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Virtual built-up land transfers embodied in China's interregional trade

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Abstract

China’s vibrant interregional trade has widened the gaps between production and consumption, which transfers the pressure of built-up land resources caused by population expansion and supply/demand imbalances. This study comprehensively analyzes China’s built-up land use issues, considering the complex interregional trading network. Accordingly, the virtual built-up land transfers embodied in China’s interregional trade is illustrated, based on a multi-regional input-output analysis. In China, the national average of virtual built-up land intensity illustrates a downward trend. This demonstrates the effectiveness of the intensive built-up land utilization policies implemented in many parts of the country. Three economic regions of China with the most active trade activities (the Yangtze River Delta, Beijing-Tianjin-Hebei regions, and Guangdong Province) have attracted many virtual land flows to relieve the built-up land resource pressures caused by rapid economic development. These flows have mainly derived from neighboring provinces. Considering the detail virtual built-up land transfer profiles embodied in China’s interregional trade, policymakers must collaborate to formulate differentiated policies and optimize built-up land types that combine industrial structure and trade patterns.

1. Introduction

Approximately 29 % of the world’s land has been appropriated for agricultural or as built-up land to support human development (Costello et al., 2011). According to the latest Land-Use Alteration Survey (MLR, 2017), only 4.06 % of China’s total land area is used for built-up land. Although a relatively small proportion of the total available land, built-up land is connected to socio-economic activities. China's urbanization continues to grow at an unprecedented rate (United Nations, 2018), producing new challenges for environmental pollution, food security and public health (Chen, 2007; Guo et al., 2020; Hubacek et al., 2009). Simultaneously, the overexpansion of some urban areas has led to many social and natural problems, such as an increase in the floating population, traffic congestion, property bubbles, high living costs, and increased land waste (Li et al., 2018a). To avoid the negative impacts of land use transitions on the ecosystem, the government limits the spatial expansion of built-up land. However, these policies are challenged by an increasingly limited supply of land resources for development, increased demand for built-up land, and supply/demand imbalances. This raises new questions about the use of built-up land to meet China's growing production and consumption demand. The effective and rational allocation of built-up land is an urgent policy consideration.

The modern mode of the economic organization enables the supply and demand for resources to rebalance through the supply chain or trading network (Costanza, 1980). Indirect land use, related to consumption through trade flows, has attracted much attention in efforts to balance the supply and demand of land (Han and Chen, 2018; Weinzettel et al., 2013a; Wu et al., 2018). More specifically, globalization enhances collaboration among regions around the world through commodity, resource, and information flows (Ercin and Hoekstra, 2014; Skelton et al., 2011). In the worldwide division system, various regions act as "producers" or "consumers," partly separating production and consumption locations (Kanemoto et al., 2012; Lambin and Meyfroidt, 2011). Given the complex globalized economic network, cross-border trade in resource-intensive goods or services has become more prominent. As economic globalization intensifies, regional economic links are increasingly intertwined. Interregional trade increases the possibility of improving land use efficiency through regional specialization (Costello et al., 2011). As a result of differences in geographical location and different regional resources in China, interregional trade plays an increasingly important role in the transfer and relocation of hidden resources (Lambin and Meyfroidt, 2011). This is especially true for builtup land resources that facilitate the bulk of economic or industrial activity.

In an attempt to understand the regional transfer and relocation of resources, the multiregional input-output (MRIO) model is used to quantify the resource flow hidden behind complex trading networks. Numerous studies have used the MRIO model to analyze many virtual land, virtual water, embodied energy, embodied carbon emissions, and other factors that underlie interregional trade (Lenzen, 2009; Li et al., 2018b; Meng et al., 2018; Su and Ang, 2014; Wiedmann, 2009; Zhang et al., 2013). The concept of "virtual land", also known as "embodied land" (Hubacek and Feng, 2016), was first advanced by Würtenberger et al. (2006) and was defined as productive land areas embodied in traded goods or services. "Land footprint" refers to the sum of direct and indirect land occupancy in addition to the entire supply chain of goods or services (Bruckner et al., 2015; Weinzettel et al., 2013b). "Virtual land flow" means the regional transfer of virtual built-up land hidden behind the interregional trade,

Bicknell et al. (1998) proposed a modified form of input-output analysis (IOA) to estimate the land needed to support consumption demand for a particular population in New Zealand. Based on this research, Ferng (2001) calculated the virtual land for each land category using the composition of land multipliers. Lenzen and Murray (2004) expanded the research scale to multiple regions by establishing an MRIO model to calculate virtual land use in Australia. Many scholars in the field of virtual land use are now dedicated to applying the inputoutput (IO) model, usually using different scales to track land area occupancy through interregional supply chains (Guo et al., 2014, Guo et al., 2019a; Hubacek and Giljum, 2003; Würtenberger et al., 2006; Wilting and Vringer, 2009). For example, Costello et al. (2011) used an IO model to explore the links between lands embodied in production and consumption of certain goods in the United States. On the other hand, Wu et al. (2018) used IOA to calculate the arable land use of the global economy from the source of exploitation, through global supply chains, to the point of final consumption. Chen and Han (2015) revealed the effects of domestic demand and international trade on land use distribution in China, between 2002 and 2010. They considered multi-type land use, high-sectoral resolution, and time-series IO data. Guo and Shen (2015) constructed the MRIO model to simultaneously analyze China's use of agricultural land and water, which is embodied in consumption and interregional trade.

However, despite the breadth of such studies, built-up land is relatively overlooked. In fact, few studies focus on how growing crossborder trade affects the planning and utilization of built-up land. Current research on virtual built-up land is mainly conducted in the accounting for all types of land footprint in specific countries, such as China (Chu et al., 2017), the United States (Costello et al., 2011), Austria (Erb, 2004), Italy (Wackernagel et al., 1999), and the European Union (O'brien et al., 2015). For example, Erb (2004) calculated the demand for cultivated land, forestland, pasture land and built-up land in Austria in 1926–2000. In addition, in studies on China's virtual cultivated land, the relations between cultivated land and built-up land are also discussed (Qiang et al., 2013; Chen and Han, 2015; Wu et al., 2018). These studies attribute the loss of arable land in China to urban sprawl and built-up land occupancy. However, these studies use only built-up land as a part of their research objectives, and hence virtual built-up land use is not fully explained. "Virtual land" describes the total land occupancy by a specific economic activity, such as production, consumption and trade activity. Built-up land is highly relevant to the human's socio-economic system, but has received little attention. This study aims to bridge this gap and to systematically reveal China's virtual built-up land transfer embodied in interregional trade.

Therefore, this study uses high spatial resolution IO data to conduct a systematic embodiment analysis of land use in urban areas in China. In doing so, the way in which China's built-up land is used to meet domestic consumption and interregional trade requirements, based on the MRIO model, is closely examined. This study provides both a theoretical basis and supporting data to complement current land use policies from a consumption perspective. Finally, this study advances several policy proposals for the joint management of built-up land resources, based on the demonstrated understanding of virtual built-up land.

2. Data and methodology

2.1. Data

China publishes official annual land use data, based on land statistics data from all levels of government and a remote sensing image database from multi sources. Built-up land use data for 31 regions in China for 2007, 2010, and 2012 are provided in three China Land and Resources Statistical Yearbooks: 2008, 2011, and 2013 (MLR, 2008, 2011, 2013). According to these yearbooks, China’s built-up land use is categorized as follows: land for tertiary uses, land for industry and mining storage, land for administration and public services, land for transport, and land for water resources facilities.

China’s provincial single region input-output (SRIO) tables are published by the National Statistics Bureau every five years. However, compiling MRIO tables is challenged due to the difficulty in collecting and processing data. This is because interregional trade data are unavailable in China. The widely used MRIO table is compiled by researchers from the Chinese Academy of Science and China’s National Bureau of Statistics. They have published China’s MRIO tables in 2007, 2010, and 2012 (Liu et al., 2012, 2014a; Liu et al., 2018). The MRIO table includes 30 regions and 30 sectors in 2007 and 2010, and 31 regions and 42 sectors in 2012. Additionally, the interregional trade matrix is estimated using a gravity model (Erlander and Stewart, 1990). These MRIO tables are widely used to calculate various factors in China, including virtual land, virtual water, embodied energy, embodied carbon emissions, and embodied $PM_{2.5}$ emissions (Guo and Shen, 2015; Jiang et al., 2015; Liang et al., 2015; Zhang et al., 2013; Zhang and Anadon, 2014; Zhao et al., 2014). This study used the MRIO tables compiled by the scholars from the Chinese Academy of Science and China's National Bureau of Statistics for 2007, 2010, and 2012 because of the popularity and temporal continuity of this source.

2.2. Methodology

IOA is a top-down method of relocating resources or environmental emissions to final consumption through trade. This model combines regional resource endowment with the economic network and uses sector currency transaction volumes to explain the complex interdependence between industries in the modern economy (Larsen and Hertwich, 2009; Peters et al., 2011; Skelton et al., 2011). It determines the origin of resources and the ultimate direction of use in the intensive supply chain. This guides macro policy by quantifying the relationship between commodity production and material exchange between economic sectors (Wiedmann, 2009). To understand the regional transfer and relocation of built-up land resources, considering the differences in regional production technology and interregional trade connections, this study uses the MRIO model to connect regional characteristics and interregional built-up land use.

Based on the basic balance of IOA, the relationship of economic activities can be expressed as follows:

zrr + frr +∑ ∑zsr +fsr = xr

s r≠ s r≠ (1) where Z^{rr} represents the intermediate demand of region r derived from the local region, Z^{sr} indicates the intermediate demand of region r produced in region s, f^{rr} is the final demand of region r from the local economy, and f^{sr} is the final demand of region r from region s.

The transnational and cross-regional flows of production factors lead to the separation of production capacity and consumption demands. Land resource flows are integrated into the relevant economy

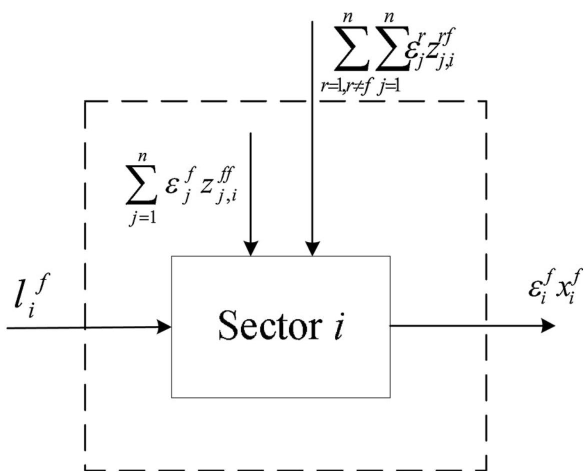


Fig. 1. The basic balance between sectoral built-up land flows.

through production, consumption, and trade activities. Given the industrial dependence between different economic regions, some regions import goods from others, which may shift the pressure on land resources from consumption regions to production regions. Specifically, land resources are occupied during the production process, transferred through interregional trade, and finally reach consumers in the form of final products. According to the balanced relationship of each entry's built-up land flows, as shown in Fig. 1, the basic resource balance can be obtained as follows:

$lif + \sum^{30} \sum^{30} \varepsilon^{r}_{j}{}^{rf} = \varepsilon zji \qquad if\, xif$

$r = =1\; j\; 1$ (2) where ε stands for the virtual built-up land intensity and r represents the direct built-up land use.

With regard to China's MRIO table, 900 entries are established by 30 regions, each comprising 30 sectors. This study then converts the balance equation into a matrix form, as follows (Eq. (3)):

$$R + \varepsilon Z = \varepsilon \hat{X}, \qquad (3)$$

in which the virtual land use intensity matrix $\varepsilon = [\varepsilon^{1}_{1}, \varepsilon^{1}_{2}, \ldots, \varepsilon^{1}_{30}; \ldots\ldots; \varepsilon_{1}^{30}, \varepsilon^{30}_{2}, \ldots, \varepsilon^{30}_{30}]^{T}$; and the direct land use matrix $R = [r^{1}_{1}, r^{1}_{2}, \ldots, r^{1}_{30}; \ldots\ldots; r_{1}^{30}, r^{30}_{2}, \ldots, r^{30}_{30}]^{T}$. Moreover, $\hat{X}$ is the diagonal matrix of the total output, that is:

$$\hat{X} = \begin{bmatrix} x11 & & & & & \\ & \cdots & & & & \\ & & x_{1}30 & & & \\ & & & \cdots\cdots & & \\ & & & & x^{1}_{30} & \\ & & & & & \cdots \\ & & & & & x^{30}_{30} \end{bmatrix}$$

and the intermediate IO matrix:

$$\left[\begin{pmatrix} z^{11}_{11} & \cdots & z^{11}_{130} \end{pmatrix} \begin{pmatrix} z^{130}_{11} & \cdots & z^{130}_{130} \end{pmatrix}\right]$$

$$
Z=\begin{pmatrix}
\begin{pmatrix} z_{11}^{11} & \cdots & z_{130}^{11} \\ \vdots & \ddots & \vdots \\ z_{3011}^{11} & \cdots & z_{3030}^{11} \end{pmatrix} & \cdots & \begin{pmatrix} z_{11}^{130} & \cdots & z_{130}^{130} \\ \vdots & \ddots & \vdots \\ z_{301}^{130} & \cdots & z_{3030}^{130} \end{pmatrix} \\
\vdots & \ddots & \vdots \\
\begin{pmatrix} z_{11}^{301} & \cdots & z_{130}^{301} \\ \vdots & \ddots & \vdots \\ z_{301}^{301} & \cdots & z_{3030}^{301} \end{pmatrix} & \cdots & \begin{pmatrix} z_{11}^{3030} & \cdots & z_{130}^{3030} \\ \vdots & \ddots & \vdots \\ z_{301}^{3030} & \cdots & z_{3030}^{3030} \end{pmatrix}
\end{pmatrix}
$$

Finally, the virtual land use intensity matrix ε can be calculated as:

$$\varepsilon = R(\hat{X} - Z)^{-1} \qquad (4)$$

To clarify environmental responsibility, this study compares the actual built-up land use and national built-up land footprint at the regional level. The production-based accounting principle focuses on actual built-up land use for local production activities. Contrastingly, the consumption-based accounting principle related to the built-up land resources that account for the final demand within the targeted research boundaries (Davis and Caldeira, 2010; Wiedmann, 2009). These two principles differ from the entity responsible for the environmental impact caused by the occupation of built-up land use.

Production-based built-up land use (BLP) is equal to the actual builtup land use and is expressed as follows:

$$BLP = \sum_{j} l \quad (5)$$

Consumption-based built-up land use (BLC) is the built-up land use embodied throughout community supply chains that are consumed as final demand in the targeted region. BLC is also called “built-up land footprint” and is expressed as follows:

$$BLC = \sum_{f} \varepsilon^{f} F^{fr}, \quad (6)$$

where Fj is the final consumption of Sector j.

The regional transfer of built-up land flows embodied in interregional trade plays an important role in redistributing built-up land resources. In the face of imbalance between supply and demand of built-up land and excessive expansion of urban built-up land, the balance of regional land use demand and supply, and the shortage and surplus of land use resources must be fully understood. Embodied land use in the trade balance (BLT) is an important indicator in assessing the regional transfer of built-up land flows.

BLT can be expressed as the difference between built-up land use embodied in export and import:

$$BLI = \sum_{f} \varepsilon^{f} T^{fr} \quad (7)$$

$$BLE = \sum_{f} \varepsilon^{f} T^{rf} \quad (8)$$

$BLT = BLE - BLI$ (9) where T^{fr} stands for the economic value of exports to other regions, and T^{rf} denotes the imports from other regions.

3. Results

3.1. Actual built-up land distribution

In 2007, China had 32.72 million hectares of built-up land, which is 3.44 % of the total national land area. This figure increased to 35.68 million hectares in 2010 and 36.91 million hectares in 2012, which is 3.72 % and 3.84 %, respectively. As shown in Fig. 2(a), the four regions with the largest built-up land areas are Shandong, Henan, Jiangsu, and Hebei, which accounted for over 2 million hectares in 2012. As for the share of built-up land in the total land area, Shanghai, Tianjin, and Beijing are at the forefront, with the built-up land in Shanghai accounting for 47.45 %, almost half of the total land area, in 2012.

China's average per capita built-up land area was 0.02 ha per capita in 2007 and 2010. This figure increased to 0.03 ha per capita in 2012. As shown in Fig. 2(b), the per capita built-up land area tends to decrease from East to West China. Regions with large per capita built-up land areas are usually undeveloped, such as Xinjiang, Inner Mongolia, Qinghai, and Ningxia. With large built-up land areas and small populations, Xinjiang and Inner Mongolia had the largest per capita built-up land area in 2007, 2010, and 2012. Contrastingly, regions with small per capita built-up land areas tend to be developed regions with dense populations, such as Shanghai, Fujian, and Guangdong.

Fig. 3 shows the annual increase in the built-up land area between 1999 and 2016. A tremendous increase was observed from 82,600 ha to 615,220 ha before 2012. However, China's built-up land area gradually

(a) The proportion of built-up land

(b) Per capita built-up land areas

Fig. 2. Actual built-up land cover distribution in China (2007–2012).

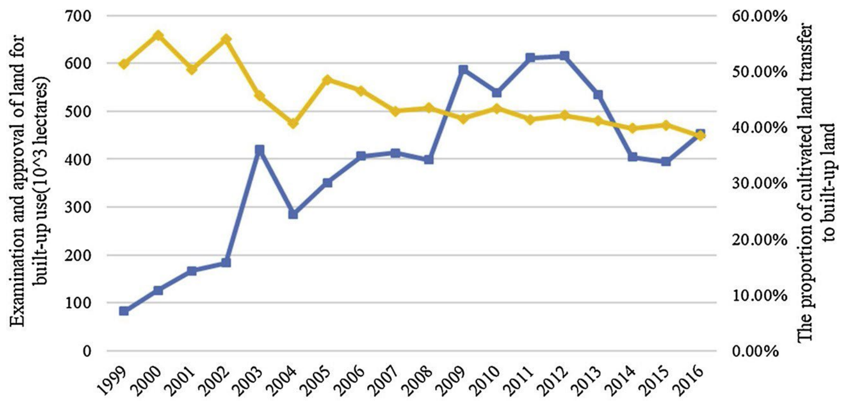


Fig. 3. The annual increased built-up land use.

Note: The blue line depicts the annual increase in built-up land examined and approved by the government. The yellow line describes the proportion of cultivated land converted to built-up land.

decreased between 2012 and 2016, from 615,220 ha to 452,750 ha. Newly built-up land in China was mainly taken from cultivated land, as demonstrated in Fig. 3. The proportion of cultivated land transferred to built-up land initially decreased from 51.31 % in 1999 to 42.85 % in 2007. After fluctuating between 1999 and 2007, the value leveled off at about 40 % between 2007 and 2012, and gradually decreased over the next four years. Evidently, the Chinese government is striving to control the total amount of built-up land by reducing the share of cultivated land converted into built-up land. Compared to other regions, China has the greatest rate of change in the built-up land area between 2000 and 2017 amounting to 18.03 %.

3.2. National built-up land footprint "Virtual built-up land" refers to the direct and indirect built-up land resources engaged in economic activities. We use the index of "built-up land use intensity” to account for virtual built-up land areas required, to calculate the unit of the economic value of a commodity or service. Fig. 4 shows the regional virtual built-up land use intensity. The national average of virtual built-up land intensity tends a decrease: a decline from 0.74 ha per million yuan in 2007 to 0.51 ha per million yuan in 2010, and 0.57 ha per million yuan in 2012. Additionally, there were fewer regions above the national average and more regions below the average in 2012 than in 2007 and 2010. These figures show that the intensive built-up land utilization policies implemented in many parts of China have taken effect.

Fig. 5 shows the relationship between regional economic development and built-up land use intensity. The virtual built-up land use intensity has a negative correlation with economic development, which may be affected by the socio-economic properties of the built-up land. The regions with the lowest virtual built-up land use intensity are economically developed eastern coastal provinces, such as Zhejiang, Shanghai, Guangdong, and Beijing. In these areas, the populations are large, and efficiency in the use of built-up land alleviates the pressure of the per capita shortage. As shown in Table 1, the region with the highest intensity is Qinghai, with 2.23, 1.58, and 1.24 ha per million yuan in 2007, 2010, and 2012, respectively. Regions located in North and West China, such as Gansu, Xinjiang, Heilongjiang, and Inner Mongolia, also have higher virtual built-up land use intensity. In these areas, the per capita built-up land areas are large, but built-up land efficiency is relatively low.

As shown in Fig. 6, China had a built-up land footprint value of

18.41 million hectares in 2007, 21.55 million hectares in 2010, and 25.60 million hectares in 2012. This increase was due to an adjustment in consumption structure and an increase in infrastructure investment. With large built-up land areas and increasing consumption and investment, Henan, Shandong, Jiangsu, Guangdong, and Sichuan have the largest built-up land footprint in the country of more than a million hectares. Contrastingly, regions with fewer built-up land areas, including Tianjin, Guizhou, Qinghai, Hainan, and Ningxia, have the smallest values.

There is a positive correlation between the actual built-up land areas and built-up land footprint in some regions, as shown in Fig. 6. For example, Shandong, Henan, Guangdong, Jiangsu, and Sichuan have numerous actual built-up land areas and a high built-up land footprint. On the other hand, in Tianjin, Guizhou, Qinghai, Hainan, and Ningxia, there are few actual built-up land areas and a low built-up land footprint. Therefore, there is a strong consistency between the regional distribution of the actual built-up land areas and the built-up land footprint. Compared with other land use types, such as cultivated, forest, and pasture land—this consistency indicates that the allocation of built-up land resources has achieved a supply/demand balance. Regions with large actual built-up land areas, such as Shandong, Henan, Jiangsu, and Sichuan, all have a large population. This is partly because the distribution of built-up land is closely related to population density. For human production (especially the secondary and service industries) and for life, built-up land is essential for hosting human settlements and responding directly to human needs. High-density populations lead to increasing regional consumption demands, which lead to the occupation of virtual built-up land. In contract, for the regions with the low values of actual and virtual built-up land areas, terrain conditions and level of economic development become important factors restricting virtual built-up land areas. For example, Guizhou, Qinghai, and Ningxia are located in western China, where population densities and consumption levels are low. Tianjin and Hainan also have small built-up land areas and maintain a low level of built-up land use intensity by the development of the service industry. Because of high utilization efficiency and low consumption demand, these areas do not occupy much virtual built-up land.

3.3. Regional virtual built-up land transfers

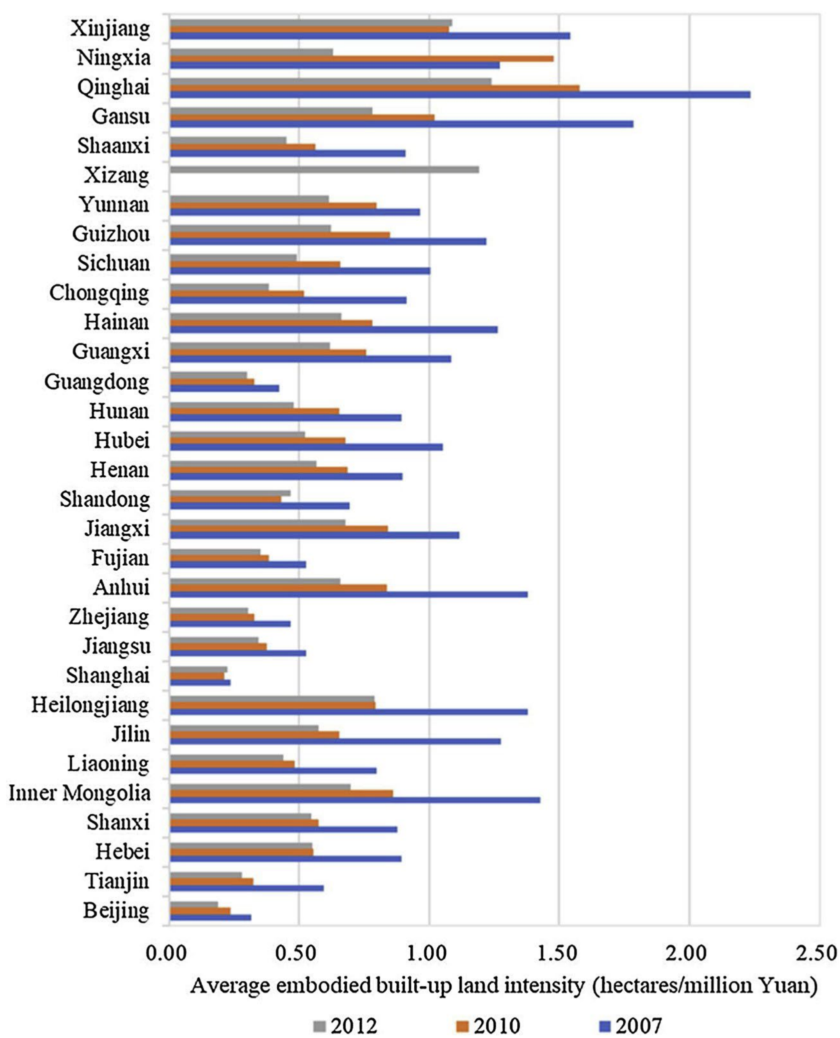


Fig. 4. Regional virtual built-up land intensity (2007–2012).

Fig. 7 shows the regional transfer of virtual built-up land flows, based on the indicator of China's built-up land embodied in the trade balance. Trade leads to the transfer of virtual land. To clearly compare the regional transfer of virtual built-up land flows, regions with positive BLT values are defined as built-up land resource suppliers, and regions with negative values are defined as built-up land resource receivers. The eastern coastal regions, including Guangdong, Shanghai, Zhejiang, Beijing, Jiangsu, Tianjin, and Fujian, serve as receivers of built-up land resources. Most inner areas, such as Hebei, Inner Mongolia, Anhui, Heilongjiang, and Henan, are suppliers of built-up land resources. Consequently, developed regions occupy a substantial amount of the built-up land of other regions by transferring low-end industries across borders. On the other hand, the suppliers of built-up land are mainly located inland and face the pressures of industrial transformation and modernization.

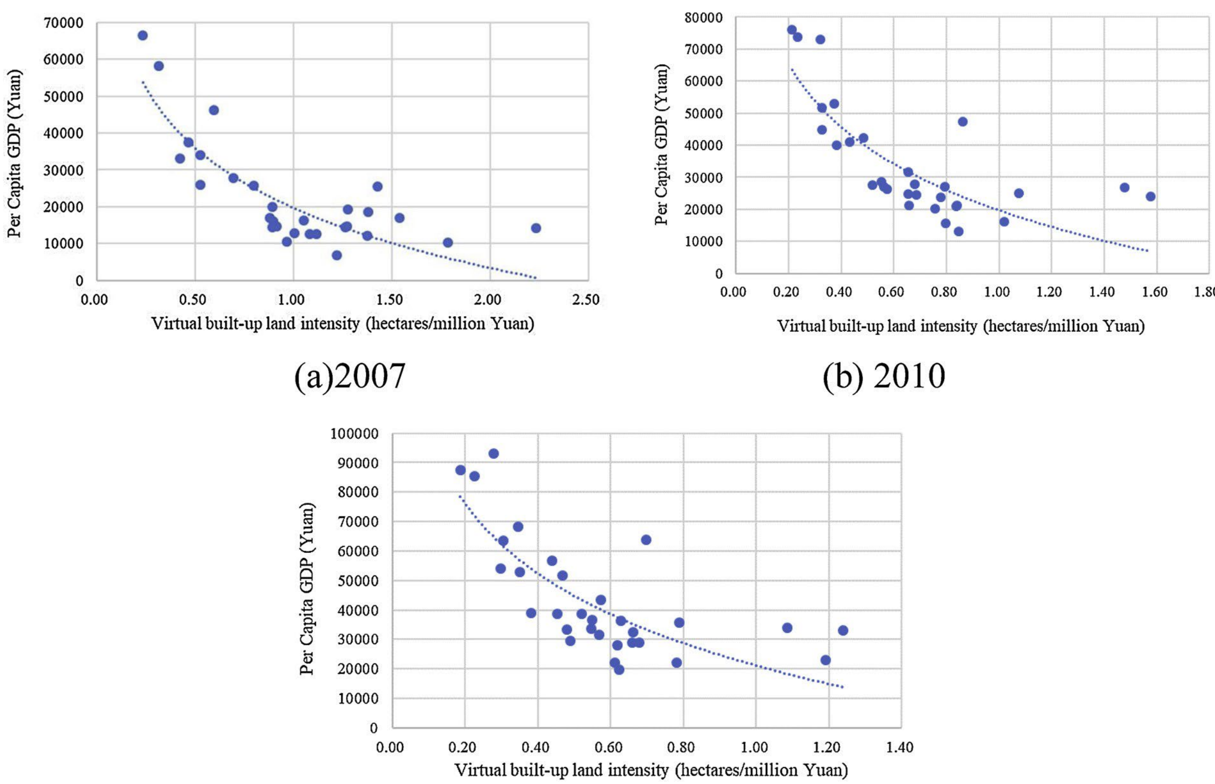
Regional roles are partially shaped by their natural conditions, such as regional topography, altitude, and climate. These geographical conditions limit the development of built-up land. Industry structure, policy, and development play a significant role in determining whether a region is a supplier or a receiver. Indeed, this role may change. For instance, regions in southwestern China have accelerated economic development by encouraging the development of some use-intensive industries, resulting in a change of their role. In 2007 and 2010, Chongqing, Sichuan, Shanxi, Ningxia, and Guizhou served as suppliers. In 2012, these regions became receivers. Nonetheless, most regional roles remained unchanged between 2007 and 2012. For example, located on the east coast, and rich in land resources, Hebei Province exports substantial built-up land resources to other developed regions, such as Beijing, Tianjin, Shanghai, Jiangsu, and Zhejiang. Hebei's role as a supplier is largely due to its irrational industrial structure, which is reliant on heavy industries, such as the steel industry.

Fig. 8 shows the major virtual built-up land flows embodied in interregional trade in 2007, 2010, and 2012, with the values exceeding 0.04 million hectares. Some of the most active trade regions in China, that is, the Yangtze River Delta, Guangdong Province, and BeijingTianjin-Hebei region, attract a significant amount of virtual built-up land flows originating from nearby provinces. The Yangtze River Delta is China's largest economic area. With the highest volume of total imports and exports in the country, the Delta's GDP accounts for 20 % of China's total output. Amid the trend of globalization, resource reallocation is strongly affected by economic flows. As the most developed region in China, the Yangtze River Delta received huge built-up land flows from neighboring provinces, including Henan, Anhui, Shandong, Jiangxi, Hebei, and Inner Mongolia. With the greatest GDP of China's provincial regions, Guangdong attracted a significant amount of virtual land flows from Guangxi, Hunan, and Yunnan in 2007 and 2010, and from Shandong, Inner Mongolia, and Hebei in 2012. As the core of the Beijing-Tianjin-Hebei region, Beijing and Tianjin received a large number of built-up land flows from Hebei and Inner Mongolia. These three regions share two characteristics: a highly developed trading economy and abundant built-up land resources. Despite the fact that these three economic regions possess a substantial amount of highquality land resources, they still occupy virtual land resources from neighboring regions to relieve the resource pressures resulting from rapid economic development.

4. Discussion

4.1. The impact of urbanization on virtual built-up land transfers

Involving the aggregation and growth of an urban population, urbanization is an important



(c) 2012

Fig. 5. The relationship between virtual built-up land intensity and per capital GDP (2007–2012).

indicator in measuring urban development. As most labor force capital goods accrue in cities, demands for built-up land have increased. Consequently, it is necessary to discuss how to satisfy the growing demand for built-up land necessary for production and livelihoods. This section discusses the impact of urbanization on virtual built-up land transfer.

Currently, the impact of urbanization on built-up land use mainly includes the built-up land use quantity (Deng et al., 2015; Li et al., 2018a; Wu and Zhang, 2012), structure (Deng et al., 2009; Jiang et al., 2017), efficiency (Chen et al., 2016; Zitti et al., 2015), expansion pattern (Chen et al., 2009; Jiang et al., 2016; Long et al., 2014) and its environmental impact (Ali and Nitivattananon, 2012; Chuai et al., 2015; Lai et al., 2016; Zhu et al., 2019). For example, based on the spatial analysis of RS and GIS, Wu and Zhang (2012) find that built-up land expands in the process of urbanization, especially the urban occupation of natural land. Population growth and economic expansion

Table 1

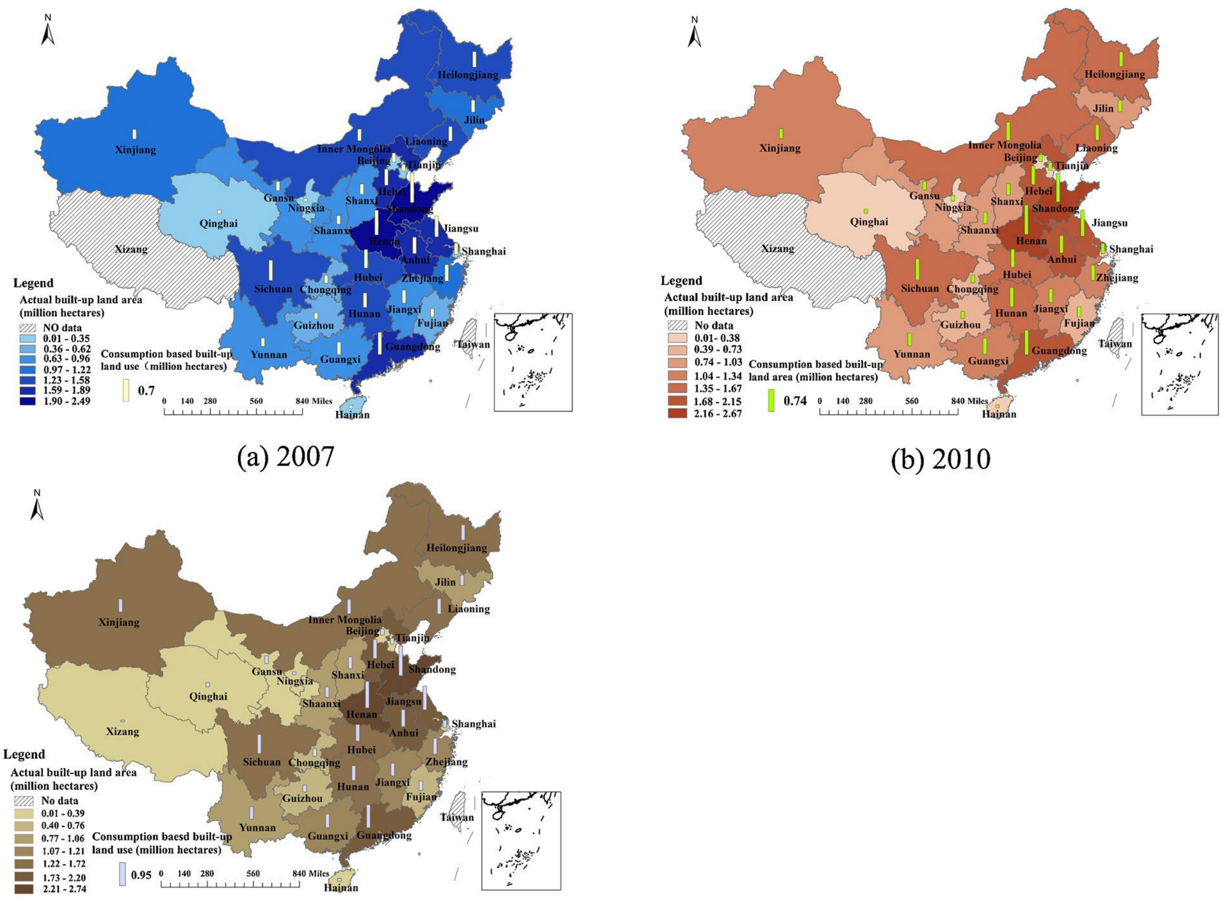
	Region	Intensity (hectares/ million Yuan)	Per capita GDP ranking	Region	Intensity (hectares/ million Yuan)	Per capita GDP ranking	Region	Intensity (hectares/ million Yuan)	Per capita GDP ranking
Highest									
1	Qinghai	2.23	23	Qinghai	1.58	22	Qinghai	1.24	21
2	Gansu	1.78	29	Ningxia	1.48	17	Xizang	1.19	28
3	Xinjiang	1.54	14	Xinjiang	1.08	19	Xinjiang	1.09	18
4	Inner Mongolia	1.43	10	Gansu	1.02	28	Heilongjiang	0.79	17
5	Heilongjiang	1.38	13	Inner Mongolia	0.86	6	Gansu	0.78	30

Lowest									
1	Shanghai	0.24	1	Shanghai	0.21	1	Beijing	0.19	2
2	Beijing	0.31	2	Beijing	0.23	2	Shanghai	0.22	3
3	Guangdong	0.42	6	Tianjin	0.32	3	Tianjin	0.28	1
4	Zhejiang	0.47	4	Zhejiang	0.33	5	Guangdong	0.30	8
5	Fujian	0.53	8	Guangdong	0.33	7	Zhejiang	0.30	6
Year	2007			2010			2012		

The highest and lowest regional virtual built-up land use intensity (2007–2012).

are the key drivers of land use and land-cover change in the process of global urbanization. Siciliano (2012) confirms that China's urbanization strategy encourages changes in land use structure. Deng et al. (2009) find that, in the urbanization process, the landscape pattern in China experienced a fundamental transformation: from an agriculturally dominant landscape to one dominated by urban built-up land. Chuai et al. (2015) show that urban land has the highest concentration and intensity of carbon emission, mostly contributed to by the conversion of cultivated land to built-up land.

This study provides new insight into the connection between urbanization and built-up land.



(a) 2007 (b) 2010 (c) 2012

Fig. 6. Built-up land use embodied in the final consumption (2007–2012).

Note: Shading represents the actual built-up land use, while the column represents embodied built-up land use.

The focus is on exploring the relationship between urbanization development level and virtual built-up land flows. The results show that urbanization promotes virtual built-up transfers. This may be because urbanization leads to economic, social, production, and lifestyle changes through the aggregation of human, capital, technology, and other factors (Zhang et al., 2014; Guo et al., 2019b). Urbanization increases the demand for food, energy, and public services (Jiang and Lin, 2012) to attract more built-up land flows.

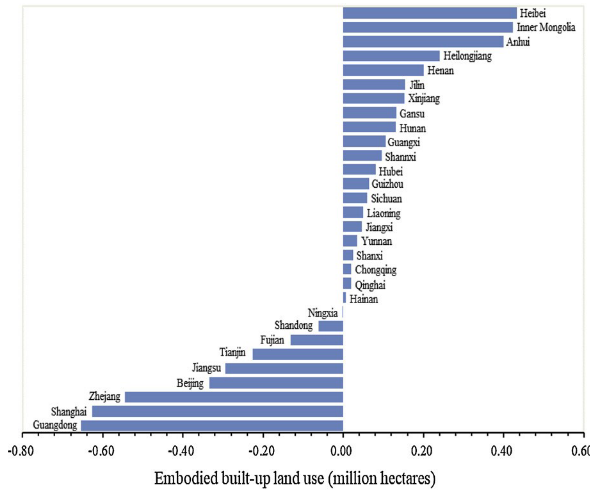
Fig. 9 depicts the relationships between the virtual built-up land flow and urbanization rate. An urbanization rate above 50 % means that the urban population is larger than the rural population. The net built-up land resource importers are generally regions with higher urbanization rates (i.e., > 50 %), such as Shanghai, Beijing, Tianjin, Guangdong, Zhejiang, and Jiangsu. However, Inner Mongolia, Heilongjiang, Jilin, and Liaoning, with higher urbanization rates, still need to export plenty of built-up land resources across boundaries. This indicates the need for an industrial adjustment. As the old industrial base, Northeast China is an example of this pattern, which is necessary for modernizing technologies and for adjusting the structure of the industry. As important trading provinces, Fujian and Shandong depend on the import and export of goods and services to develop their economies. They both have a slightly lower urbanization rate (i.e., slightly less than 50 %) but import a large number of built-up land resources via interregional trade. The different built-up land transfer patterns exhibit the characteristics of urban development in different stages. Provinces with lower urbanization rates need to set clear development goals and follow the direction of developed regions, in order to adjust the role of suppliers of built-up land resources accordingly.

An analysis of demographics from 2007 and 2012 shows that, by optimizing trade structures, China's urbanization rate increased significantly, and the efficiency of overall resource utilization improved over the five-year period. A comparison of the data from 2007, 2010, and 2012 revealed two phenomena. First, some provinces with an urbanization rate below 50 %, including Sichuan, Guizhou, Shanxi, and Shannxi, gradually reduced their supply of built-up land to other regions. Second, several provinces, including Chongqing, Yunnan, and Guangxi, have transformed into built-up land resource receivers by optimizing their trade structures. Overall, the built-up land utilization efficiency in the country was improved by the adjustment of industrial and trading structure, from 2007 to 2012.

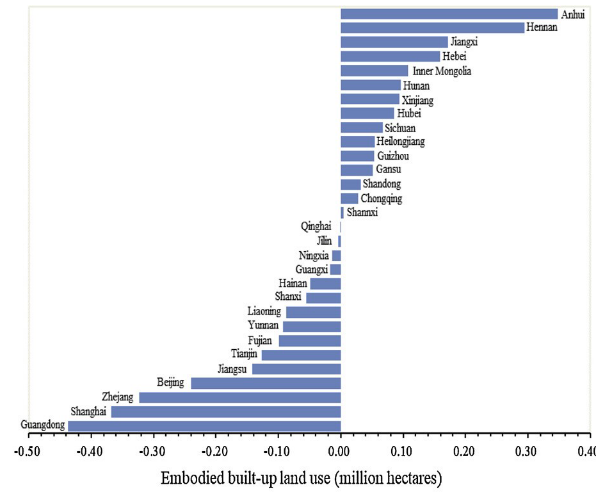
4.2. Policy implications

As a space in which humans work and live, built-up land is an important indicator that affects sustainable development. China is experiencing rapid industrialization and urbanization, and this process is accompanied by a rapid increase in land use for construction. This is particularly true for developed coastal regions (Lei, 2014; Wang et al., 2012; Zhao et al., 2011). China still faces numerous existing land use issues, including structural imbalance, overexploitation, ineffective utilization, and the inconsistencies between supply and demand (Chen et al., 2016; Guan-Yin et al., 2010; Shen and Zhou, 2014).

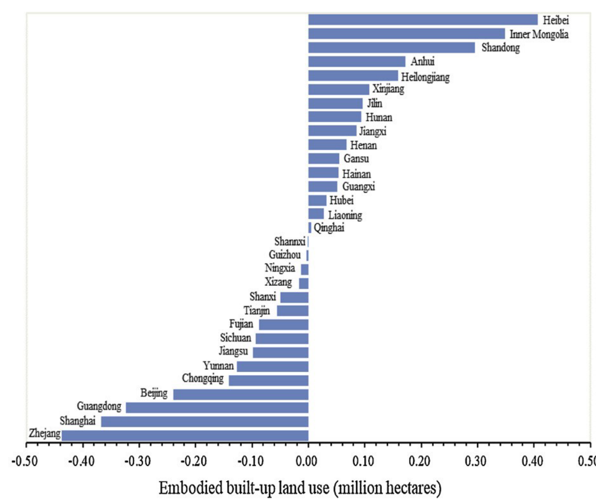
Consequently, the Chinese government has established a principle of intensive use of built-up land, based on a top-down design (Ding, 2003; Liu et al., 2014b). In 2016, the Outline of the 13th Five-Year Plan for China's land resources advanced dual control measures for the



(a) 2007



(b) 2010



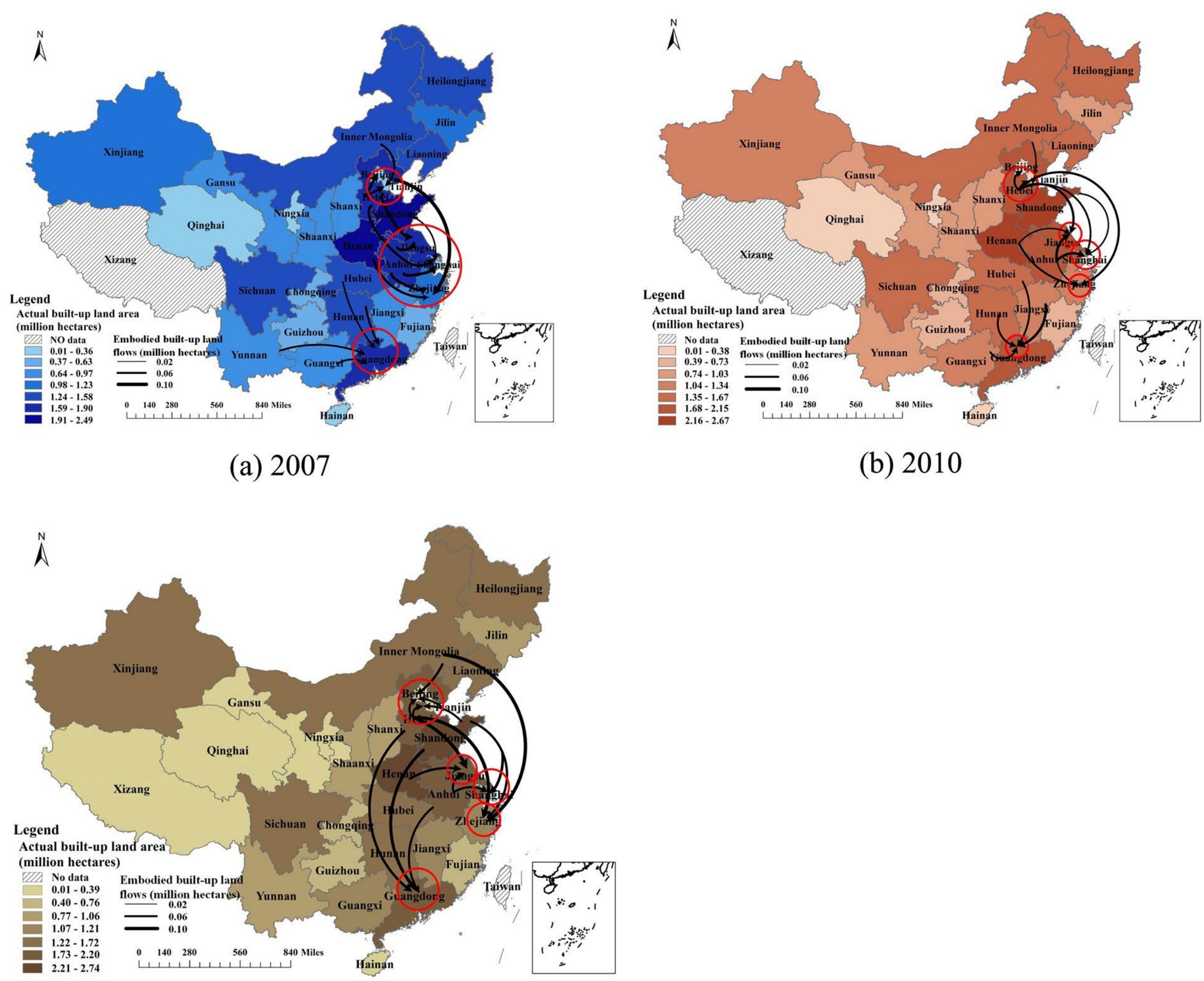
(c) 2012

Fig. 7. Built-up land embodied in the trade balance (2007–2012).

total amount of built-up land and land use intensity. Specifically, the plan required that the total newly added built-up land be controlled at 2.17 million hectares by 2010, which is 446.00 thousand hectares less than stipulated in the 12th five-year plan covering 2012–2017. The plan provides for a 20 % reduction in the built-up land areas for per unit of GDP, and ensure an annual rate of decline of at least 4.36 %.

In addition, as shown in Fig. 3, given that the newly built-up land in China was mainly drawn from cultivated land, the Chinese government has also strengthened the protection of cultivated land and established a stringent agricultural land protection system. "Outline of National Land Use Master Plan (2006–2020)" requires that China has no less than 124.33 million hectares of cultivated land by 2020. Additionally, the government aims to ensure permanent and protected basic agricultural land of at least 103.07 million hectares by 2020. This includes establishing 53.33 million hectares of high-standard agricultural land, with plans for a further 66.67 million hectares. Concerning cultivated land, a "requisition-compensation balance" land use policy has been established, which is the compensation policy for the occupation of cultivated land. Local governments need to supplement the same quantity and quality of cultivated land through land development and land reclamation if cultivated lands are occupied by construction. Considering that land reclamation is costly financially and in terms of human and physical resources, this requisition/compensation balance will partially and effectively control the growth of built-up land and prevent the occupation of cultivated land.

Achieving these goals requires collaboration at all levels of government to control the development of areas, activate stock, optimize the structure, and improve land use efficiency (Huang et al., 2014; Long et al., 2012). Additionally, the central government has established an "increasing versus decreasing balance" land use policy that seeks to balance the increase in urban built-up land by reducing rural built-up land. However, the current built-up land regulation strategy fails to distinguish regional consumption responsibility (Tao et al., 2015; Ying, 2012). Instead of rational planning based on scientific evaluation, the central government reallocates built-up land management tasks to provinces by setting mandate targets through administrative negotiations (Qian, 2013; Xiao, 2012). This is due to the lack of scientific foundation and data support. This study provides a theoretical basis and supporting data to supplement current land use policies in terms of perspective. This will help reduce the regional imbalance of built-up land use and contribute to the coordinated development of the regional economy. The specific policy directions proposed in this study can be summarized in two points.



(a) 2007 (b) 2010 (c) 2012

Fig. 8. Major virtual built-up land flows in interregional trade (2007–2012).

Note: The direction of the arrow represents the virtual land flow direction, while the width of the arrow shows the size of the virtual land flow.

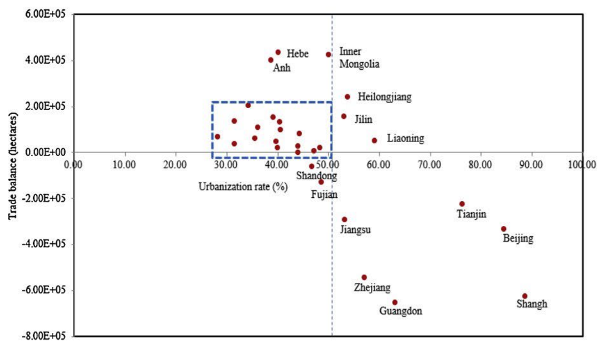
First, this study provides a scientific foundation for the Chinese government to optimize the structure of built-up land use by implementing differentiated control policies according to the different roles played by regions in achieving the overall supply/demand balance. As shown in Figs. 6 and 7, considerable built-up land flows are embodied in interregional trade. Built-up land receivers, such as Beijing, Tianjin, Guangdong, and the Yangtze River Delta, require a large amount of virtual built-up land resources from nearby provinces to support their final consumption. These developed regions are therefore responsible for promoting sustainable development of the surrounding areas by providing financial and technical support. Builtup land suppliers, such as Hebei, Shandong, Anhui, and Inner Mongolia, rely heavily on industrial and mining storage land to develop heavy industries. As such, these regions need to upgrade their industrial structure and strengthen the development of the tertiary industry. In short, all regional governments need to cooperate to achieve sustainable built-up land use in China.

Second, this study provides policy suggestions based on understanding the virtual built-up land flows. As shown in Figs. 4 and 5, virtual built-up land use intensity is relatively high, especially in Qinghai, Gansu, Xinjiang, Inner Mongolia, and Heilongjiang. China's massive built-up land use embodied in final consumption indicates the importance of protecting scarce built-up land resources, improving the efficiency of built-up land use, and revitalizing the stock of built-up land to encourage economic and intensive use.

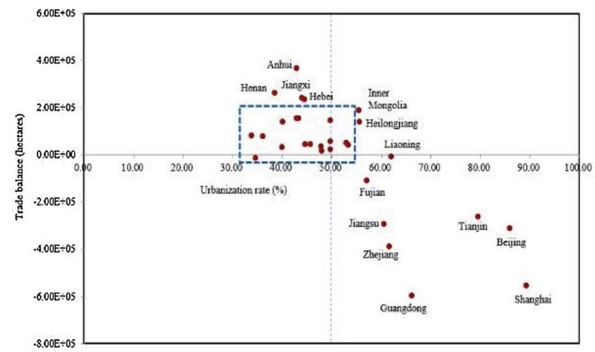
Based on the understanding of virtual land resources, this study provides the following policy suggestions concerning the conservation of scarce built-up land resources. Virtual land can be used as a supplementary indicator to measure the intensity of use and total demand of regional built-up land resources, which indicates the pressure of built-up land use faced by a region. As shown in Fig. 4, the intensity of virtual built-up land use is high, especially in Qinghai, Gansu, Xinjiang, Inner Mongolia, and Heilongjiang. At the same time, these areas have less built-up land. Therefore, the most direct land protection policy implemented by the local government focus on increasing built-up land use intensity. The current state of extensive land resource use requires a change to improve the efficiency and implementation of the intensive and economical utilization of land resources. Fig. 5 shows the total amount of built-up land use embodied in final consumption. Areas with high consumption demand, such as Henan, Shandong, Jiangsu, Guangdong, and Sichuan, also have abundant actual built-up land resources. Making full use of the existing built-up land resources should be a key policy focus in these areas.

4.3. Study limitations

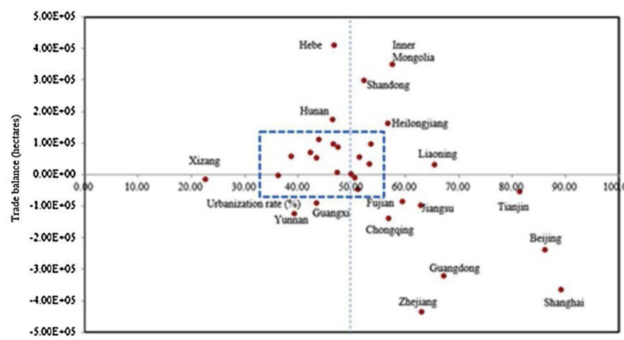
This study has some limitations in evaluating China's virtual builtup land use that can be



(a) 2007



(b) 2010



(c) 2012

Fig. 9. Relationships between the virtual built-up land transfers and urbanization rate (2007–2012).

Note (a): The regions in the blue box include Shanxi, Jiangxi, Henan, Hubei, Hunan, Guangxi, Hainan, Chongqing, Sichuan, Guizhou, Yunnan, Shannxi, Gansu, Qinghai, Ningxia, and Xinjiang.

Note (b): The regions in the blue box include Shanxi, Jilin, Shangdong, Hubei, Hunan, Guangxi, Hainan, Chongqing, Sichuan, Guizhou, Yunnan, Shannxi, Gansu, Qinghai, Ningxia, and Xinjiang.

Note (c): The regions in the blue box include Shanxi, Jilin, Anhui, Jiangxi, Hubei, Henan, Hainan, Sichuan, Guizhou, Shannxi, Gansu, Qinghai, Ningxia, and Xinjiang.

resolved through future research. The first limitation concerns the methodological approach.

This study assumed that "imported goods/services have the same virtual land intensities as domestic ones because of the limitation of IO economic data, though the imported commodities show a substantial difference from domestic ones." (Guo et al., 2014) The second limitation arises from the restricted amount of available data. Built-up land use data come mainly from the statistics provided by all levels of the Chinese government, which may include some human errors, caused by differences in human perceptual and cognitive abilities. To improve the data quality, China's third National Land Investigation, organized by the State Council since 2017, has applied heavily remote sensing datasets. The third limitation is the lack of empirical analysis exploring the mechanism of the interregional interaction mechanism of virtual built-up land transfer in China. This study mainly focuses on how built-up land meets China's various domestic needs through interregional trade. Based on the results of this study, further studies can, through empirical analysis, explore the driving factors of virtual built-up land transfer. Additionally, considering the correlation and difference of spatial coupling, the key nodes, critical paths and important industrial carriers of the virtual built-up land flows must be identified. The main driving factors behind the mismatch between supply and demand of China's virtual built-up land also need to be analyzed by using a decomposition analysis model. The way to form a unique sustainable land development pattern among the major urban agglomeration is the focus of future research. We believe that, as data quality improves, future research on virtual built-up land use will be more accurate and detailed.

5. Conclusions

With the acceleration of urbanization in China, the demand for built-up land has increased dramatically. On the other hand, the excessive expansion of some cities has resulted in a significant waste of built-up land resources (Liu et al., 2018). The effective use and rational allocation of built-up land in China, therefore, requires urgent attention. This study addresses the gap by demonstrating how China's builtup land meets various domestic needs through interregional trade. To achieve this, this study uses an MRIO model to analyze and compare China's actual built-up land distribution, built-up land footprint, and virtual built-up land transfer in 2007, 2010, and 2012. Thus, the results reveal the following concerning China's built-up land footprint and virtual built-up land transfers.

First, the national average virtual built-up land intensity shows a downward trend, decreasing from 0.74 ha per million yuan in 2007 to 0.51 ha per million yuan in 2010, to 0.57 ha per million yuan in 2012. On the other hand, the built-up land footprint increased from 18.41 million hectares in 2007 to 25.60 million hectares in 2012. Thus, this study demonstrates that the built-up land footprint is positively related to the actual built-up land areas, proving that the current allocation of built-up land resources in most regions of China is reasonable.

Second, a large number of virtual built-up land flows in developing regions are transferred to meet the needs of the rapid development of developed regions. Three of the most active economic regions of China, namely, the Yangtze River Delta, Beijing-Tianjin-Hebei region, and Guangdong Province, have attracted a great deal of virtual land flows to relieve the built-up land resource pressures caused by their rapid economic development. These virtual land flows mainly come from nearby provinces and, thus, developed regions occupy a substantial amount of the built-up land in regions beyond their boundaries through the transfer of their own low-end industries. Additionally, the suppliers of built-up land are mainly located inland and face their own pressures concerning industrial transformation and modernization.

These findings will help policymakers cooperatively formulate differentiated policies based on the characteristics of built-up land use in various regions. Additionally, the supporting data provided by this study should aid the collaborative optimization of China's built-up land. Improvements in land use data quality and IO models will extend future research on virtual land on a spatial and temporal scale, providing a stronger foundation for policy planning.

Declaration of Competing Interest

Authors have no conflicts of interest to declare.

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