that agglomeration economy is promoted through compactness for large cities (Yang et al., 2019; Andersson et al., 2016; Pan et al., 2021a; Tao et al., 2019). Melo et al. (2009) also point out that the agglomeration economy effects are more pronounced in large cities with a stronger service industry base. For smaller cities in China, economic development is highly dependent on manufacturing and consumption of land resources during rapid urbanization (Li et al., 2020). Thus, higher population density and compactness do not promote their efficiencies.

The results for boundary limitation also indicate the different types of development between smaller and larger cities. Stricter boundary limitation decreases the technical efficiency of small cities, which need more land resources for promoting agglomeration of the manufacturing industry. For large cities, boundary limitation tends to increase technical efficiencies. That is, when the size of cities is larger, usage of available

Table 4
Summary of the effectiveness of dependent variables on two types of efficiencies with three city types.

		Population Density	Road Density	Boundary Limit	Sector Structure	R & D Investment	Human resource	Population Size
Small Cities	Technical	–	+	–		+		
	Comprehensive	–			+	+		+
Medium Cities	Technical	–	+		+	+	–	+
	Comprehensive	+	+	–	+	+	–	+
Large Cities	Technical		–	+		+		+
	Comprehensive	+	+			+		+

Notes: "+"and"-"indicate significant positive and negative effects respectively.

land resources is more likely to increase knowledge spillover. This corresponds to the effects that many megacities are developing land resources close to the boundary to promote mega-city region integration, such as the Yangtze River Delta (Pan et al., 2020), Great Bay Area (Hui et al., 2020) in China, Mexico City (Aguilar et al., 2003) in North America, and Ghanaian city-region in Sub-Saharan African (Agyemang et al., 2019). Road density is positive for most efficiency measures, which is as expected that better road density and transport connectivity leads to better supply-chain performance and market integration of manufacturing industries in small and medium cities (Aleksandrova et al., 2020). However, road density leads to decreased technical efficiency of large cities, possibly because high road density may also cause pollution and lower quality-of-life, which in turn harm agglomeration of service and creative industries in large cities (Ren et al., 2016; Liang et al., 2019).

6.1. Takeaway for practices

The empirical results of this paper shed light on the formation of land use policy against the conflict between limited arable land scarcity and rapid urbanization needs, thus having several policy implications for urban efficiency with regards to three compactness indicators of cities. The main policy implications include:

1) For large cities, promoting agglomeration economies through compactness should be focused on service and high-tech sectors, since these sectors can generate higher productivity per land unit and per capita. With such policy, co-benefits of saving land resources and improving knowledge spillovers can be realized. Population density is found to be positively related to human capital accumulation in many countries, improving productivity for the U.S. cities (Abel et al., 2012) and promoting wage of employment at neighborhood levels in Sweden (Andersson et a, 2016).
2) For large cities, infrastructure provision for large cities should be cautioned as over-crowding and pollution could create agglomeration diseconomy in compact cities. Increasing road density has been found to negatively affect technical efficiencies. The negative externalities of pollution from proximity to transportation infrastructure are found in both Chicago (Yang et al., 2019) and Brussel (Da Schio et al., 2019). Instead of the traditional provision of transportation infrastructure through highways, more sustainable alternatives, such as public, active transit and sharing mobility should be provided for large cities (Cong et al., 2022; Chen et al., 2021a).
3) For small and medium cities, compactness has not been consistently conducive for economic efficiencies, and thus transitions are necessary from the current developmental pattern of high demands of land resources. Currently, increasing population size and road density and promoting manufacturing industries are the main channel for high economic efficiencies in these cities. In the future, more sustainable and compact developmental patterns, which emphasize more on human capital and R&D, should be adopted to avoid intensive consumption of land resources. For example, upgrading industrial parks into eco-industrial parks (Susur et al., 2019) have been implemented worldwide to improve manufacturing efficiencies as well as achieving sustainability and conservation of resources.

The paper also has several limitations. One potential limitation of our study is the inadequate discussions of how poly-centricity development relates to the measure of compact city and agglomeration efficiency. Recent literature has discussed emerging agglomeration in urban sub-centers worldwide and proposed it as a solution to curbing urban sprawl (Pan et al., 2018; Yang et al., 2021). Measurement and identification of polycentricity would require data with better spatial granularity than official statistics, such as land use and mobile phone big data (Yang, 2019b, 2020; Hu et al., 2020; Xiao et al., 2020). The urban efficiency measures do not incorporate certain aspects including external connectivity and different forms of compactness for economic activities (e.g. vertical versus horizontal cities). Although trade is to some extension implicit in the efficiencies of agglomeration economies (Parr et al., 2002), and the vertical dimension of the cities is implicit in the density, these factors should still deserve an explicit variable to examine, such as trade networks and built-up form of the cities. Moreover, the city-level panel data cannot study sub-city level issues such as the impact of compact development and density on quality-of-life (Bardhan et al., 2015), open space availability (Chen et al., 2008), and administrative/organizational structure (Tang and Hewings, 2017). These sub-city level investigations require data of higher spatial granularity.

7. Conclusions

Our study aims to understand the relationship between compactness indicators and agglomeration economy efficiency by verifying four hypotheses. For the first hypothesis on population density and urban economic efficiencies, we find that higher population density and compact urban form are beneficial to the urban economic efficiencies of large cities, but not for the technical efficiency of small cities. Second, regarding boundary limitations, we find that limited land resources constrain the development and economic efficiencies for small and medium cities, but strict boundary limitations have promoted knowledge spillover and thus technical efficiencies for large cities. For the third hypothesis concerning road density, we find that road density is conducive to efficiencies for small and medium cities, but not technical efficiencies for large cities. Moreover, we find heterogeneity for the relationship between each indicator-efficiency pair for each city type, which validates our fourth hypothesis on the heterogeneity of the examined relationships. Furthermore, R&D investment is one factor that we find significantly positive for efficiencies of cities of all types. We confer that the heterogeneity may be explained by the economic structure compositions of cities of different sizes: smaller cities depend on manufacturing and land urbanization for economic development, while large cities have entered the stage for service and high-tech economies.

Practically, our findings suggest that compact city policies should be catered to the heterogeneity of urban size and economic structure. For example, high population density and size can be encouraged for large cities to further develop service and high-tech economies. For small cities, the tradeoff between economic development and land resource sustainability should be carefully managed, and transportation infrastructure provision should be the main target for improving economic efficiencies for small cities.

The future step of this study includes combining current methodology with “big data” sources to be able to study micro-dynamics that relate compactness to agglomeration economies, such as inter-city human capital concentration, interactions, and start-up formations. It is also worthy to understand how polycentric urban form relates to compact city principles and agglomeration economy efficiency.

Acknowledgment

This Research is supported by [the National Natural Science Foundation of China (Grant No. 52000130)].

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.landusepol.2022.106005.

References

Abel, J.R., Dey, I., Gabe, T.M., 2012. Productivity and the density of human capital. J. Reg. Sci. 52 (4), 562–586.
Accetturo, A., Giacinto, Di, Micucci, V., Pagnini &, G., M, 2018. Geography, productivity, and trade: Does selection explain why some locations are more productive than others? J. Reg. Sci. 58 (5), 949–979.

Aguilar, A.G., Ward, P.M., Smith Sr, C.B., 2003. Globalization, regional development, and mega-city expansion in Latin America: analyzing Mexico City's peri-urban hinterland. Cities 20 (1), 3–21.
Agyemang, F.S., Silva, E., Poku-Boansi, M., 2019. Understanding the urban spatial structure of Sub-Saharan African cities using the case of urban development patterns of a Ghanaian city-region. Habitat Int. 85, 21–33.
Aleksandrova, E., Behrens, K., Kuznetsova, M., 2020. Manufacturing (co) agglomeration in a transition country: Evidence from Russia. J. Reg. Sci. 60 (1), 88–128.
Anas, A., Rhee, H.J., 2006. Curbing excess sprawl with congestion tolls and urban boundaries. Reg. Sci. Urban Econ. 36 (4), 510–541.
Andersson, M., Klaesson, J., Larsson, J.P., 2016. How local are spatial density externalities? Neighbourhood effects in agglomeration economies. Reg. Stud. 50 (6), 1082–1095.
Baldwin, J.R., Beckstead, D., Mark Brown, W., Rigby, D.L., 2008. Agglomeration and the geography of localization economies in Canada. Reg. Stud. 42 (1), 117–132.
Bardhan, R., Kurisu, K., Hanaki, K., 2015. Does compact urban forms relate to good quality of life in high density cities of India? Case of Kolkata. Cities 48, 55–65.
Becker, B., 2015. Public R&D policies and private R&D investment: A survey of the empirical evidence. J. Econ. Surv. 29 (5), 917–942.
Billings, S.B., Johnson, E.B., 2016. Agglomeration within an urban area. J. Urban Econ. 91, 13–25.
Bond, S., Bowsher, C., Windmeijer, F., 2001. Criterion-based inference for GMM in autoregressive panel data models. Econ. Lett. 73 (3), 379–388.
Bosma, N., Stam, E., Schutjens, V., 2011. Creative destruction and regional productivity growth: evidence from the Dutch manufacturing and services industries. Small Bus. Econ. 36 (4), 401–418.
Capello, R., Faggian, A., 2005. Collective learning and relational capital in local innovation processes. Reg. Stud. 39 (1), 75–87.
Chatman, D.G., Noland, R.B., 2014. Transit service, physical agglomeration and productivity in US metropolitan areas. Urban Stud. 51 (5), 917–937.
Chen, H., Jia, B., Lau, S.S.Y., 2008. Sustainable urban form for Chinese compact cities: Challenges of a rapid urbanized economy. Habitat Int. 32 (1), 28–40.
Chen, Y., Chen, Z., Xu, G., Tian, Z., 2016. Built-up land efficiency in urban China: Insights from the General Land Use Plan (2006–2020). Habitat Int. 51, 31–38.
Chen, Y., Ma, J., Miao, C., Ruan, X., 2020. Occurrence and environmental impact of industrial agglomeration on regional soil heavy metalloid accumulation: A case study of the Zhengzhou Economic and Technological Development Zone (ZETZ), China. J. Clean. Prod. 245, 118676.
Chen, S., Yan, X., Pan, H., Deal, B., 2021a. Using big data for last mile performance evaluation: An accessibility-based approach. Travel Behav. Soc. 25, 153–163.
Chen, J., Guo, X., Pan, H., Zhong, S., 2021b. What determines city's resilience against epidemic outbreak: Evidence from China's COVID-19 experience. Sustain. Cities Soc. 70, 102892.
Ciccone, A., Hall, R.E., 1996. Productivity and the density of economic activity. Am. Econ. Rev. 86 (1), 54–70.
Cohen, J.P., Paul, C.J.M., 2005. Agglomeration economies and industry location decisions: the impacts of spatial and industrial spillovers. Reg. Sci. Urban Econ. 35 (3), 215–237.
Cong, C., Kwak, Y., Deal, B., 2022. Incorporating active transportation modes in large scale urban modeling to inform sustainable urban development. Comput., Environ. Urban Syst. 91, 101726.
Da Schio, N., Boussauw, K., Sansen, J., 2019. Accessibility versus air pollution: A geography of externalities in the Brussels agglomeration. Cities 84, 178–189.
De Bok, M., Van Oort, F., 2011. Agglomeration economies, accessibility, and the spatial choice behavior of relocating firms. J. Transp. Land Use 4 (1), 5–24.
Deilmann, C., Hennersdorf, J., Lehmann, I., Reißmann, D., 2018. Data envelopment analysis of urban efficiency—Interpretative methods to make DEA a heuristic tool. Ecol. Indic. 84, 607–618.
Drucker, J., Feser, E., 2012. Regional industrial structure and agglomeration economies: An analysis of productivity in three manufacturing industries. Reg. Sci. Urban Econ. 42 (1–2), 1–14.
Eberts, R.W., McMillen, D.P., 1999. Agglomeration economies and urban public infrastructure. Handb. Reg. Urban Econ. 3, 1455–1495.
Faggian, A., Partridge, M., Malecki, E.J., 2017. Creating an environment for economic growth: creativity, entrepreneurship or human capital? Int. J. Urban Reg. Res. 41 (6), 997–1009.
Fracasso, A., Marzetti, Vittucci, G, 2018. Estimating dynamic localization economies: the inadvertent success of the specialization index and the location quotient. Reg. Stud. 52 (1), 119–132.
Gao, X., Zhang, A., Sun, Z., 2019. How regional economic integration influence on urban land use efficiency? A case study of Wuhan metropolitan area, China. Land Use Policy, 104329.
Gennaio, M.P., Hersperger, A.M., Bürgi, M., 2009. Containing urban sprawl—Evaluating effectiveness of urban growth boundaries set by the Swiss Land Use Plan. Land Use Policy 26 (2), 224–232.
Gov.cn, 2014, Notification of city size classification adjustment by State Council. Available at ⟨http://www.gov.cn/zhengce/content/2014–11/20/content_9225.htm⟩. Retrieved 2020/07/28 (in Chinese).
Graham, D.J., 2007. Agglomeration, productivity and transport investment. J. Transp. Econ. Policy (JTEP) 41 (3), 317–343.
Gudipudi, R., Fluschnik, T., Ros, A.G.C., Walther, C., Kropp, J.P., 2016. City density and CO_2 efficiency. Energy Policy 91, 352–361.
Holl, A., 2004. Transport infrastructure, agglomeration economies, and firm birth: empirical evidence from Portugal. J. Reg. Sci. 44 (4), 693–712.
Hu, L., Yang, J., Yang, T., Tu, Y., Zhu, J., 2020. Urban spatial structure and travel in China. J. Plan. Lit. 35 (1), 6–24.
Huang, Z., He, C., Wei, Y.H.D., 2016. A comparative study of land efficiency of electronics firms located within and outside development zones in Shanghai. Habitat Int 56, 63–73.
Huber, F., 2012. Do clusters really matter for innovation practices in Information Technology? Questioning the significance of technological knowledge spillovers. J. Econ. Geogr. 12 (1), 107–126.
Hui, E.C., Li, X., Chen, T., Lang, W., 2020. Deciphering the spatial structure of China's megacity region: A new bay area—The Guangdong-Hong Kong-Macao Greater Bay Area in the making. Cities 105, 102168.
Jiang, G., Ma, W., Dingyang, Z., Qinglei, Z., Ruijuan, Z., 2017. Agglomeration or dispersion? Industrial land-use pattern and its impacts in rural areas from China's township and village enterprises perspective. J. Clean. Prod. 159, 207–219.
Johnson, M.P., 2001. Environmental impacts of urban sprawl: a survey of the literature and proposed research agenda. Environ. Plan. A 33, 717e735.
Jun, M.J., 2020. The effects of polycentric evolution on commute times in a polycentric compact city: A case of the Seoul Metropolitan Area. Cities 98, 102587.
Kwak, Y., Park, C., Deal, B., 2020. Discerning the success of sustainable planning: A comparative analysis of urban heat island dynamics in Korean new towns. Sustain. Cities Soc. 61, 102341.
Kwak, Y., Deal, B., 2021. Resilient planning optimization through spatially explicit, Bi-directional sociohydrological modeling. J. Environ. Manag. 300, 113742.
Lee, J.H., Lim, S., 2018. The selection of compact city policy instruments and their effects on energy consumption and greenhouse gas emissions in the transportation sector: The case of South Korea. Sustain. Cities Soc. 37, 116–124.
Li, X., Hui, E.C.M., Lang, W., Zheng, S., Qin, X., 2020. Transition from factor-driven to innovation-driven urbanization in China: A study of manufacturing industry automation in Dongguan City. China Econ. Rev. 59, 101382.
Lin, G.C., Ho, S.P., 2003. China's land resources and land-use change: insights from the 1996 land survey. Land Use Policy 20 (2), 87–107.
Liu, Y., 2018. Introduction to land use and rural sustainability in China. Land Use Policy 74 (1–4.o.9), 72–77.
Liu, Y., Fang, F., Li, Y., 2014. Key issues of land use in China and implications for policy making. Land Use Policy 40, 6–12.
Liu, Y., Li, J., Yang, Y., 2018a. Strategic adjustment of land use policy under the economic transformation. Land Use Policy 74, 5–14.
Liu, Y., Zhang, Z., Zhou, Y., 2018b. Efficiency of construction land allocation in China: an econometric analysis of panel data. Land Use Policy 74, 261–272.
Meliciani, V., Savona, M., 2015. The determinants of regional specialisation in business services: agglomeration economies, vertical linkages and innovation. J. Econ. Geogr. 15 (2), 387–416.
Melo, P.C., Graham, D.J., Noland, R.B., 2009. A meta-analysis of estimates of urban agglomeration economies. Reg. Sci. Urban Econ. 39 (3), 332–342.
Melo, P.C., Graham, D.J., Levinson, D., Aarabi, S., 2017. Agglomeration, accessibility and productivity: Evidence for large metropolitan areas in the US. Urban Stud. 54 (1), 179–195.
Meng, Y., Zhang, F., An, P., Dong, M., Wang, Z., Zhao, T., 2008. Industrial land-use efficiency and planning in Shunyi, Beijing. Landsc. Urban Plan. 85 (1), 40–48.
Mitra, A., 1999. Agglomeration economies as manifested in technical efficiency at the firm level. J. Urban Econ. 45 (3), 490–500.
Mouratidis, K., 2017. Is compact city livable? The impact of compact versus sprawled neighbourhoods on neighbourhood satisfaction. Urban Stud. 55 (11), 2408–2430.
Mouratidis, Kostas, 2019. Compact city, urban sprawl, and subjective well-being. Cities 92 (2019), 261–272.
Nguyen, X.T., Heber, G.A., Hennersdorf, B., J.örg, Lehmann, Iris, 2002. Evaluation of urban land-use structures with a view to sustainable development. Environ. Impact Assess. Rev. 22 (2), 475–492.
Ouyang, X., Mao, X., Sun, C., Du, K., 2019. Industrial energy efficiency and driving forces behind efficiency improvement: Evidence from the Pearl River Delta urban agglomeration in China. J. Clean. Prod. 220, 899–909.
Pan, H., Deal, B., Chen, Y., Hewings, G., 2018. A Reassessment of urban structure and land-use patterns: distance to CBD or network-based?—Evidence from Chicago. Reg. Sci. Urban Econ. 70, 215–228.
Pan, H., Cong, C., Zhang, X., Zhang, Y., 2020. How do high-speed rail projects affect the agglomeration in cities and regions? Transp. Res. Part D: Transp. Environ. 88, 102561.
Pan, H., Page, J., Cong, C., Barthel, S., Kalantari, Z., 2021b. How ecosystems services drive urban growth: Integrating nature-based solutions. Anthropocene 35, 100297.
Pan, H., Yang, T., Jin, Y., Dall'Erba, S., Hewings, G., 2021a. Understanding heterogeneous spatial production externalities as a missing link between land use planning and urban economic futures. Reg. Stud. https://doi.org/10.1080/00343404.2019.1701186.
Parr, J.B., Hewings, G.J., Sohn, J., Nazara, S., 2002. Agglomeration and trade: some additional perspectives. Reg. Stud. 36 (6), 675–684.
Patil, G.R., Sharma, G., 2020. Urban Quality of Life: An assessment and ranking for Indian cities. Transp. Policy.
Ren, W., Xue, B., Geng, Y., Lu, C., Zhang, Y., Zhang, L., Hao, H., 2016. Inter-city passenger transport in larger urban agglomeration area: emissions and health impacts. J. Clean. Prod. 114, 412–419.
Liang, L., Wang, Z., Li, J., 2019. The effect of urbanization on environmental pollution in rapidly developing urban agglomerations. J. Clean. Prod. 237, 117649.
Roodman, D. (2006, July). How to Do xtabond2. In North American Stata Users' Group Meetings 2006 (No. 8). Stata Users Group.
Salvati, L., 2014. Agro-forest landscape and the 'fringe' city: a multivariate assessment of land-use changes in a sprawling region and implications for planning. Sci. Total Environ. 490, 715e723.

Sato, Y., Tabuchi, T., Yamamoto, K., 2012. Market size and entrepreneurship. J. Econ. Geogr. 12 (6), 1139–1166.
Shi, L., Yang, S., Gao, L., 2016. Effects of a compact city on urban resources and environment. J. Urban Plan. Dev. 142 (4), 05016002.
Siedschlag, I., Smith, D., Turcu, C., Zhang, X., 2013. What determines the location choice of R&D activities by multinational firms? Res. Policy 42 (8), 1420–1430.
Sorensen, A., 1999. Land readjustment, urban planning and urban sprawl in the Tokyo metropolitan area. Urban Stud. 36, 2333e2360.
Squicciarini, M.P., Voigtländer, N., 2015. Human capital and industrialization: Evidence from the Age of Enlightenment. Q. J. Econ. 130 (4), 1825–1883.
Susur, E., Hidalgo, A., Chiaroni, D., 2019. A strategic niche management perspective on transitions to eco-industrial park development: A systematic review of case studies. Resour., Conserv. Recycl. 140, 338–359.
Tian, Y., Jim, C.Y., Wang, H., 2014. Assessing the landscape and ecological quality of urban green spaces in a compact city. Landsc. Urban Plan. 121, 97–108.
Tan, M., Li, X., Lu, C., Luo, W., Kong, X., Ma, S., 2008. Urban population densities and their policy implications in China. Habitat Int. 32 (4), 471–484.
Tang, W., Hewings, G.J., 2017. Do city–county mergers in China promote local economic development? Econ. Transit. 25 (3), 439–469.
Tan, F., Lu, Z., 2019. he impact of urban compactness on urban sustainable development in China: The case of Nanjing. Sustainable Development 27 (3), 270–280.
Tao, J., Ho, C.Y., Luo, S., Sheng, Y., 2019. Agglomeration economies in creative industries. Reg. Sci. Urban Econ. 77, 141–154.
Wang, S., Wang, J., Fang, C., Li, S., 2019. Estimating the impacts of urban form on CO_2 emission efficiency in the Pearl River Delta, China. Cities 85, 117–129.
Westerink, J., Haase, D., Bauer, A., Ravetz, J., Jarrige, F., Aalbers, C.B., 2013. Dealing with sustainability trade-offs of the compact city in peri-urban planning across European city regions. Eur. Plan. Stud. 21 (4), 473–497.
Wu, C., Wei, Y.D., Huang, X., Chen, B., 2017. Economic transition, spatial development and urban land use efficiency in the Yangtze River Delta, China. Habitat Int. 63, 67–78.
Xiao, C., Silva, E.A., Zhang, C., 2020. Nine-nine-six work system and people's movement patterns: Using big data sets to analyse overtime working in Shanghai. Land Use Policy 90, 104340.
Yamagata, Y., Seya, H., 2013. Simulating a future smart city: An integrated land use-energy model. Appl. Energy 112, 1466–1474.
Yang, Y., Liu, Y., Li, Y., Li, J., 2018. Measure of urban-rural transformation in Beijing-Tianjin-Hebei region in the new millennium: population-land-industry perspective. Land Use Policy 79, 595–608.
Yang, T., 2020. Understanding commuting patterns and changes: Counterfactual analysis in a planning support framework. Environ. Plan. B: Urban Anal. City Sci., 2399808320924433
Yang, T., Pan, H., Hewings, G., Jin, Y., 2019. Understanding urban sub-centers with heterogeneity in agglomeration economies—Where do emerging commercial establishments locate? Cities 86, 25–36.
Yang, T., Pan, H., Zhang, X., Greenlee, A., Deal, B., 2021. How neighborhood conditions and policy incentives affect relocation outcomes of households from low-income neighborhoods—Evidence from intra-city movement trajectories. Cities 119, 103415.
You, L., Li, Y., Wang, R., Pan, H., 2020. A benefit evaluation model for build-up land use in megacity suburban districts. Land Use Policy 99, 104861.
Zhang, L., Zhang, L., Xu, Y., Zhou, P., Yeh, C.H., 2020. Evaluating urban land use efficiency with interacting criteria: An empirical study of cities in Jiangsu China. Land Use Policy 90, 104292.
Zheng, S., Du, R., 2020. How does urban agglomeration integration promote entrepreneurship in China? Evidence from regional human capital spillovers and market integration. Cities 97, 102529.
Zhong, T., Qian, Z., Huang, X., Zhao, Y., Zhou, Y., Zhao, Z., 2018. Impact of the top-down quota-oriented farmland preservation planning on the change of urban land-use intensity in China. Habitat Int. 77, 71–79.