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Quantifying Urban Fragmentation under Economic Transition in Shanghai City, China

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Abstract: Urban fragmentation affects sustainability through multiple impacts on economic, social, and environmental cost. Characterizing the dynamics of urban fragmentation in relation to economic transition should provide implications for sustainability. However, rather few efforts have been made in this issue. Using the case of Shanghai (China), this paper quantifies urban fragmentation in relation to economic transition. In particular, urban fragmentation is quantified by a time-series of remotely sensed images and a set of landscape metrics; and economic transition is described by a set of indicators from three aspects (globalization, decentralization, and marketization). Results show that urban fragmentation presents an increasing linear trend. Multivariate regression identifies positive linear correlation between urban fragmentation and economic transition. More specifically, the relative influence is different for the three components of economic transition. The relative influence of decentralization is stronger than that of globalization and marketization. The joint influences of decentralization and globalization are the strongest for urban fragmentation. The demonstrated methodology can be applicable to other places after making suitable adjustment of the economic transition indicators and fragmentation metrics.

Keywords: urbanization; urban fragmentation; economic transition; urban sustainability

1. Introduction

Our planet is contemporarily an urbanizing world [1]. A number of megacities, which denote a metropolitan area with a population over 10 million, emerged in Asia [2,3]. However, Asian megacities develop in an uncontrolled manner, posing great threats to urban sustainability [4]. Megacity development typically involves two processes, namely expansion and fragmentation [5,6]. Expansion denotes the physical growth of urban land areas. It provides a baseline to describe the magnitude and scope of urban development. Fragmentation refers to the morphological changes (e.g., irregularity and complexity) of urban land patches and their dispersion in space [7]. This concept of fragmentation is proposed on the assumption that the optimum functions of urban systems (e.g., production efficiency and ecosystem protection) are highly correlated with the spatial arrangement of urban land [7]. Urban fragmentation affects sustainability through multiple impacts on economic, social, and environmental cost [8]. Several studies have explored sustainability in relation to urban fragmentation, and they demonstrate that irregularity and dispersion can result in low efficiency of land use [9,10]. Urban fragmentation can also decrease the economic returns of land use and therefore lower the incentives for planners [11,12]. In addition, many observations have evidenced that the efficiency of urban land is the key direct drivers of ecosystem service degradation and habitat isolation [13,14]. Consequently, the fragmentation process should be investigated in order to provide a comprehensive set of land use indicators to support urban sustainability [7].

However, previous studies usually focus on the expansion process and the fragmentation process is largely ignored.

The specific geographical, political and socioeconomic context should be considered in the investigation of urban fragmentation, given that urban development is not uniform in its occurrence [4]. The dramatic economic transition in China provides a unique example to study urban fragmentation [15]. After 1993, the whole nation underwent a fundamental transformation from socialism to a market economy [15]. Local government is granted authority to approve land use by the land market reform [16]. Land subsequently becomes one of the most essential instruments to accumulate wealth and establish public facilities and infrastructures for the local states [17]. Economic restructuring is also enhanced by the globalization, given China's rapid mixing into the world economic system [18]. Driven by these factors, urban land expands in China at an accelerating pace [19]. However, due to the absence of scientific guidance, urban development usually occurs in a disorderly way and presents a fragmented pattern. Recent literature has seen growing efforts in employing remote sensing to characterize urban expansion in the context of China's economic transition [3,20–22]. However, few cases have quantified urban fragmentation in relation to economic transition.

Against the above backdrop, this paper attempts to quantify urban fragmentation in relation to economic transition. Using the case of Shanghai (China), the specific objectives are to: (1) characterize the fragmentation process within Shanghai city across time; (2) analyze the dynamic characteristics of economic transition in Shanghai; and (3) quantify the relationships between urban fragmentation and economic transition.

2. Materials and Method

2.1. Study Area

The Shanghai city is located is the middle part of the Chinese eastern coast, where the Yangtze River empties into the East China Sea (Figure 1). It borders with the Jiangsu and Zhejiang Province. These three regions constitute the Yangtze Delta Economic Zone, the most developed area in China. It covers about 6300 km^2, extending from 30°40′ N to 31°53′ N and from 120°52′ E to 122°12′ E. Shanghai City is the largest one by population in China, and the largest one in terms of urban population proportion (89.8% in 2012) in the world. As the commercial and financial center of China, Shanghai is the fastest urbanizing megacity in China during the last few decades. Its gross domestic product (GDP) saw annual double-digit growth between the 1990s and 2000s. The total population experienced a net growth of approximate 10 million from 1952 and 2012. Besides, the peri-urban areas experienced intensive low-density urban expansion, generating a disorderly and fragmented pattern. Shanghai city provides a useful case to analyze the urban fragmentation in response to economic transition.

2.2. Data Source and Processing

Time-series Landsat and CBERS (China–Brazil Earth Resources Satellite) images are used for extracting the urban land information from 1994 to 2013 within Shanghai city. This specific temporal interval is chosen given the start point of market transformation in 1993 and data availability. The images are then visually interpreted by delineating the boundaries of urban land polygons. Visual interpretation is performed because previous studies demonstrate that machine based algorithms are limited to extract accurate information from images of coarse resolution [13–15]. Accuracy assessment is performed by using field survey data and randomly selected points from the original images. The overall accuracy statistics for each year are all higher than 90%. In order to provide an overall view, three years (first, middle, and last) of urban land use maps are shown in Figure 1.

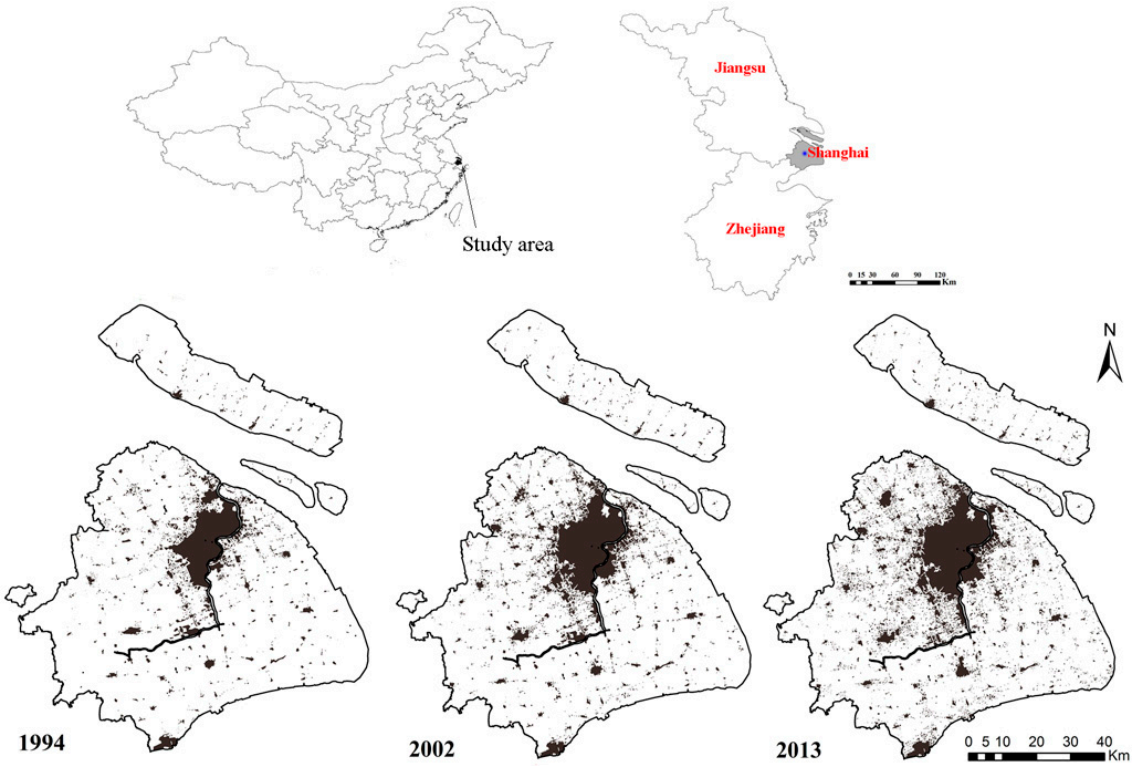


Figure 1. Location of Shanghai (China) and distribution of urban land within it (mapping source: Time-series Landsat imageries) [23].

2.3. Metric Analysis

Fragmentation is described by using multidimensional landscape ecological metrics, which typically includes patch size, shape, edge, isolation, and connectivity [24]. However, it is superior to applying a set of metrics rather than employing all metrics, given that metrics always present significant redundancy [25,26]. Metric analysis in this study follows the methodology demonstrated in [25]. In brief, metrics are selected based on literature review and then reduced by combining Pearson's correlation analysis, Shapiro–Wilk test, and principal component analysis (PCA). The PCA generates three components and the metrics whose loadings are greater than 0.75 in these three components are kept (Table A1). Five metrics are finally obtained to indicate urban fragmentation, including patch density (PD), edge density (ED), mean Euclidean nearest neighbour distance (ENND), area-weighted shape index (AWSI), and aggregation index (AI). The five metrics describe urban fragmentation from different aspects. As the ratio between urban land patch number and total land area, PD describes the density of urban land and the extent of fragmentation. ED measures the total edge lengths divided by the total land area. ENND measures the average distance between urban land patches. AWSI reflects the shape irregularity of urban land patches. AI measures the frequency of adjacent pairs of urban land patches. Metric calculation is facilitated by the Patch Analyst 4.0 [27].

2.4. Indicators Selection

Previous studies indicate that China's economic transition can be described from three aspects: globalization, decentralization, and marketization [20,28–30]. Following the three dimensional framework, I first select 45 indices to indicate economic transition in Shanghai based on literature review and data availability. Pearson's correlation analysis is further applied. If one pair of indices presents high correlation ($|r| \geqslant 0.75$), one of them is removed. The final set includes 11 indices

(Table 1). Data sources include the Shanghai Statistical Yearbook, China City Statistical Yearbook and China Statistical Yearbook. Reasons for selecting these indicators are summarized as follows.

Table 1. Selected indicators of market transition in Shanghai.

Dimension	Variable	Definition
Globalization	Foreign direct investment (FDI)	Total foreign direct investment
	Total international trade (TIT)	Total volume of foreign trade
	Number of the listed companies (NLC)	Number of listed companies within Shanghai city
	Number of oversea companies (NOC)	Number of foreign companies within Shanghai city
Decentralization	Municipality level financial decentralization (MLFD)	The ratio of fiscal expenditure per capita at municipality level to that at national level
	Prefectural level financial decentralization (PLFD)	The ratio of fiscal expenditure per capita at prefectural level to that at municipality level
	Number of national high-tech development zones (NNHZ)	Number of national high-tech development zones in Shanghai city
Marketization	Private economy proportion (PEP)	Ratio between private economy and total gross domestic product
	Private companies proportion (PFP)	Ratio between number of private companies and total number of companies
	Economic contribution of land market (ECLM)	Ratio between land transferring fees and fiscal revenue
	Real estate investment proportion (REIP)	Ratio between investment in real estate and total investment in fixed assets

As mentioned above, urban development usually occurs in a disorderly way and presents a fragmented pattern, due to the absence of scientific guidance. We therefore select the indicators that have potential impact on urban development. First, the liberalization of international trade makes Shanghai exposed to global competition [31,32]. Under globalization, Shanghai attracts increasing oversea trade and investment [33]. It would promote urban development since more land is required to establish production bases. We therefore choose three variables to indicate international trade and investment, including foreign direct investment (FDI), total international trade (TIT), and number of oversea companies (NOC). I also choose one more variable (number of listed companies, NLC) to indicate the mixing of local economy with the global economy. Second, decentralization reflects the degree of authority to allocate land resources by the local government. Land is one of the most essential instruments to accumulate wealth and establish public facilities and infrastructures for the local states. Under decentralization, the local government is prone to allocate more land for urban development. We therefore select two variables indicative of financial decentralization at municipality level and prefectural level. Besides, local government always provides preferential terms to attract oversea investment in high-tech development zones. It would definitely promote the allocation of urban land for development. The number of national high-tech development zones (NNHZ) is therefore chosen. Marketization stimulates urban development from two aspects. For one thing, demand for land is increased by the boom of private enterprises and industrialization [30,34]. The variables including private economy proportion (PEP) and private companies proportion (PFP) are therefore selected. For another, supply of land is also increased by the development of urban land market [35]. I therefore choose one more variable: the real estate investment proportion (REIP).

2.5. Statistical Analysis

Multivariate linear regression is applied to characterize the relationship between urban fragmentation and economic transition. In particular, metrics are dependent variables, and economic transition indicators are independent variables. All the variables are first subjected to Box-Cox

normalization transformation and standardization. Then, these variables are entered and removed into the regression model in a stepwise manner, given the problem of multicollinearity. Before regression, a Pearson's correlation is performed to confirm that potential linear relationships exist between urban fragmentation and economic urbanization (Table A2). Also, the traditional variance-in-inflation method is used to identify the multicollinearity among the exploratory variables.

In order to quantify the relative influence of the three components of economic transition (globalization, decentralization, and marketization), we further apply the variance partitioning method, which can decompose the explained variances into fractions for corresponding explanatory factors [21,36]. Specifically, we decompose the total explained variances (adjust R^2) into different fractions: (1) individual contributions of one component; (2) joint contributions of two components; and (3) joint contributions of three components.

3. Results

3.1. Trend of Urban Fragmentation in Shanghai

Temporal dynamics of urban fragmentation in Shanghai from 1994 to 2013 are exhibited in Figure 2. PD increases linearly from 0.3 to 1.9, with a net increase of 533%. It denotes that the extent of urban fragmentation is enlarged. ED and AWSI also show an increasing linear trend, denoting that urban land patches become more fragmented and irregular. Conversely, AI presents a declining linear tendency, signifying that urban land patches are more dispersed in space. ENND decreases from 105 to 33 and it shows that the average distance between urban land patches is increased. The trend of these metrics is in line with each other. For example, high density and dispersion co-occur and further shorten the average distance between urban land patches. All these results suggest that urban fragmentation has been intensified in Shanghai during the study period.

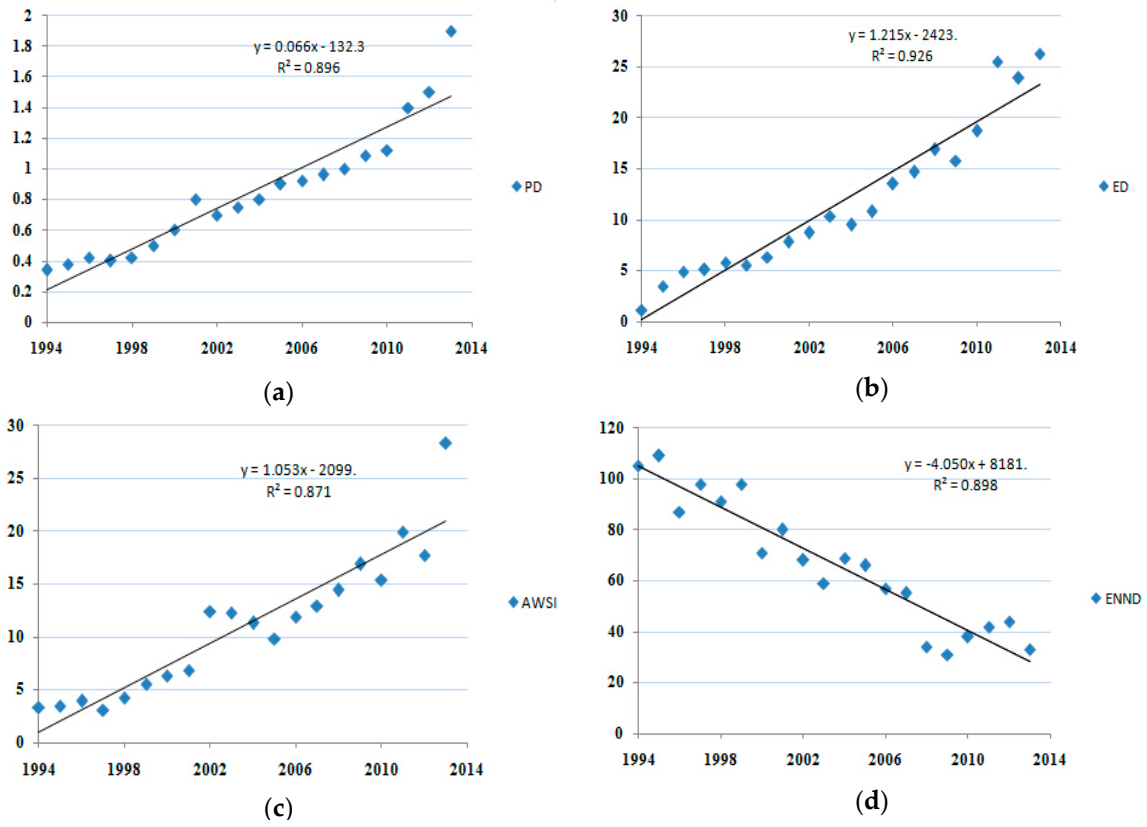
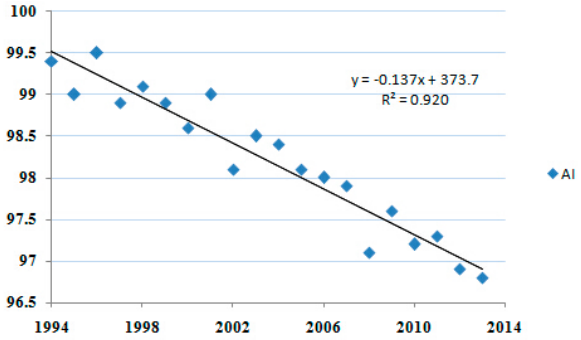


Figure 2. *Cont.*



(**e**)

Figure 2. Temporal trend of urban fragmentation metrics from 1994 to 2013 in Shanghai, China: (**a**) patch density, PD; (**b**) edge density, ED; (**c**) mean Euclidean nearest neighbour distance, ENND; (**d**) area-weighted shape index, AWSI; (**e**) aggregation index, AI.

3.2. Economic Transition Process of Shanghai

Temporal changes of economic transition indicators in Shanghai from 1994 and 2013 are shown in Figure 3. For indicators of globalization, all the indicators present an increasing exponential trend. It indicates that Shanghai city has attracted more and more oversea investment and engaged actively in international trade. Such a trend also suggests that the local economy has gradually blended into the global economic system and globalization is accelerated during the 20 years. For indicators of decentralization, MLFD and PLFD present a growing trend. It denotes that the local government has obtained more autonomy in allocating land resources. The NNHZ presents similar tendency, which denotes that more land is allocated for developing high-tech industry. For indicators of marketization, RELP presents an increasing linear tendency and the other variables show a growing exponential trend. It signifies that marketable economic system has become prominently bigger and market forces have gradually achieved an essential role in allocating land resources.

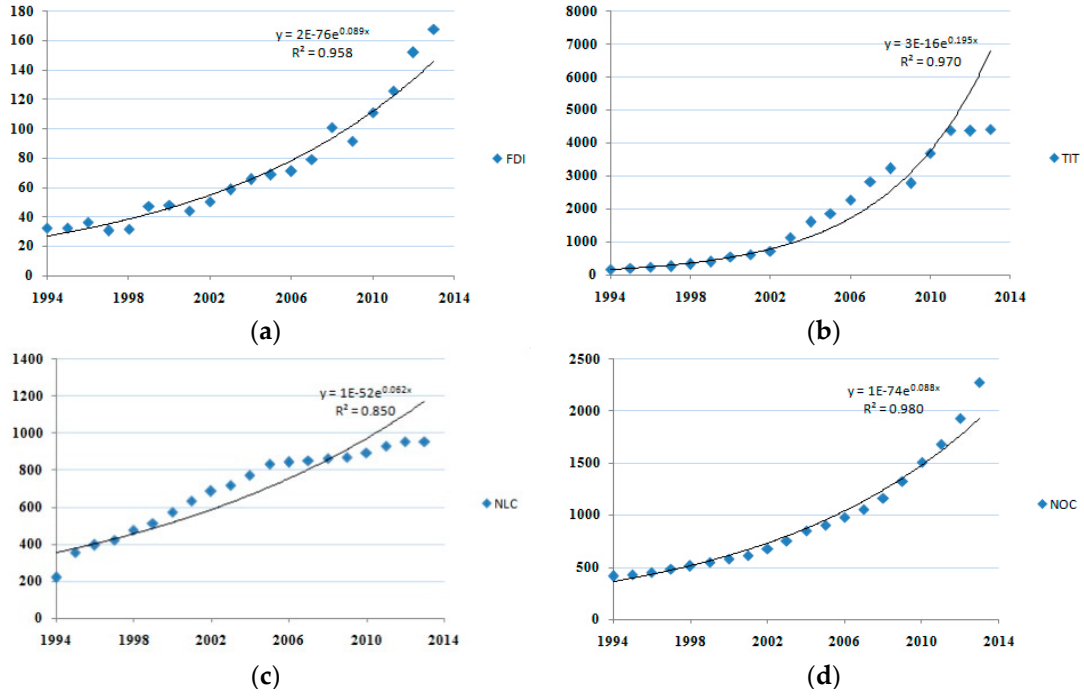


Figure 3. *Cont.*

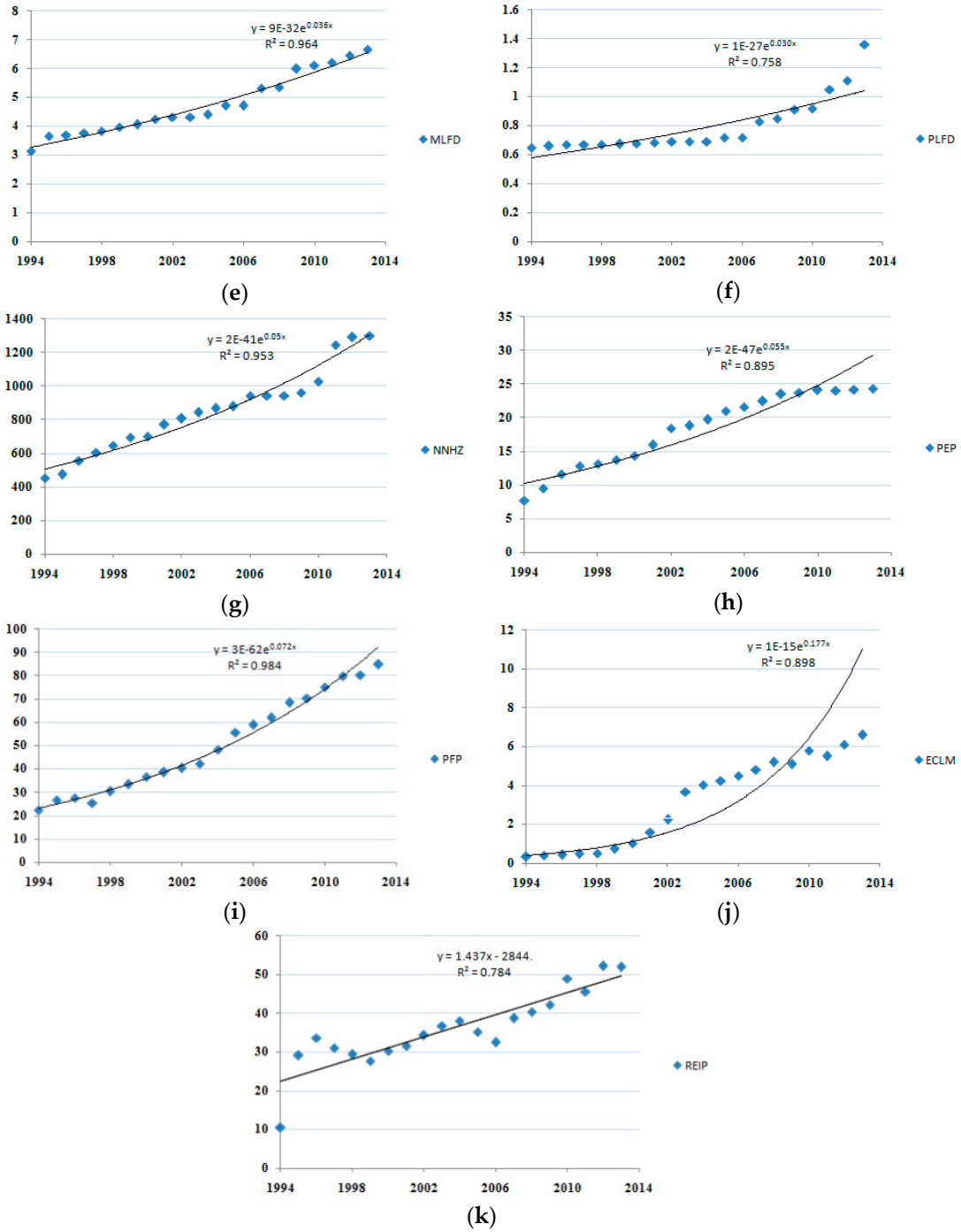


Figure 3. Temporal trend of economic transition indicators from 1994 and 2013 in Shanghai, China: (**a**) foreign direct investment (FDI; US billion dollar); (**b**) total international trade (TIT; US billion dollar); (**c**) number of the listed companies (NLC); (**d**) number of oversea companies (NOC); (**e**) municipality level financial decentralization (MLFD); (**f**) prefectural level financial decentralization (PLFD); (**g**) number of national high-tech development zones (NNHZ); (**h**) private economy proportion (PEP; %); (**i**) private companies proportion (PFP; %); (**j**) economic contribution of land market (ECLM; %); (**k**) real estate investment proportion (REIP; %).

3.3. Response of Urban Fragmentation to Economic Transition

Relationships between urban fragmentation and economic transition are shown in Table 2. The regression models are capable of predicting the response of urban fragmentation to economic

transition, since over 70% of the total variances are explained. The exploratory economic transition indicators vary with the urban fragmentation metrics. For PD, FDI, PLFD, NNHZ, and ECLM are positive exploratory variables. It denotes that the urban land density is closely correlated with foreign investment, high-tech development zone, prefectural level financial decentralization, and land market. NOC, MLFD, NNHZ, and PEP are positive predictors of ED, and TIT, MLFD and PFP are positive predictors of AWSI. The coefficients denote that instability and irregularity have positive correlations with globalization, decentralization, and marketization. ENND is significantly correlated with NOC, PLFD, REIP, and ECLM. It denotes that the average distance among urban land patches would be decreased when foreign economy, land market, and private economy develop. Through similar analysis, it can be seen that urban land would become more dispersed as international trade and private economy develop. Table 3 shows the relative influence of different components of economic transition on urban fragmentation. It can be seen that the individual influence of decentralization is generally lower than that of globalization and marketization. Besides, the joint influences of decentralization and globalization are the strongest. These results imply that urban fragmentation is more influenced by decentralization and globalization.

Table 2. Relationships between urban fragmentation metrics and economic transition indicators.

Dependent Variables	Exploratory Variables	Regression	Adjust R^2
PD	FDI, PLFD, NNHZ, ECLM	Y = 0.145 × FDI + 0.224 × PLFD + 0.173 × NNHZ + 0.089 × ECLM	0.71 **
ED	NOC, MLFD, NNHZ, PEP	Y = 0.105 × NOC + 0.187 × MLFD + 0.133 × NNHZ + 0.102 × PEP	0.61 **
AWSI	TIT, MLFD, PFP	Y = 0.185 × TIT + 0.177 × MLFD + 0.137 × PEP	0.62 **
ENND	NOC, PLFD, REIP,ECLM	Y = 0.113 × NOC + 0.239 × PLFD + 0.099 × REIP + 0.258 × ECLM	0.59 **
AI	TIT, PLFD, PEIP	Y = 0.356 × TIT + 0.245 × PLFD + 0.146 × PEIP	0.55 **

** $p < 0.01$. Abbreviations: patch density (PD), edge density (ED), mean Euclidean nearest neighbour distance (ENND), area-weighted shape index (AWSI), aggregation index (AI), foreign direct investment (FDI), total international trade (TIT), number of oversea companies (NOC), municipality level financial decentralization (MLFD), prefectural level financial decentralization (PLFD), number of national high-tech development zones (NNHZ), private economy proportion (PEP), private companies proportion (PFP), economic contribution of land market (ECLM), real estate investment proportion (REIP).

Table 3. Relative influences of different components of economic transition on urban fragmentation (%).

	PD	ED	AWSI	ENND	AI
Globalization	7.5	8.9	8.4	8.8	11.6
Decentralization	13.3	15.6	14.2	16.4	12.7
Marketization	6.3	7.9	12.0	6.7	7.9
Globalization & Decentralization	25.1	24.1	20.4	22.2	21.5
Globalization & Marketization	18.2	15.7	15.9	19.5	20.3
Decentralization & Marketization	18.1	17.7	22.2	18.1	20.1
Globalization & Decentralization & Marketization	11.5	10.1	6.9	8.3	5.9

Abbreviations: patch density (PD), edge density (ED), mean Euclidean nearest neighbour distance (ENND), area-weighted shape index (AWSI), aggregation index (AI).

4. Discussion

Some fruitful quantitative insights are produced by multivariable regression models, regarding the correlation between urban fragmentation and economic transition. The coefficients for decentralization indicators suggest that urban fragmentation is positively correlated with decentralization. In particular, ED and AWSI are closely related to municipality level decentralization, while PD, ENND, and AI are influenced by prefectural level decentralization. It makes sense in that the local government at a prefectural level is fond of allocating the urban area for real estate development and high-tech development zones in pursuit of more revenue. Municipality level governors pay more attention to the general urban development in the city, but the lack of urban

form planning in the master land use plan results in the disorderly distribution of urban land, which leads to the increases of irregularity.

Indicators of marketization include two categories: economy and land. Our results show that the two categories of marketization both have significant correlations with urban fragmentation. The identified relationships provide detailed figures to support the hypothesis on public land finance [16]. More specifically, ED and AWSI are subjected to economic marketization, while PD, ENND, and AI are influenced by land marketization. It implies that real estate development is the key contributor to the density and size changes in fragmentation, while industrial development is the critical driver of shape changes in fragmentation. It makes sense because housing land is approved by the master land use plan, while industrial land usually lacks united planning.

Developing countries rely on their abundant resources and cheaper labor to participate in the global competition [37]. A number of oversea companies set up production bases in Shanghai, and the industrial development zones become hotspots of urban development [38]. The problem is that industrial development zones are generally located in suburban areas, and these newly-constructed buildings present a relatively sparse pattern in space [38]. It therefore increases the urban fragmentation. Besides, the local government encourages the local firms to elevate the brand to an international level. Many local firms actively participate in international trade [33]. These local firms, when growing, require more space to enlarge the production base and accommodate the increasing labor. However, the managers usually lose track of the large scale construction in these places, which leads to intensifying urban fragmentation. Therefore, the positive influence of TIT on urban fragmentation should be attributed to the pulling force of international trade and poor regulation.

Comparing the relative influence of the three components of economic transition, we find that decentralization is the most influential factor for urban fragmentation. It makes sense that the development of private and overseas enterprises relies on the support from the local government. We also discover that the joint influences of decentralization and globalization are the strongest. It should be attributed to the fact that the degree of market-orientation and economic openness are heavily determined by the autonomy of the local government.

Wu *et al*. [39] hypothesize that urban development should experience two stages of diffusion and coalescence. They suggest that a threshold should exist for urban fragmentation with the intensification of anthropogenic activities [40–42]. Our results show that all the metrics exhibit monotonic trend during the 30 years and correlate linearly with economic transition indicators. These results imply that no threshold exists for the dynamic changes of urban fragmentation. The temporal interval only covers 20 years and urbanization may be still in the diffusion phase. The limited temporal scope may contribute to the discrepancy with the hypothesis. Besides, metric calculation is sensitive to spatial extent [40]. The urban fragmentation in Shanghai may be different from that in the study area of [39].

5. Conclusions

This paper characterizes the dynamics of urban fragmentation using time-series remotely sensed imageries and a set of landscape metrics. Urban fragmentation presents an increasing linear trend. I also find positive linear response of urban fragmentation to economic transition. More specifically, the relative influence of decentralization is stronger than that of globalization and marketization. The joint influences of decentralization and globalization are the strongest for urban fragmentation. This study demonstrates an analytical framework for quantifying urban fragmentation in response to economic transition. The case of Shanghai reveals that the association between urban fragmentation and economic transition is effectively characterized under the analytical framework. This framework can be applicable to other places after making suitable adjustment of the economic transition indicators and fragmentation metrics.

It should be underlined that this study only identifies a statistical correlation between economic transition and urban fragmentation. It does not mean that these three economic forces directly promote urban fragmentation. Instead, economic transition just promotes urban development in general and the absence of strict land use planning should be a key mediator. Urban fragmentation would definitely result in the low efficiency of land use since isolated land is considered unsuitable for urban development [42]. It will aggravate the problem of land resource shortage. Fragmented urban land is prone to further fragmentation [42]. Therefore, the intensifying urban fragmentation will decrease the incentives for the rational exploitation of land resources in Shanghai. In order to enhance urban sustainability, Shanghai city should implement a more scientific urban planning to promote a smart growth mode as well as an orderly growth spatial pattern.

Though this study provides quantitative insights into the issue of urban fragmentation, it covers only 20 years of temporal interval. To monitor the ongoing urban fragmentation and evaluate the influence of economic transition, further investigation should be conducted over a longer time span. In addition, the response of urban fragmentation to economic transition is simply quantified by multivariate regression. With enough cities, more reliable estimations of the true relationship between the variables could be obtained. To get a better sense of the casual mechanisms between economic transition and urban fragmentation, it requires the comparison of multiple cities in China and examination of these relationships. In order to obtain deeper knowledge of the complex influential mechanism of economic transition on urban fragmentation, further studies should identify the mediating variables, build structural models, and investigate more cities.

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Conflicts of Interest: The author declares no conflict of interest.

Appendix

Table A1. Components extracted by PCA.

	Component 1	Component 2	Component 3
AREA_AM	0.254	0.584	0.358
PD	0.854	0.203	0.449
ED	0.774	0.403	0.501
AWSI	0.304	0.796	0.607
PARA	0.349	0.712	0.308
ENND	−0.228	−0.556	−0.811
DIVISION	0.637	0.207	0.631
MESH	−0.658	–0.109	−0.507
SPLIT	0.505	0.432	0.557
IJI	0.347	0.661	0.304
AI	−0.138	−0.802	−0.701

Table A2. Pearson's correlation analysis between fragmentation metrics and economic transition indicators (** $p < 0.01$).

	FDI	TIT	NLC	NOC	MLFD	PLFD	NNHZ	PEP	PFP	ECLM	REIP
PD	0.79 **	0.55 **	0.49 **	0.31	0.29 **	0.69 **	0.65 **	0.68 **	0.53 **	0.70 **	0.44
ED	0.26 **	0.38	0.25	0.81 **	0.62 **	0.46 **	0.74 **	0.57 **	0.67 **	0.49	0.24
AWSI	0.49 **	0.70 **	0.39 **	0.21	0.68 **	0.28	0.51 **	0.75 **	0.52 **	0.35	0.17
ENND	0.15 **	0.27	0.32	0.69 **	0.28	0.67 **	0.42 **	0.54 **	0.47 **	0.71 **	0.64 **
AI	0.54 **	0.68 **	0.55 **	0.24	0.33 **	0.59 **	0.25	0.35	0.27	0.39	0.72 **

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