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Constructing compact cities: How urban regeneration can enhance growth and relieve congestion☆

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ABSTRACT

Urban population growth worsens congestion. However, this effect can be weakened by taller and denser city centers. Considering the important role played by intraurban density patterns, we modeled a mechanism to explain how urban regeneration can relieve population congestion. The model suggests two effects as follows: a direct concentration and an indirect growth effect. The direct concentration effect worsens congestion with little loss of welfare, whereas an indirect growth effect reduces the marginal congestion of population growth. These findings suggest that megacities should build taller and denser city centers through urban regeneration. Moreover, governments should regenerate megacities to support population growth instead of investing in new or smaller cities. This study helps bridge research on urban growth and planning, which warrants further investigation.

1. Introduction

People and their corresponding economic activities are becoming increasingly concentrated in large cities, producing growth and congestion. Therefore, understanding the relationship between city-led growth and related costs is becoming increasingly important for economists and urban planners. Congestion is considered a major living cost caused by population growth in large cities (Anas et al., 1998; Bertaud and Brueckner, 2005; Parry et al., 2007; Geshkov and DeSalvo, 2012). Many scholars believed that congestion is induced by longer commuting distances corresponding to the expansion of a city's radius (Alonso, 1964; Mills, 1967, 1972; Muth, 1969; Bertaud and Brueckner, 2005; Kulish et al., 2011). Thus, urban concentration has been regarded as a means of congestion mitigation (Arnott and MacKinnon, 1977; Duranton and Turner, 2018; Glaeser et al., 2005; Glaeser, 2011; Lee, 2007). This argument, however, is based on simple average density. Does it matter if the density is evenly distributed or if the density in the city center is high and that in the city edge is low? To shed light on the role of density patterns, we propose that urban regeneration can alleviate population congestion through an intraurban concentration, that is, by constructing compact cities.

Specifically, this study answered the following question: How does urban regeneration affect the population–congestion relationship? A brief answer is that the density pattern plays an important role. When the urban population concentrates in the core and disperses in the periphery instead of being evenly distributed, congestion is directly worsened with minor welfare loss, but it is relieved indirectly if the population continues to grow.

This study proceeds as follows. First, taking bombings in WWII as exogenous shocks on regeneration costs, the stylized facts confirmed the significant correlation between urban regeneration and the population–congestion relationship. Second, the empirical results revealed a significant correlation between urban regeneration and intraurban concentration as well as between intraurban concentration and the population–congestion relationship. Then, we modeled the location-choice equilibrium with an endogenous intraurban density pattern. Moreover, we investigated how urban regeneration can reshape the intraurban density pattern and eventually affect the population–congestion relationship.

Viewing intraurban density patterns as endogenously shaped by technology or by historical shocks, the whole urban economy, including population, commuting cost, congestion, and growth, is determined as an

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outcome of the tradeoff between agglomeration benefits and costs. In this view, urban planners can hardly identify a “favorable” intraurban density pattern with little cost. Any deviation from the optimal spatial pattern may result in either loss of growth or more serious congestion or both.

This study belongs to the strand of literature that bridges the gap between urban economics and urban planning. The main contribution of this study is to theorize that the relationship between urban population and congestion is endogenously determined by the intraurban density pattern instead of the overall density. Furthermore, both our theoretical model and empirics illustrated that the intraurban density pattern results from regeneration costs.

The rest of this paper is organized as follows. Section 2 reviews the literature. Section 3 presents some stylized facts based on our empirical work using a global cross-sectional database. Section 4 presents our model and a comparative analysis. Finally, Section 5 presents the conclusion and discussion.

2. Literature review

Optimal city size is often considered an outcome reflecting the tradeoff between benefits and costs as functions of population (Dixit, 1973; Helpman, 1998; Au and Henderson, 2006; Desmet and Rossi-Hansberg, 2013). With a larger population, both agglomeration forces created by industry specialization and human capital externalities emerge (Moretti, 2004; Glaeser and Lu, 2018). Moreover, certain types of urban diseconomies, such as congestion, pollution, and high housing prices arise (Henderson, 1974; Duranton and Puga, 2004; Rosenthal and Strange, 2004; Fan et al., 2021).

Although most prior theoretical and empirical research have only linked marginal benefits and costs to population size, some recent studies have modeled urban spatial patterns and city sprawl as the key factors of congestion, considered a major living cost in large cities (Anas et al., 1998; Bertaud and Brueckner, 2005; Parry et al., 2007; Geshkov and DeSalvo, 2012). However, spatial patterns have been characterized only exogenously using a simple dichotomy between concentration and dispersion. The endogeneity of urban spatial patterns is often overlooked. Therefore, the mechanism of urban cost remains unclear compared with the benefits of urban expansion, which are relatively better investigated in research on the economics of agglomeration (Berliant et al., 2006; Duranton and Puga, 2004; Ellison et al., 2010; Rivera-Batiz, 1988).

Taking congestion as a representative urban cost resulting from a large population, the literature has widely accepted that congestion is mainly induced by the longer commuting distance corresponding to the expansion of a city's radius (Alonso, 1964; Mills, 1967, 1972; Muth, 1969; Bertaud and Brueckner, 2005; Kulish et al., 2011). Therefore, urban concentration is considered a means of mitigating congestion (Arnott and MacKinnon, 1977; Duranton and Turner, 2018; Glaeser et al., 2005; Glaeser, 2011; Lee, 2007; Harari, 2020).

However, when discussing the urban concentration, the existing literature has somewhat ignored the importance of the intraurban density pattern, which relates to maximum density and the density gradient resulting from the tradeoff between density- and distance-related costs for inhabitants' location choices. The effects of a reduction in distance-related costs on intraurban density patterns have been modeled endogenously in some theoretical studies (Zhang and Kockelman, 2014). However, neither the effects of a reduction in density-related cost on the intraurban density pattern nor the effects of the intraurban density pattern on congestion have been formally studied.

In summary, the relevant literature can be divided into two categories. One, mostly empirical, characterizes the overall density as a dichotomy of concentration versus dispersion and examines how population density affects congestion levels. The other, mostly theoretical, focuses on modeling location choice and how intraurban density patterns are determined. Compared with this work, the former strand ignores the role of density distribution patterns, whereas the latter fails to notice the effects of density pattern on the population–congestion relationship.

The density-related costs come from both building technologies (Bertaud and Breckner, 2005) and institutional “soft” regeneration costs, such as building-height limitations (Brueckner and Sridhar, 2012; Ding, 2013; Geshkov and DeSalvo, 2012; Glaeser, 2011; Naik et al., 2015; Sridhar, 2010). Thus, when technical and institutional improvements reduce density-related costs and facilitate urban concentration to relieve congestion, the population will also increase (Desmet and Rossi-Hansberg, 2013) and eventually intensify congestion. The literature has not modeled the tradeoff between these two contradictory effects.

This study filled this gap by modeling how regeneration costs endogenously determine the intraurban density pattern and its effects on the population–congestion relationship under general equilibrium. Specifically, this study's empirical and theoretical parts both aimed to show that the relationship between urban population and congestion is determined by the intraurban density pattern, which is affected by regeneration costs. This has not yet been discussed in the literature.

3. Stylized facts based on empirical study

Usually, regeneration cost is endogenously determined in practice. However, in our theoretical work, it is assumed to be exogenous. We followed Davis and Weinstein (2002) and used WWII as an exogenous shock on cities to mitigate the endogeneity issue. As we will show in the stylized facts, cities that were bombed during WWII have had less tension between population growth and congestion. Two major correlations are presented as follows: (1) bombed cities built not only more but also higher skyscrapers and (2) cities with more and higher skyscrapers have had less tension between population growth and congestion.

3.1. Data sources and summary statistics

Congestion data for 2019 were obtained from TomTom. The indexes are the average percentage increases in travel times. This refers to the difference between travel time during peak periods and that during noncongested periods, divided by travel time during noncongested periods. The indexes were multiplied by 100, thus ranging from 0 to 100.

Data for the variable “skyscraper index” came from the Council on Tall Buildings and Urban Habitat,[1] from which we can obtain accurate data on the number of buildings taller than 150 m (year: 2020). Using these data, we constructed an index of skyscrapers taller than 150 m in a city. A building received a score of 1.5 if it was taller than 150 m and shorter than 200 m, 2.0 if it was between 200 m and 300 m, and so on. Then, we summed the scores for skyscrapers in the city as the “skyscraper index.”

“Bombed during WWII” is a dummy variable that equals 1 if the city was bombed during WWII and equals 0 otherwise. “Population” is the city's population, the unit of which is one million. Meanwhile, “Area” is the area of the city, the unit of which is km2. “Population density” is the population divided by the area of the city, the unit of which is one thousand.

We obtained different sample sizes for different variables because of missing information. We had 447 samples with the congestion level but

[1] The Council on Tall Buildings and Urban Habitat (CTBUH; http://www.skyscrapercenter.com/cities)is a well-known organization focused on tall buildings. CTBUH records data on most of the world's skyscrapers. We tested the data against those of some similar organizations in China, such as High-Building Fans. We found that CTBUH had the most complete records. The higher the skyscraper index, the slacker the regulation may be. Some cities have regulation of commercial buildings different from that of residential buildings; therefore, we generated two alternative indexes of tall residential buildings by multiplying the skyscraper index by the proportion of residential or mixed-use buildings (only using data for 2014). The regression results were almost the same. See Tables S2 and S3.

Table 1
Data sources and summary statistics.

Variable	Obs.	Mean	Std. Dev.	Min	Max	Data Sources
Congestion	447	21.200	8.602	7	54	TomTom Company, Gaode Company
SI (skyscraper index)	200	47.288	92.552	3	802.5	CTBUH
Bombed	513	0.415	0.493	0	1	Materials and Records of WWII, Websites of Cities, and Wikipedia
Population (million)	510	1.760	3.207	.045	28.514	Statistics Department, Websites of Cities, Wikipedia, and Baidu
lnpop	510	13.455	1.307	10.717	17.1659	Statistics Department, Websites of Cities, Wikipedia, and Baidu
Area (km^2)	509	1103.459	3166.48	3.19	43,263	Statistics Department, Websites of Cities, Wikipedia, and Baidu
Density	509	3753.472	5208.534	33.386	46183.71	Statistics Department, Websites of Cities, Wikipedia, and Baidu

only 134 had both data for congestion level and the skyscraper index. Table 1 reports the summary statistics.

3.2. Decline in regeneration costs alleviates congestion

One factor that determines urban spatial patterns and congestion is regeneration cost. However, measuring regeneration costs directly is difficult. Therefore, we hypothesized that bombings during WWII sharply reduced a city's regeneration costs. This is similar to Davis and Weinstein (2002), who used bombings in Japan during WWII as an exogenous shock on urban development.

Fig. 1 depicts the empirical findings regarding the effect of regeneration on congestion. The solid dots are cities bombed during WWII, whereas the hollow dots are cities not bombed. As bombing during WWII was an exogenous shock to cities, the hollow dots constitute the counterfactual group for the solid dots. In Fig. 1, the parabolic opening of the fitted line for the population–congestion relationship of the bombing group is upward, whereas that of the control group is downward. On average, the slope of the fitted line of the bombed group is flatter than that of the control group. This means that regeneration after WWII changed the population–congestion relationship and mitigated the congestion level of megacities. However, it worsened the congestion level of relatively smaller cities. This phenomenon is further analyzed using Fig. 6, based on our theoretical modeling.

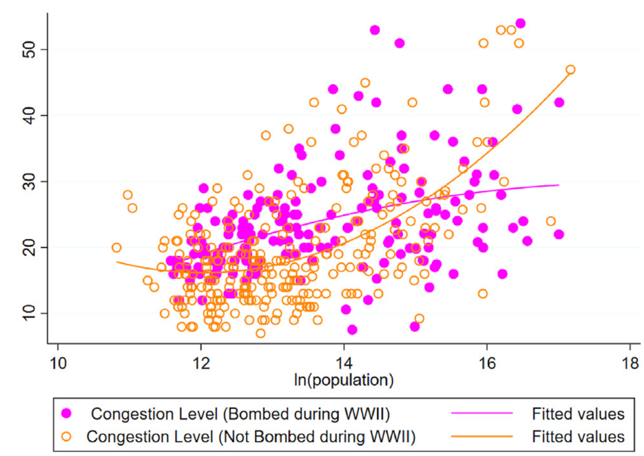

Fig. 1. Effect of regeneration on the population–congestion relationship.

3.3. Regeneration cost, urban spatial pattern, and congestion

Many mechanisms are available by which city regeneration alleviates congestion or promotes the overall development of a city (e.g., speeding up infrastructure construction and increasing urban density). We understand that urban regeneration is more likely to occur in the city center; thus, the urban spatial pattern should be affected by regeneration. A decline in regeneration costs will make a city more compact, thereby alleviating congestion and promoting the city's development.

3.3.1. Urban spatial patterns and the Population–Congestion relationship

Although each city has a unique spatial pattern, we can roughly categorize cities into three types of urban spatial patterns with different congestion levels. The first type of city looks like a mountain. The inner city has the tallest buildings, which, like mountain peaks, gradually descend to the periphery (e.g., ladders); population density distribution also follows this pattern. Examples include New York City, Toronto, Tokyo, and Shanghai. Congestion in this type of city is usually not as serious as in other types. Meanwhile, the urban spatial pattern of the second type of city looks like a basin, with a relatively low inner city and relatively high periphery. Typical basin cities include Paris, Beijing, and Mumbai. Congestion in such cities is often more serious because of inner-city building height controls, which are intended to protect historical buildings, among other purposes.

Lastly, the spatial structure of the third type of city is flat.[2] The following are two types of flat cities: Type I cities, which have clear urban boundaries, and Type II cities that sprawl freely. Flat Type I cities are generally tall, although sometimes city size is limited by the total land area, as in Hong Kong, Singapore, and Vancouver. However, commuting conditions are often the best in such cities. Meanwhile, serious congestion exists in Type II flat cities, which sprawl freely, regardless of the height. Some of these cities are relatively tall, such as Wuhan, Rio de Janeiro, Istanbul, and Mexico City, whereas others sprawl at a low height, for example, Los Angeles, regardless of inner-city height.

3.3.2. Relieving the Population–Congestion relationship in more compact cities

The urban spatial pattern of all cities is difficult to measure. However, we found that skyscrapers are usually built in the city centers, and more skyscrapers means more people living in the city center.[3] Therefore, we can use the quantity and height of skyscrapers in a city to measure the urban spatial pattern.

The building of skyscrapers and the urban spatial pattern, which is affected by regeneration costs, affect congestion and city development.

[2] The spatial structures of these cities are still sloped but flatter, especially in Type II cities.

[3] Although the conclusions about where industries gather vary, service industries usually gather in city centers (Couture, 2020; Wei et al., 2020). Large cities and metropolises are also the greatest beneficiaries of economic spillovers between enterprises, which further promote the development of the city center (He et al., 2021).

More skyscrapers mean more people living and working in the city centers; thus, congestion is internalized.

Otherwise, as more people live in the outer suburbs, fewer people live in the city center, which decreases population density in the urban areas. In this case, working people need to commute between home and work, placing great pressure on urban infrastructure.

In one study, simulation results for data from Bangalore showed that welfare loss measured by commuting cost was approximately 1.5%–4.5% of the household consumption (Bertaud and Brueckner, 2005). Ordinary least-squares (OLS) estimations have shown that building-height restrictions led to population suburbanization in India (Sridhar, 2010) and city sprawl in both India and the US (Brueckner and Sridhar, 2012; Geshkov and DeSalvo, 2012). Similar consequences were observed in Beijing (Ding, 2013). Fig. 2 shows that congestion (vertical axis) becomes serious when a city's population increases (horizontal axis). However, in cities with a higher density of skyscrapers (solid circles), the congestion level increases slowly.

3.3.3. Decline of regeneration costs makes cities more compact

The regeneration costs is difficult to measure because laws and policies on regeneration are not easily changed, and urban regeneration usually progresses slowly. However, we observed that if a city was bombed during WWII, it needed to be rebuilt on a large scale, indicating a sharp decline in regeneration costs. Regarding skyscrapers, the historic buildings in a city were more likely to be destroyed during bombings. Thus, building-height regulation was more likely to be relaxed, and the density of skyscrapers would, therefore, be higher. Otherwise, old cities had more historic buildings in their city centers; thus, they had to build skyscrapers from the center, which supposedly would not relieve congestion.

Skyscrapers were more likely to be built in the city center if a city was bombed. This is illustrated by examples such as Paris versus London and Beijing versus Shanghai. Paris and Beijing were not bombed during WWII, and their ancient/historic buildings were well protected. Hence, the centers of both cities are still as low as they were decades ago. Meanwhile, London and Shanghai were bombed in WWII during "The Blitz" and the "Songhu Battle," respectively. Moreover, many old buildings were destroyed. Thus, the city centers are now newer and higher. Similarly, in Rotterdam, more skyscrapers are in the area bombed during WWII (Koster et al., 2012). For example, the skyscraper index of Beijing is 79.5 and that of Shanghai is 295. Meanwhile, the congestion index of Beijing is 0.24 with 21.89 million people vs. 0.22 in Shanghai, which has 24.87 million people (year: 2020). Fig. 3 shows that large cities usually have more skyscrapers, but cities bombed during WWII have more skyscrapers than nonbombed cities.

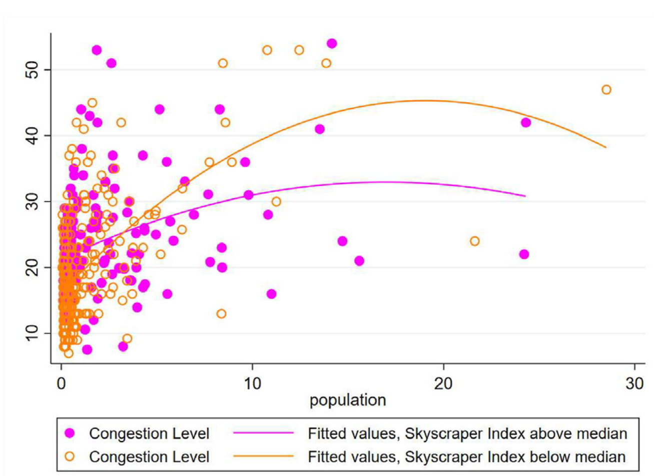

Fig. 2. Effect of intraurban concentration on the population–congestion relationship.

Fig. 3. Effect of regeneration on intraurban concentration.

3.4. Econometric results

3.4.1. Effect of being bombed during WWII on the building of skyscrapers

We used the following regression model to investigate whether a bombed city built more skyscrapers:

$$SI_i = \alpha_0 + \alpha_1 Bomb_i + \alpha_2 Pop_i + \alpha_3 Bomb_i \times Pop_i + \varepsilon_i, \quad (1)$$

where i refers to a city, SI_i is the skyscraper index, and Pop_i is urban population. $Bomb_i$ is a dummy variable that equals 1 if the city was bombed during WWII; 0 otherwise. $Bomb_i \times Pop_i$ is the interaction of bombing and population; ε_i is a disturbance term.

Table 2 shows that bombed cities had a skyscraper index 18.641 points higher than that of nonbombed cities. After adding the interaction term "Pop × Bomb," the coefficient of bombed became significantly negative, and the interaction term was significantly positive. This means the effect of being bombed on the skyscraper index existed mainly in large cities. In other words, skyscrapers are not needed in small cities but are necessary for large cities. In Columns (4)–(6), we controlled country-fixed effects to exclude differences in the measurement of city size in different countries; the results remained robust.

3.4.2. Effect of skyscraper index on congestion

We performed OLS estimation as follows:

$$Congestion_i = \beta_0 + \beta_1 SI_i + \beta_2 Pop_i + \beta_3 SI_i \times Pop_i + u_i, \quad (2)$$

where $Congestion_i$ is the congestion level, $SI_i \times Pop_i$ is the interaction of skyscraper index and population, u_i is a disturbance term, and the other variables are the same as the ones controlled in Equation (1).

Table 3 reports the results. Generally, we found that the larger the city, higher the congestion level, and skyscrapers can relieve congestion. Column 1 shows that the congestion level of a city with 10 million or more people is approximately 11.59 higher (1.159 × 10, Column 1), which is more than 1 standard deviation (8.6) or about half of the mean of congestion level (21.2). Moreover, the coefficient of the interaction term SI × pop is significantly negative, which means that in a city of one million or more, the marginal effect of one more 150–200 m building (1.5 skyscraper index) is a decline in congestion by 0.009 (0.006 × 1.5) (Column 3). If a city with 10 million or more people has 300 or more 150–200 m buildings, the congestion level increases by 9.13 (=1.678 × 10 + 0.043 × 300 × 1.5–0.006 × 1.5 × 300 × 10), which is less than half of the mean. Considering the endogeneity issue, we realize this estimation can only be understood as correlation rather than causality. The

Table 2
Influence of having been bombed on Skyscraper Index (SI).

Variables	(1) SI	(2) SI	(3) SI	(4) SI	(5) SI	(6) SI
Bombed	18.412**	−22.501***	−23.649***	12.143	−32.184**	−35.678***
	(7.538)	(5.419)	(5.207)	(14.531)	(12.649)	(12.225)
Pop		3.258***	4.099***		4.800***	5.849***
		(0.798)	(0.936)		(1.452)	(1.326)
Pop*bombed		8.117***	8.704***		7.794***	8.452***
		(1.438)	(1.401)		(2.055)	(1.727)
Area			−0.002**			−0.002***
			(0.001)			(0.001)
Constant	28.154***	20.507***	20.806***	18.500***	3.855	1.155
	(3.613)	(3.597)	(3.578)	(0.000)	(4.430)	(3.988)
Country FE	No	No	No	Yes	Yes	Yes
Obs.	195	195	195	195	195	195
R2	0.032	0.529	0.541	0.137	0.649	0.664

Notes: Robust standard errors in parentheses; ***p < 0.01, **p < 0.05, *p < 0.1. The Dubai, Hong Kong, Shenzhen, and New York samples were excluded as outliers, but the results were almost the same when including those four cities.

Table 3
OLS estimation on the effect of the skyscraper index on congestion.

Variables	(1) Congestion	(2) Congestion	(3) Congestion	(4) Congestion	(5) Congestion	(6) Congestion
Pop	1.159***	1.678***	1.865***	0.726***	0.928**	0.680
	(0.195)	(0.458)	(0.485)	(0.190)	(0.423)	(0.456)
SI		0.043**	0.037*		0.036*	0.043**
		(0.021)	(0.022)		(0.021)	(0.020)
Pop*SI		−0.006***	−0.005**		−0.003*	−0.004**
		(0.002)	(0.002)		(0.002)	(0.001)
Area			−0.000			0.000*
			(0.000)			(0.000)
Constant	19.172***	16.317***	16.503***	21.786***	20.678***	21.272***
	(0.414)	(1.369)	(1.367)	(0.580)	(1.169)	(1.250)
Country FE	No	No	No	Yes	Yes	Yes
Obs.	441	130	130	441	130	130
R2	0.198	0.288	0.301	0.723	0.758	0.768

Notes: Robust standard errors in parentheses; ***p < 0.01, **p < 0.05, *p < 0.1. The Dubai, Hong Kong, Shenzhen, and New York samples were excluded as outliers, but the results were almost the same when including those four cities.

coefficients of the interaction terms were still significantly negative when we controlled for country-fixed effects or replaced the index of congestion with "morning peak congestion," "evening peak congestion," "highway congestion," and "nonhighway congestion" using data from 2014 (see Tables S1 and S2).

4. Model

In the theoretical part, we model the density pattern of the population to examine how congestion is affected by urban regeneration, which reduces density-related costs. Precisely, in the model, urban construction technologies and administration institutions determine building and maintenance costs and other density-related costs, thereby affecting rent. Given perfect labor mobility and free location choice, residential costs, including rent and commuting costs, should be indifferent to any location. Hence, the spatial pattern in equilibrium is an outcome of the tradeoff between density-related and distance-related costs. Therefore, when regeneration costs decline, a city can be regenerated to apply new technologies and institutions and thus reduce density-related costs (e.g., rent). Consequently, people live closer to the city center, buildings are made taller, the city becomes more compact (especially in the center), and average commuting distance is reduced. However, with higher compactness, more severe congestion could arise. This model is built to examine the equilibrium results of these two opposite effects.

4.1. *Basic model: static equilibrium*

First, we adapted Ogawa and Fujita's (1980) framework to an urban economy where density is endogenously determined. Meanwhile, urban structure is assumed to be monocentric to simplify the calculation. This assumption would make the numerical simulation results inaccurate because, in reality, cities are more likely to be polycentric. Nevertheless, it does not harm the generality of this research as long as the core–periphery theory holds. Assume that income falls into three categories: commuting expense, rent expense, and net income

$$w = NI + r(x) + tx, \tag{3}$$

where NI denotes net income, t denotes commuting expense per unit of distance, x denotes the distance between a person's home and the central business district (CBD), and r(x) denotes the rent per unit of floorspace at location x. Assume that all rent is used to cover density-related costs, including building, maintenance, and regeneration costs. Meanwhile, all density-unrelated expenses for housing and interior trim, landscaping, and other expenses are classified as consumption, which is covered by net income. This assumption is crucial because it establishes the linkage between the location choice of a representative household and the intraurban density pattern.

Assume congestion is external, whereas commuting expense is internal for individuals. Citizens maximize their net income through location choice. Thus, we can characterize the representative citizen's location choice by minimizing the internal cost of settlement (ICS), including commuting expense and rent, as follows:

$$\min_{x}.ICS(x) = r(x) + tx. \tag{4}$$

Rent is determined by the equilibrium of the real estate market, which, for simplicity, is presumed to be completely competitive, given by

$$r(x) = \frac{C(x)}{d(x)}, \tag{5}$$

where C(x) denotes the density-related cost, including construction and maintenance, at location x, and d(x) represents the floorspace density at location x. Meanwhile, assume that the density-related cost obeys the power law, given by

$$C(x) = Bd(x)^{\theta+1}, B > 0, \theta > 0, \tag{6}$$

where B is a technology and institution parameter, and θ is the density elasticity of rent. Assuming perfect labor mobility and identical citizens, ICS will be the same for all citizens. For simplicity, assuming that rent is zero on the city edge, the city radius denoted by s is determined by the condition of indifferent location, given by

$$ts = r(0) = ICS. \tag{7}$$

Hence, density is determined as a function of location and city radius, as follows:

$$d(x) = \left[\frac{t}{B}(s-x)\right]^{\frac{1}{\theta}}. \tag{8}$$

Then, we establish the equilibrium of the real estate market. The total floorspace supply (TFS) is obtained by accumulating the density on both sides of the linear city as follows:

$$TFS = 2\int_0^s d(x)dx. \tag{9}$$

Assume each individual consumes one unit of floorspace for habitation and needs a unit of floorspace for production. Then, total floorspace demand (TFD) is obtained by summing all individual demand as follows:

$$TFD = (1+\alpha)l, \tag{10}$$

where l denotes the size of a representative agglomeration (a city), which is measured by the number of employees. Thus, the function of equilibrium city radius is obtained by equating TFS to TFD as follows:

$$s = \left[\left(\frac{B}{t}\right)^{\frac{1}{\theta}}\frac{\theta+1}{\theta}\frac{1+\alpha}{2}l\right]^{\frac{\theta}{\theta+1}}. \tag{11}$$

Therefore, ICS is obtained as follows:

$$ICS = t\left[\left(\frac{B}{t}\right)^{\frac{1}{\theta}}\frac{\theta+1}{\theta}\frac{1+\alpha}{2}l\right]^{\frac{\theta}{\theta+1}}. \tag{12}$$

Assuming perfect labor mobility, the function of wage (w) is given by

$$w = NI + t\left[\left(\frac{B}{t}\right)^{\frac{1}{\theta}}\frac{\theta+1}{\theta}\frac{1+\alpha}{2}l\right]^{\frac{\theta}{\theta+1}}. \tag{13}$$

Then, we assume an increasing return in the production function and that only one factor is used to simplify the calculation. Moreover, we focus on the location-choice issue by ignoring the differences between labor and capital. The production function is given by

$$Y = pAl^{\gamma+1}, \gamma > 0, \tag{14}$$

where p denotes price, which is presumed to be exogenous for simplicity; A is the technology parameter; and γ denotes the scale economy. Assume that the city is governed by an organization, such as a firm, that maximizes the profit rate. Meanwhile, the city has complete information and a reasonable expectation regarding the effects of hiring on wages and rent. Assume all production departments face the same rent level, which, for simplicity, is determined by the density of the city center. Then, the profit rate (PR) function is given by

$$PR = pAl^{\gamma} - w - \alpha r(0). \tag{15}$$

Therefore, the city's behavior can be characterized as follows:

$$\max_{l}.\left\{pAl^{\gamma} - NI - (1+\alpha)t\left[\left(\frac{B}{t}\right)^{\frac{1}{\theta}}\frac{\theta+1}{\theta}\frac{1+\alpha}{2}l\right]^{\frac{\theta}{\theta+1}}\right\}. \tag{16}$$

When $\frac{\theta}{\theta+1} - \gamma > 0$, a stable inner solution exists. Thus, urban population (l) is obtained from the first-order condition as follows:

$$UrbanPopulation = \left[\left(\frac{\theta+1}{\theta}\right)^{\frac{1}{\theta+1}}\frac{\gamma pA}{(1+\alpha)t}\left(\frac{t}{B}\right)^{\frac{1}{\theta+1}}\left(\frac{2}{1+\alpha}\right)^{\frac{\theta}{\theta+1}}\right]^{\frac{1}{\frac{\theta}{\theta+1}-\gamma}}. \tag{17}$$

Thus, the urban density pattern in equilibrium can be characterized with the following variables:

$$CityRadius = \left\{\left(\frac{t}{B}\right)^{\frac{1}{\theta-(\theta+1)\gamma}-\frac{1}{\theta}}\left(\frac{\theta+1}{\theta}\right)^{\frac{1}{\theta-(\theta+1)\gamma}+1}\left(\frac{2}{1+\alpha}\right)^{\frac{1}{\theta-(\theta+1)\gamma}-1}\left[\frac{\gamma pA}{(1+\alpha)t}\right]^{\frac{1}{\frac{\theta}{\theta+1}-\gamma}}\right\}^{\frac{\theta}{\theta+1}}, \tag{18}$$

$$CenterDensity = \left\{\left(\frac{t}{B}\right)^{\frac{1}{\theta-(\theta+1)\gamma}+1}\left(\frac{\theta+1}{\theta}\right)^{\frac{1}{\theta-(\theta+1)\gamma}+1}\left(\frac{2}{1+\alpha}\right)^{\frac{1}{\theta-(\theta+1)\gamma}-1}\left[\frac{\gamma pA}{(1+\alpha)t}\right]^{\frac{1}{\frac{\theta}{\theta+1}-\gamma}}\right\}^{\frac{1}{\theta+1}}. \tag{19}$$

Suppose the urban structure is monocentric, which means all production departments are located around the city center to form the CBD, whereas all workers settle in other spaces to form the living districts. In that case, the market-clearing condition of the real estate market in the CBD is given by

$$2\int_0^b d(x)dx = \alpha l, \tag{20}$$

where b denotes the CBD radius. The analytical solution of b is obtained as follows:

$$s^{\frac{\theta+1}{\theta}} - (s-b)^{\frac{\theta+1}{\theta}} = \frac{\alpha}{2}\frac{\theta+1}{\theta}\left(\frac{B}{t}\right)^{\frac{1}{\theta}}l. \tag{21}$$

Suppose the congestion peak time is when each individual must arrive at the city center, no later than a fixed time. However, exogenous infrastructure, such as road width, limits the passing capacity to M, or the permitted throughput is M per unit of time.

Meanwhile, some other types of infrastructure, such as road flatness, limit the fluent commuting speed to be E. The infrastructures that limit the throughput and speed are classified as Type I and Type II commuter infrastructure, respectively. Hence, congestion is measured as the term of additional commute time relative to a smooth commute. This assumption set greatly simplifies the calculation by avoiding the complexity caused by gradually varying commuting speed resulting from congestion. Meanwhile, fluent commuting time (FCT) limited by distance is given by

$$\mathrm{FCT}(x) = \frac{x}{E}, E > 0. \tag{22}$$

For simplicity, it is assumed that the distances from the CBD rank commuters' priorities for passing congested intersections. This assumption simplifies the model by ignoring the variance caused by random ranking. Thus, the permitted commuting time (PCT) limited by passing capacity is given by

$$\mathrm{PCT}(x) = \frac{\int_b^x d(v)dv}{M}, M > 0, b \le x \le s. \tag{23}$$

The analytical solution of PCT is

$$\mathrm{PCT}(x) = \left(\frac{t}{B}\right)^{\frac{1}{\theta}} \frac{\theta}{\theta+1}\left[(s-b)^{\frac{\theta+1}{\theta}} - (s-x)^{\frac{\theta+1}{\theta}}\right]\frac{1}{M}. \tag{24}$$

Moreover, congestion time (CT) is given by

$$\mathrm{CT}(x) = \mathrm{PCT}(x) - \mathrm{FCT}(x). \tag{25}$$

Note that the CT value could be negative in this definition. This definition is adopted to simplify the calculation without a great loss of generality. This is because our conclusions are based on comparative analysis, which is not affected by the absolute values of the variables. Thus, given the limitations of the empirical evidence, urban congestion level in this study is solely measured by peak congestion:

$$\mathrm{Congestion} = \max_x . \mathrm{CT}(x). \tag{26}$$

Peak congestion happens when citizens living in x^* arrive at the city center, as follows:

$$x^* = s - \frac{BM^\theta}{tE^\theta}. \tag{27}$$

Suppose the congestion value is positive. The analytical solution for congestion can be obtained from the first-order condition as follows:

$$\mathrm{Congestion} = \frac{l}{2M} - \frac{\theta s + x^*}{(\theta+1)E}. \tag{28}$$

4.2. Effects of urban regeneration

Suppose the density-related cost (parameter B) has decreased in period 1 because of urban regeneration, whereas other parameters remain the same as those in period 0. Thus, floorspace is redistributed to form a new density pattern because of the resettlement of the urban population. Note that in long-term equilibrium, immigrants flow into the city and eventually cause urban net income to converge with net reservation income. In period 1, we study the effects in the short term to simplify calculation without great loss of generality. This is because our model inferences at this stage focus on the structural effects, including density pattern and cost components, rather than the growth effects caused by immigrants. The new density pattern in period 1 is given by

$$d(x)_1 = \left[\frac{t}{(1-\delta)B}(s_1 - x)\right]^{\frac{1}{\theta}}, \delta_1 > 0, \tag{29}$$

where δ denotes the reduction of density-related cost, which negatively correlates with regeneration cost. Thus, the new equilibrium is obtained as follows:

$$\mathrm{CityRadius}_1 = (1-\delta)^{\frac{1}{\theta+1}}\left[\frac{1+\alpha}{2}\frac{\theta+1}{\theta}\left(\frac{B}{t}\right)^{\frac{1}{\theta}} l_0\right]^{\frac{\theta}{\theta+1}} = \mathrm{CityRadius}_0(1-\delta)^{\frac{1}{\theta+1}}, \tag{30}$$

$$\mathrm{CenterDensity}_1 = (1-\delta)^{\frac{-1}{\theta+1}}\left(\frac{1+\alpha}{2}\frac{\theta+1}{\theta}\frac{t}{B}l_0\right)^{\frac{1}{\theta+1}} = \frac{\mathrm{CenterDensity}_0}{(1-\delta)^{\frac{1}{\theta+1}}}, \tag{31}$$

$$\mathrm{Rent}_1 = \mathrm{Rent}_0(1-\delta)^{\frac{1}{\theta+1}}, \tag{32}$$

$$b_1 = b_0(1-\delta)^{\frac{1}{\theta+1}}, \tag{33}$$

$$\mathrm{Congestion}_1 = \frac{l_0}{2M} - \frac{(1-\delta)^{\frac{1}{\theta+1}}\theta s_0 + (1-\delta)x^*}{(\theta+1)E}. \tag{34}$$

Based on Equations (29)–(31), the comparative analysis can start from the effect of urban regeneration on the intraurban density pattern, as shown in Fig. 4. In Fig. 4, the horizontal axis represents distance from the city center, and the vertical axis represents density. The lines represent density patterns. When the density elasticity of rent is elastic ($\theta > 1$), the density pattern curve is concave, as shown by the dashed line. When the density elasticity of rent is inelastic ($\theta < 1$), the density pattern curve is convex, as shown by the thin solid line. When the density elasticity of rent is unit elasticity ($\theta = 1$), the density pattern curve is a straight, as shown by the bold solid line. After the shock of urban regeneration, the density pattern curve rotates clockwise, implying that the city is more compact.

Then, based on Equations (15) and (32), we can analyze the effect of urban regeneration on the microeconomy. Given the production function, we obtain the marginal output value rate (MV) and marginal cost rate (MC) in period 1 as follows:

$$\mathrm{MV}_1 = pAl^{\gamma-1} = \mathrm{MV}_0, \tag{35}$$

$$\mathrm{MC}_1 = \frac{\theta}{\theta+1}(1+\alpha)t\left\{\left[\frac{B(1-\delta)}{t}\right]^{\frac{1}{\theta}}\frac{\theta+1}{\theta}\frac{1+\alpha}{2}\right\}^{\frac{\theta}{\theta+1}} l^{\frac{-1}{\theta+1}} = \mathrm{MC}_0(1-\delta)^{\frac{1}{\theta+1}}. \tag{36}$$

In this way, we can show the effects of urban regeneration on the microeconomy. In Fig. 5, the horizontal axis represents the urban population, and the vertical axis represents the marginal rate. The MC curve moves from MC_0, the dashed line, downward to MC_1, the thin solid line,

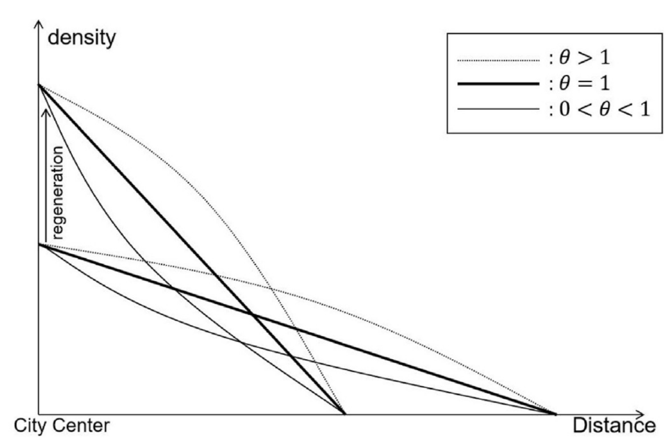

Fig. 4. Effects of regeneration on the intraurban density pattern.

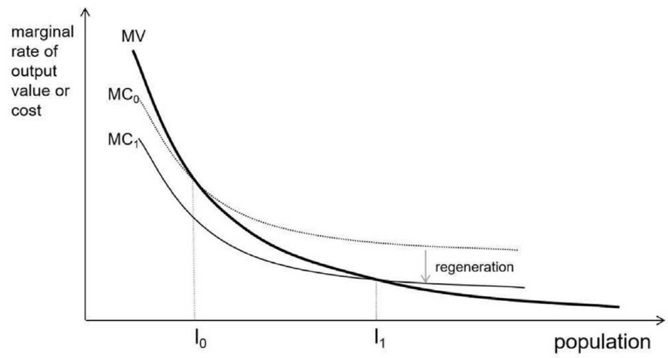

Fig. 5. Effects of regeneration on the microeconomy.

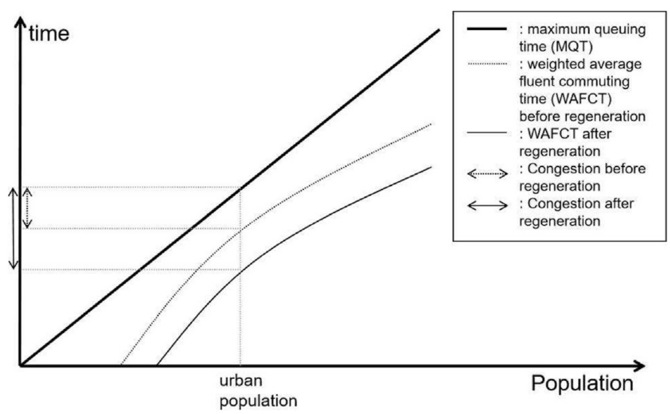

Fig. 6. Direct effects of regeneration on congestion.

because of the shock of urban regeneration. Meanwhile, the MV curve, the bold solid line, remains unchanged. Therefore, the optimal urban population increases from l_0 to l_1; a gap between the MV and MC emerges before new immigrants flow into the city. This means the PR increases because of urban regeneration.

Finally, we can analyze the effect of urban regeneration on the relationship between urban population growth and congestion. From Equation (28), we identify two components of congestion. One is the maximum queuing time (MQT), limited by the unit time throughout of traffic nodes, which is determined by the reciprocal of the per capita Type I commuter infrastructure. The other is the weighted average fluent commuting time (WAFCT), which is determined by the density pattern and Type II commuter infrastructure, as shown in the following equation:

$$MQT = \frac{1}{2M}, \tag{37}$$

$$WAFCT = \frac{\theta s + x^*}{(\theta + 1)E}. \tag{38}$$

We expect that congestion will worsen in the short term because urban regeneration shortens the average commuting distance. In other words, people now spend more time waiting and less time driving, if driving is the main means of commuting. Thus, in period 1, the aforementioned two components can be obtained as follows:

$$MQT_1 = MQT_0, \tag{39}$$

$$WAFCT_1 - WAFCT_0 = -\frac{\left[1 - (1-\delta)^{\frac{1}{\theta+1}}\right]\theta s_0 + \delta_1 x^*}{(\theta + 1)E}. \tag{40}$$

This direct effect caused by shortened commuting distance is called the “concentration effect” (Fig. 6). In Fig. 6, the horizontal axis represents the urban population, and the vertical axis represents time. MQT remains the same after regeneration, as shown by the bold solid line. WAFCT shifts downward from the dashed line to the thin solid line as a result of regeneration. Thus, congestion worsens from the smaller gap, shown by the dashed double arrow, to the bigger gap, shown by the thin solid line double arrow.

Indirectly, however, we expect population growth because the benefit of regeneration will attract immigrants. Thus, we assume that the urban economy is in long-term equilibrium in period 2. Therefore, the population in period 2 can be obtained based on Equation (17) as follows:

$$Population_2 = \frac{Population_0}{(1-\delta)^{\frac{1}{\theta-(\theta+1)\gamma}}}. \tag{41}$$

Then, the city radius in period 2 can be obtained based on Equation (18) as follows:

$$CityRadius_2 = \frac{CityRadius_0}{(1-\delta)^{\frac{1}{\frac{\theta}{\gamma}-(\theta+1)}}}. \tag{42}$$

Then, suppose the population grew to l_2 flatly without regeneration. Therefore, the counterfactual congestion can be obtained based on Equation (11) as follows:

$$Congestion_2 = \frac{l_2}{2M} - \frac{\left[\left(\frac{B}{t}\right)^{\frac{1}{\theta}}\frac{\theta+1}{\theta}\frac{1+\alpha}{2}l_2\right]^{\frac{\theta}{\theta+1}}}{E} + \frac{BM^{\theta}}{(\theta+1)tE^{\theta+1}}. \tag{43}$$

Therefore, the long-term effect of urban regeneration on congestion (LTI) or the gap between congestion in the compact city and congestion in the flat city can be obtained as follows:

$$LTI = Congestion_2 - Congestion_2 = -\frac{\left[\left(\frac{B}{t}\right)^{\frac{1}{\theta}}\frac{\theta+1}{\theta}\frac{1+\alpha}{2}l_2\right]^{\frac{\theta}{\theta+1}}}{E}\left[(1-\delta)^{-\frac{1}{\frac{\theta}{\gamma}-(\theta+1)}} - 1\right]. \tag{44}$$

The analytical solution of the boundary condition cannot be obtained, but it is obvious that LTI will be negative if the urban population is large enough. This indirect effect caused by population growth in the long term is called the “growth effect” of urban regeneration. Fig. 7 shows the total long-term effect, mixed with the concentration and growth effects. In Fig. 7, the horizontal axis represents the urban population, and the vertical axis represents congestion. Based on Equations (27), (28) and (44), we can show the population–congestion relationship before urban regeneration as the thin line and after regeneration as the bold line. If the city is small, its population will increase slightly from l_0 to l_2. Meanwhile, if the city is large, its population will increase sharply from L_0 to L_2. The larger the city, the less the congestion. If the city is large enough, congestion could possibly even be relieved after regeneration.

These results suggest two effects: concentration and growth effect. The concentration effect means that part of the internal commuting cost will be transformed into congestion when citizens are closer to the city center. Meanwhile, growth effect means that urban population growth causes less congestion because of less commuting demand.

5. Conclusion and discussion

This research contains two main parts. The empirical study provides evidence that urban regeneration can cause intraurban concentration and eventually relieve population congestion. The theoretical part models the mechanism to explain the empirical results and suggests two effects of intraurban concentration. One is a concentration effect that directly aggravates congestion. However, this concentration effect does not cause great welfare loss because such loss from congestion aggravation can be largely offset by the welfare gain from saving on commuting costs. The other is a growth effect that reduces the marginal congestion caused by

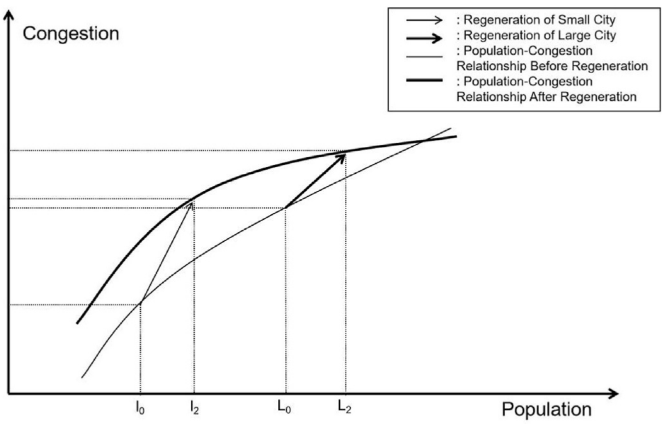

Fig. 7. Indirect effects of regeneration on congestion.

population growth. This growth effect mitigates congestion for regenerated cities with large population growth.

Specifically, in the empirical study, we took the skyscraper index to measure the urban spatial pattern and took "whether a city was bombed during WWII" as an exogenous shock, which meant regeneration costs declined exogenously and sharply. The results suggest that the effect of population on congestion can be relieved by skyscrapers, mainly for large cities. However, in small cities with more skyscrapers, congestion was more serious.

To overcome the limitations of the empirical analysis, we built a theoretical model to illustrate how regeneration affects the population–congestion relationship. The model results imply two effects: (1) a concentration effect, which means the urban population is located closer to the city center and causes more severe peak rush, placing a heavier burden on commuting infrastructure, and (2) a growth effect, which means urban population growth causes less marginal congestion because of the improved density pattern. In small cities, the concentration effect is stronger than the growth effect; thus, their congestion worsens after regeneration. Meanwhile, in megacities, the growth effect exceeds the concentration effect. Therefore, their congestion can be relieved after regeneration.

In summary, when density-related costs are reduced through urban regeneration, firms and individuals relocate closer to the city center and form a new density pattern to minimize total costs. On the one hand, intraurban concentration places a heavier burden on the evacuation capability of the commuting system in the city center because people spend less time driving and more time waiting at commuting-system nodes, leading to more serious traffic congestion (concentration effect). On the other hand, the effect of marginal population growth on congestion is reduced because of urban regeneration (growth effect). Thus, a well-regenerated city will grow with less congestion, and this growth effect will offset the concentration effect, especially in megacities with larger population growth.

The population–congestion relationship depends on the intraurban density pattern, which is determined by the urban commuting infrastructure and city planning. Therefore, our findings suggest that city planners should build compact cities with more skyscrapers, especially in the centers, to reduce density-related costs and enjoy the benefits of new construction technologies and administration institutions. Such improvements occur when urban regeneration benefit exceeds the cost. Although the urban regeneration benefit–cost tradeoff is mainly determined by technology and institutions, it is also affected by urban policies, such as height restrictions, density restrictions, and demolition compensation policies. If no other justifications exist outside our model for building-height regulations (e.g., to preserve historical sites), regeneration that favors high density in large cities (e.g., relaxing building-height regulations) could improve the welfare of residents and only slightly aggravate congestion. Regeneration can, therefore, more efficiently accommodate larger populations in megacities as opposed to a lot of small cities. This research sheds light on the planning and construction of compact cities, such that compact cities can achieve an optimal balance between urban development and "urban disease."

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Declaration of competing interest

We declare that we have no financial and personal relationships with other people or organizations that can inappropriately influence our work, there is no professional or other personal interest of any nature or kind in any product, service and/or company that could be construed as influencing the position presented in, or the review of, the manuscript entitled.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.econmod.2022.105828.

References

Alonso, W., 1964. Location and Land Use: toward a General Theory of Land Rent. Harvard University Press, Cambridge.
Anas, A., Arnott, R., Small, K.A., 1998. Urban spatial structure. J. Econ. Lit. 36 (3), 1426–1464.
Arnott, R.J., MacKinnon, J.G., 1977. Measuring the costs of height restrictions with a general equilibrium model. Reg. Sci. Urban Econ. 7, 359–375.
Au, C., Henderson, J.V., 2006. Are Chinese cities too small. Rev. Econ. Stud. 73, 549–576.
Berliant, M., Reed, R.R., Wang, P., 2006. Knowledge exchange, matching, and agglomeration. J. Urban Econ. 60 (1), 69–95.
Bertaud, A., Brueckner, J.K., 2005. Analyzing building-height restrictions: predicted impacts and welfare costs. Reg. Sci. Urban Econ. 15 (2), 109–125.
Brueckner, J.K., Sridhar, K.S., 2012. Measuring welfare gains from relaxation of land-use restrictions: the case of India's building-height limits. Reg. Sci. Urban Econ. 42, 1061–1067.
Couture, V., Handbury, J., 2020. Urban revival in America. J. Urban Econ. 119, 103267.
Davis, D.R., Weinstein, D.E., 2002. Bones, bombs, and break points: the geography of economy activity. Am. Econ. Rev. 92 (5), 1269–1289.
Desmet, K., 2013. Rossi-hansberg, E. Urban accounting and welfare. Am. Econ. Rev. 103 (6), 2296–2327.
Ding, C., 2013. Building height restrictions, land development and economic costs. Land Use Pol. 30, 485–495.
Dixit, A., 1973. The optimum factory town. Bell J. Econ. Manag. Sci. 4 (2), 637–651.
Duranton, G., Puga, D., 2004. Micro-foundations of urban agglomeration economies. In: Henderson, J.V., Thisse, J.F. (Eds.), Handbook of Regional and Urban Economics, vol. 4. Elsevier, pp. 2063–2117.
Duranton, G., Turner, M.A., 2018. Urban form and driving: evidence from US cities. J. Urban Econ. 108, 170–191.
Ellison, G., Glaeser, E.L., Kerr, W.R., 2010. What causes industry agglomeration? Evidence from Coagglomeration patterns. Am. Econ. Rev. 100 (3), 1195–1213.
Fan, H., Peng, Y., Wang, H., Xu, Z., 2021. Greening through finance. J. Dev. Econ. 102683.
Geshkov, M.V., DeSalvo, J.S., 2012. The effect of land-use controls on the spatial size of U.S. Urbanized areas. J. Reg. Sci. 52, 648–675.
Glaeser, E.L., 2011. Triumph of the City. Penguin Press.
Glaeser, E.L., Gyourko, J., Saks, R.E., 2005. Why is manhattan so expensive? Regulation and the rise in housing prices. J. Law Econ. 48, 331–369.
Glaeser, E.L., Lu, M., 2018. Human-capital externalities in China. NBER working paper 24925. http://www.nber.org/papers/w24925.
Harari, M., 2020. Cities in bad shape: urban geometry in India. Am. Econ. Rev. 110 (8), 2377–2421.
Helpman, E., 1998. The size of regions. In: Pines, D., Sadka, E., Zilcha, I. (Eds.), Topics in Public Economics. Theoretical and Applied Analysis. Cambridge University Press, Cambridge, pp. 33–54.
He, M., Chen, Y., Marrewijk, C., 2021. The effects of urban transformation on productivity spillovers in China. Econ. Modell. 95 (issue C), 473–488.
Henderson, J.V., 1974. The sizes and types of cities. Am. Econ. Rev. 64 (4), 640–656.
Koster, H.R.A., Ommeren, J., Rietveld, P. Bombs, 2012. Boundaries and buildings: a regression-discontinuity approach to measure costs of housing supply restrictions. Reg. Sci. Urban Econ. 42, 631–641.

Kulish, M., Richards, A., Gillitzer, C., 2011. Urban Structure and Housing Prices: Some Evidence from Australian Cities. Reserve Bank of Australia Research Discussion Paper. http://www.rba.gov.au/publications/rdp/2011/pdf/rdp2011-03.pdf.

Lee, B., 2007. Edge or edgeless cities? Urban spatial structure in US metropolitan areas, 1980 to 2000. J. Reg. Sci. 47 (3), 479–515.

Mills, E.S., 1967. An aggregative model of resource allocation in a metropolitan area. Am. Econ. Rev. 57, 197–210.

Mills, E.S., 1972. Studies in the structure of the urban economy. Econ. J. 6 (2), 151.

Moretti, E., 2004. Human capital externalities in cities. In: Henderson, J.V., Thisse, J.F. (Eds.), Handbook of Urban and Regional Economics, vol. 4. North-Holland, Amsterdam, pp. 2243–2291 ch. 59.

Muth, R.F., 1969. Cities and Housing. University of Chicago Press.

Naik, N., Kominers, S.D., Raskar, R., Glaeser, E.L., Hidalgo, C.A., 2015. Do people shape cities, or do cities shape people? The Co-evolution of physical, social, and economic change in five major U.S. Cities. NBER working paper 21620. http://www.nber.org/papers/w21620.

Ogawa, H., Fujita, M., 1980. Equilibrium land use patterns in a nonmonocentric city [J]. J. Reg. Sci. 20 (4), 455–475.

Parry, I.W.H., Walls, M., Harrington, C., 2007. Automobile externalities and policies. J. Econ. Lit. 45, 373–399.

Rivera-Batiz, F.L., 1988. Increasing returns, monopolistic competition, and agglomeration economies in consumption and production. Reg. Sci. Urban Econ. 18 (1), 125–153.

Rosenthal, S., Strange, W., 2004. Evidence on the nature and sources of agglomeration economies. In: Henderson, J.V., Thisse, J.F. (Eds.), Handbook of Urban and Regional Economics, vol. 4. North- Holland, Amsterdam, pp. 2119–2171 ch. 49.

Sridhar, K.S., 2010. Impact of land use regulations: evidence from India's cities. Urban Stud. 47, 1541–1569.

Wei, W., Zhang, W., Wen, J., Wang, J., 2020. TFP growth in Chinese cities: the role of factor- intensity and industrial agglomeration. Econ. Modell. 91 (issue C), 534–549.

Zhang, W., Kockelman, K.M., 2014. Urban Sprawl, Job Decentralization, and Congestion: the Welfare Effects of Congestion Tolls and Urban Growth Boundaries. Proceeding of the Transportation Research Board (TRB) 93rd Annual Meeting, Washington, DC, USA, pp. 12–16.