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Understanding Relationship Between Accessibility and Economic Growth: A Case Study from China (1990–2010)

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Abstract: China′s economy and transport infrastructure have both experienced rapid development since 1978, and especially since 1990. Today, China is the second-largest economic entity in terms of GDP and has the largest high-speed rail (HSR) network and the second-largest expressway network in the world. This paper explores the relationship between accessibility and economic growth in China from 1990 to 2010. In the study, the basic research units include 333 prefecture-level cities and four municipalities. We explore a bivariate analysis framework of accessibility and economic growth, and their increase rates, to examine this relationship using long-term panel data. The results indicate that, first, accessibility and economic growth show a significant positive relationship using both cross-section and panel data, while the increase rate in accessibility and GDP indicate no significant relationship using cross-section data and a poor significant relationship using panel data. Second, the distributions of local advantage are uneven. Cities with low local advantage with respect to accessibility and GDP are mainly located in China′s eastern coastal region or the provincial capitals, while those with low local advantage in terms of their increase rates are located in the western region. Third, as China′s economic growth and transport networks have evolved, the distribution of local advantage shows little change in terms of accessibility and GDP, but a greater change in terms of their increase rates, which is largely influenced by the distribution of expressway and HSR networks.

Keywords: accessibility; economic growth; China; GDP; transport infrastructure

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1 Introduction

China has experienced a period of rapid development since 1978, and especially since 1990, with GDP increasing from $1.854\ 79 \times 10^{12}$ yuan (RMB) in 1990 to $1.355\ 66 \times 10^{13}$ yuan in 2010, a 6.31-fold increase. Meanwhile, China has also seen a significant increase in transport investment and expansion of its transport network. During 1990–2010, the railways, highways, inland waterways, civil aviation lines, and pipelines increased by 0.58 times, 2.9 times, 0.14 times, 4.46 times, and 3.11 times, respectively. Increasing investment in infrastructure (especially transportation) is a common measure used by the Chinese central government to fight financial crisis as well as to decrease regional disparities. After the Asian financial crisis of 1998 and the global financial crisis of 2007–2008, the central government of China submitted strategies concerned with ′stimulating economic development by investment′, with a 6.6×10^{11} yuan investment during 1998–2002 and a 4.0×10^{12} yuan investment in 2009–2010, respectively. About 40% of the 4.0×10^{12} yuan investment was used to build transport infrastructure. Up to 2010, China owned the largest high-speed rail (HSR) network and the second-largest expressway network in the world; the mileage of expressway per billion dollars of GDP was

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140 km, which was three times that of Europe, twice that of the United States, and eight times that of Japan. Such a rapid expansion in the large-scale transport network over the past two decades has largely increased the accessibility of cities, which might have influenced the development of China′s economy.

The relationship between transport and economic development, and even the direction of causality, is still open to much debate. Some scholars have found transport to be an important stimulant for economic growth (Vickerman *et al*., 1999; Tam and Hansman, 2002; Jin, 2003; Song and Ma, 2006) and determining factor for the spatial distribution of regional economic activity (Ribeiro and Silva, 2011), but that it had a diminishing impact on economic development in highly developed countries and even in some developing regions (Mas *et al*., 1996; Guild, 2000). However, others found that the relationship between accessibility and economic development is not straightforward (Spiekermann and Wegener, 2006), and that improvement in accessibility can not be used to explain the distribution of economic activity (Páez, 2004). A negative relationship can be observed with an overinvestment in transportation, which does not bring a corresponding growth in economy (Gaspar *et al*., 2002). The complexity of the relationship between transport and economic development is related to the suggestions that: first, these regions already have a well-developed transport network; second, the development of the economy make transport efficiency and structure much more important than transport cost, especially in just-in-time production systems (Knowles *et al.*, 2008); and third, the interaction of socio-economic systems is becoming increasingly complex, with more factors influencing the development of the economy, such as labor and technology (Ribeiro *et al*., 2010).

Accessibility—a concept broadly defined as the potential opportunity for interaction (Hansen, 1959)—is a commonly used indicator to measure the structure and efficiency of transport networks. Accessibility indicators have also been used to measure the relationship between transport and economic development. For example, Vickerman *et al.* (1999) explored the relationship between accessibility and economic development in Europe with a new accessibility indicator, potential value, which combined GDP with location advantage. The calculation of accessibility is not enough, though, to measure the relationship between transport and economic development. Some scholars have taken accessibility to be the dominant aspect of transport and analyzed the relationship between transport and economic development (Páez, 2004; Ribeiro *et al*., 2010; Ribeiro and Silva, 2011). For example, Gauthier (1968) investigated the interrelationships between increase in accessibility to the highway network and the growth of urban centers in Sao Paulo using canonical analysis. Koopmans *et al.* (2012), taking population, potential value and travel time as proxies of the economy and transport, explored the impact of improvements in accessibility on population growth in the Netherlands and found that accessibility by railway was positively related to population growth, especially in crowded and urbanized regions. Kotavaara *et al*. (2011) built a bivariate regression of population and potential value to analyze the relationship between population change and transport in Finland and found that accessibility affected both the distribution and increase in population. Bivariate analysis was also used by Beeson *et al.* (2001) and Páez (2004). In studies of increasingly complex economic systems, multivariate analysis, spatially autoregressive models, and bivariate spatial analysis were all utilized to investigate the relationship between accessibility and economic development (Ozbay *et al*., 2003; Ribeiro *et al*., 2010; Ribeiro and Silva, 2011). However, research into transport and economic development is largely influenced by the choice of the variables in multivariate analysis, and the connectivity matrix used in spatially autoregressive models (Farber *et al.*, 2009).

Although some researchers have already addressed the relationship between transport and economy in China at national and provincial levels, most of these studies have used transport investment and transport density, instead of accessibility, as representations of transport. Démurger (2001), Hu and Liu (2009) took transport investment to be the dominant aspect of transport, and used it to examine the economic returns and spatial spillover of transport from a provincial standpoint. Using the same methods and indicators, Yu *et al.* (2012; 2013) found that transport investment in different regions yielded different economic returns: a positive spillover at the national level and for the eastern region, an unclear relationship for the northeastern region, but negative spillovers for the central and western regions. However, studies on the relationship between accessibility and economic growth in China are relatively rare, especially in international journals. Wang *et al.* (2009) examined the spatial relationship between increase in accessibility and the urban system and concluded that the development of the railway in the 20th century had significantly improved economic development and heavily influenced the formation of urban systems in China. However, the research did not cover other transport modes and the more recent developments that had given preference to the rapid development of HSR. All of these studies contribute to our understanding of the relationship between the economy and transport infrastructure. However, further studies, especially about the relationship between accessibility and economic growth using long-term panel data at city level, are needed, which could serve as an important guide in supporting future decisions on long-term planning, as well as for short-term operational policy adjustments concerning transport distribution and economy development.

This paper proposes to examine the relationship between accessibility and economic growth from 1990 to 2010 at a statistical and spatial level using panel data, by posing two questions. First, what is the relationship between accessibility and economic growth in China during the past two decades? Could the distribution of accessibility influence that of economic growth, and, if so, to what extent? Second, does a necessary correlation exist between the increase rate in accessibility and economic growth? Therefore, this study tries to explore the relationship between accessibility and economic growth from the statistical and spatial perspectives using the cross-section and panel data by building a bivariate analysis framework including the methods of Pearson′s correlation coefficient (PCC), regression analysis, local advantage and panel analysis. The analysis of this study tries to give some suggestions to the government for the development of transport and economy in the future.

2 Methodology

2.1 Procedure

Bivariate analysis, including Pearson′s correlation coefficient (PCC), regression analysis, local advantage and panel analysis, was conducted to examine the relationship between transport and economic growth using long-term panel data. PCC and regression analysis are commonly used to evaluate the relationships between transport and economic growth in cross-section regions. PCC measures the dependence of two variables, while cross-section regression can reveal both the degree and direction of the relationship between two variables. Local advantage value is constructed to identify the spatial disparity of the relationship between transport and economic growth in cross-section regions. Panel analysis can be used to reveal the relationship between transport and economic growth by combining cross-section and time series data. There are three typical panel models: pooled panel, fixed effect and random effect. The mathematical expressions of the PCC, cross-section regression, local advantage and panel analysis are as follows:

$$r_t = \frac{n\,(\sum x_{it} \times y_{it}) - (\sum x_{it}) \times (\sum y_{it})}{\sqrt{[n\sum x_{it}^2 - (\sum x_{it})^2] \times [n\sum y_{it}^2 - (\sum y_{it})^2]}} \tag{1}$$

$$y_{it} = ax_{it} + b + \varepsilon \tag{2}$$

$$LA_{it} = \frac{x_{it}}{\sum x_{it}} \times \frac{\sum y_{it}}{y_{it}} \tag{3}$$

$$y_{it}^{pm} = a_{it}x'_{it} + b_{it} + u_{it}\,;\quad y_{it}^{fe} = a_1 x'_{it} + b_i + u_{it}\,;$$

$$y_{it}^{re} = ax'_{it} + b + u_{it} + \varepsilon_{it} \tag{4}$$

where r_t is the PCC in year t; y_{it} is the dominance of economic growth of city i in year t; x_{it} is the dominance of transport of city i in year t; y_{it}^{pm}, y_{it}^{fe}, and y_{it}^{re} are the dependent variables (the dominance of economic growth) in the pooled panel, fixed effect, and random effect models, respectively; x'_{it} is the independent variable (the dominance of transport) of city i in the time point t; a and a_{it} are the coefficients of the independent variable; b, b_{it}, and b_i are constant coefficients; u_{it} and ε_{it} are between-sections error and within-sections error, respectively; n is the number of cities; and LA_{it} is the local advantage for transport over the economy of city i in year t. If the local advantage of city i is equal to one, then the city has the same degree of advantage for transport over the economy as the national average level; a local advantage for city i greater than one indicates that the city has much greater advantage for transport over the economy, compared with the national average level, and vice versa (economic growth has much greater advantage).

GDP is an important indicator to evaluate the economic performance of a whole country, while potential value is selected to be the dominant aspect of transport in this paper. Potential value, a widely used location-based accessibility indicator, is proportional to the spatial interaction between one city and the others (Gutiérrez, 2001) and can be calculated using the population or GDP of the destination (P_j) and the shortest travel time from the other municipalities to the destination (t_{ij}) using the formula $A_i = \sum_j P_j / t_{ij}^{\alpha}$, according to a recently published research (Jiao *et al.*, 2014). In the present study, the increase rate in transport and economic growth, which can be represented by the annual percentage increase in accessibility and GDP, respectively, were calculated to investigate the relationship between transport and economic growth; they are written as:

$$A_i^{t-T} = \sqrt[(T-t)]{\frac{P_i^T - P_i^t}{P_i^t}} \times 100 \tag{5}$$

where A_i^{t-T} is the increase in accessibility or GDP of city i during a time period from t to T; P_i^t is the potential value or GDP of city i in year t; and P_i^T is the potential value or GDP of city i in year T.

2.2 Data sources

This research takes 333 prefecture-level divisions and 4 municipalities in China (excluding Hong Kong, Macao, and Taiwan) as its basic study units, digitized according to the 2012 booklet' People's Republic of China Administrative Divisions'. The development of regional transport and economies is greatly influenced by the strategies and plans of the national government, especially the five-year guidelines issued by the Communist Party of China and the associated transportation plans. Therefore, the years 1990, 1995, 2000, 2005, and 2010 are chosen for analysis, as these represent the status before and after these plans are implemented. Municipal-level data for population and GDP are sourced from the 'China City Statistical Yearbook' (National Bureau of Statistics of China, 1991; 1996; 2001; 2006; and 2011); the 'China Regional Economic Statistical Yearbook' (National Bureau of Statistics of China, 1996; 2001; 2006; and 2011); as well as the corresponding provincial statistical yearbooks. A constant 1990 RMB price is used to measure the relative increase in GDP between 1990 and 2010.

Railways lines and highways have played a much more important role than other transport modes; with over 90% of passenger traffic and 85% of freight traffic transported using highways and railway lines during the period 1990–2010. Therefore, railways and highways are chosen as the basic transport networks in this paper. The transport network data for 1990, 2000, and 2010 are obtained from the Thematic Database for the Human-Earth System of the Chinese Academy of Sciences and the 1 : 4 M-scale Topographic Database of the National Fundamental Geographic Information System of China; and transport network data in 1995 and 2005 are digitized according to official maps (i.e., the atlas of expressway and urban and countryside roads published by China Cartographic Publishing House). The operating speeds of the road networks are set as 100 km/h (expressway), 80 km/h (national highway), 60 km/h (provincial highway), and 30 km/h (county highway), in consideration of the design speed limits in the 'Technical Standard of Highway Engineering (1985)' and the 'Technical Standard of Highway Engineering (JTGB01-2003)', resting time during long journeys, and traffic conditions. The operating speed of urban roads is set as 30 km/h (Jiao *et al.*, 2014). According to the train timetables in the selected years, the average operating speeds of conventional railways, but some trunk lines, are set as 48.1 km/h for 1990, 54.9 km/h for 1995, 60.3 km/h for 2000, 65.7 km/h for 2005, and 90 km/h for 2010; the speed of HSR lines is set as 160 km/h for the existing lines upgraded for HSR and 250 km/h for newly-built HSR lines. Of these, the speeds of some electrified system rail lines are set according to the six campaigns to 'speed up' railway travel in China (Table 1).

3 Results and Discussion

3.1 Development of transport and economic growth in China

During the past two decades, China's economy and transportation have experienced a period of rapid development (Fig. 1). And the specific characteristics of transport and economic growth in the following five-year plan periods were quite different, as detailed in the following sections.

Table 1 Characteristics of China's six 'speed up' railway campaigns

Year	Cumulative length of track that can carry HSR trains with maximum speed of:					National average passenger train speed (km/h)	Railway lines
	> 120 km/h	> 140 km/h	> 160 km/h	> 200 km/h	> 250 km/h		
1997	1398 km	1340 km	752 km			54.9	Beijing–Guangzhou, Beijing–Shanghai, Beijing–Harbin
1998	6449 km	3522 km	1104 km			55.2	Beijing–Guangzhou, Beijing–Shanghai, Beijing–Harbin
2000	9581 km	6458 km	1104 km			60.3	Lianyungang–Lanzhou, Lanzhou–Ürümqi, Beijing–Jiujiang, Hangzhou–Zhuzhou
2001	13 166 km	5779 km	1104 km			62.6	Wuchang–Chengdu, Beijing–shanghai, Beijing–Guangzhou, Beijing–Jiujiang, *etc*.
2004	16 500 km		7700 km	1960 km		65.7	Beijing–Shanghai, Beijing–Guangzhou, Beijing–Harbin, *etc*.
2007	22 000 km		1400 km	6003 km	846 km	70.2	Beijing–Harbin, Beijing–Shanghai, Lianyungang–Lanzhou, Hangzhou–Zhuzhou, Lanzhou–Ürümqi, Qingdao–Jinan, *etc*.

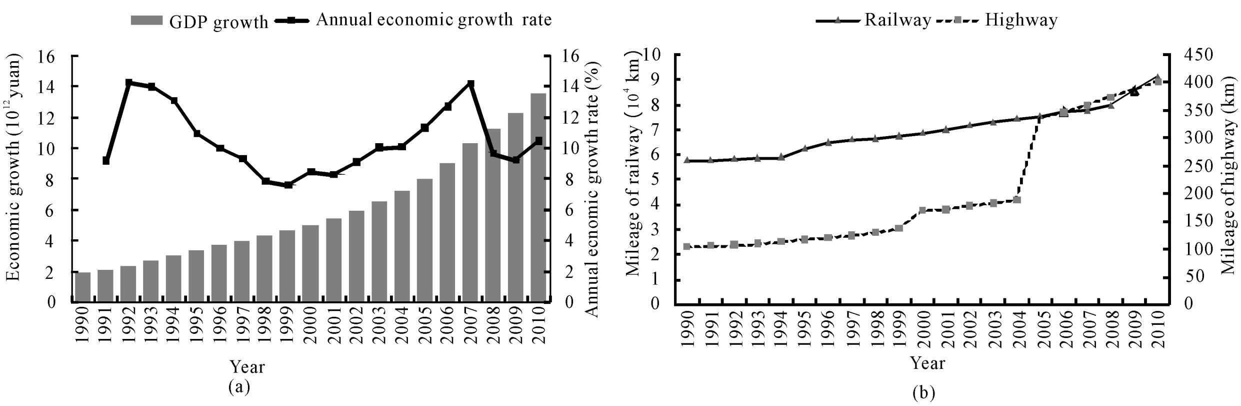

Fig. 1 China's economic growth (a) and growth of its transport system (b) (1990–2010). From 2004, the highways network contains county roads

Fig. 2 Distribution of China's transport network in (a) 1990 and (b) 2010

3.1.1 1991–1995

During the Eighth Five-Year Plan, China was just at its prosperous period of market economy reform, which largely promoted the development of the economy, especially after 1992 when Deng Xiaoping (by then retired, but still regarded as the 'paramount leader' of the People's Republic of China) affirmed the need to continue reforms during his southern tour of the country. Specifically, GDP increased from 1. 854 79 × 10^{12} yuan in 1990 to 3.307 05 × 10^{12} yuan in 1995, with an annual growth rate of more than 12%, higher than that for other countries. The annual economic growth rate steeply increased from 9.18% in 1991 to 14.24% in 1992, and then decreased steadily to 10.92% in 1995. In line with the rapid development of the economy, the mileage of railway and highway network increased from 57 900 km and 1 028 300 km in 1990 to 62 400 km and 1 157 000 km in 1995, respectively. However, annual growth rates of both railway (1.5%) and highway (2.39%) were lower than that for GDP. Meanwhile, the mileage of expressway increased from about 500 km to 2100 km, or by 3.2 times. The expressway network was mainly distributed between the provincial cities and the sub-provincial cities (e.g., Shenyang–Dalian), or between provincial cities (e.g., Hefei–Nanjing), but had not formed a complete network at the national level. The development of the transport network largely improved the accessibility of cities, with the average potential value increasing from 2.75 in 1990 to 4.32 in 1995, an increase of 1.57. From a regional perspective, the eastern region had the highest annual increase (9.95%), followed by the central (9.6%) and western regions (7.38%) (Table 2).

3.1.2 1996–2000

During the Ninth Five-Year Plan, China experienced a relatively slow development period, compared with the other three periods in this study. The GDP increased from 3. 638 0 × 10^9 yuan in 1996 to 5. 003 × 10^9 yuan in 2000, with an annual rate in economic growth of 6.58%. Influenced by the Asian financial crisis in 1997, the annual rate of economic growth declined quickly from 9.3% in 1997 to 7.83% in 1998, and achieved its lowest value (7.62%) in 1999 (Fig. 2). To deal with the economic depression caused by the Asian financial crisis in 1997, an ambitious investment policy was announced in February 1998 to build roads, railways, and power stations, with a planned total expenditure over three years of 6.6 × 10^{11} yuan, which largely promoted the development of the transport infrastructure. The Chinese government also proposed several strategies to promote the balanced development of the economy at a national level during this period. For example, the western development plan, which aimed to promote economic development in the western region, was submitted in 1999, which in turn led to much more transport investment distributed in this region. Corresponding to fluctuations in the economy, the country's highway network increased steadily from 1 185 800 km in 1996 to 1 679 800 km in 2000, or by 41.66%, while the railway network had only a 5.86% increase, from 64 900 km in 1996 to 68 700 km in 2000. The mileage of expressway network increased from 3400 km to 16 300 km, and had formed a complete network in the eastern and central regions and the metropolitan area in the western regions (e.g. the Chengdu–Chongqing Economic Zone). In addition, the Ministry of Railways implemented the first three 'speed up' campaigns (Table 1), which led to the average and maximum operating speed of trains respectively increasing to 60.3 km/h and 160 km/h on conventional railways. As a result, the average value for accessibility increased by 7.52% annually, with the eastern region achieving the highest increase (8.33%).

3.1.3 2001–2005

During the Tenth Five-Year Plan, China continued to implement balanced development strategies, and proposed the 'rise of Central China plan' to promote the development of the economy in the central region of

Table 2 Statistical characteristics of accessibility by region

Region	Accessibility					Annual percentage change (%)				
	1990	1995	2000	2005	2010	1995/1990	2000/1995	2005/2000	2010/2005	2010/1990
National level	2.75	4.32	6.83	9.87	17.07	8.92	9.29	7.52	10.97	9.16
Eastern region	3.24	5.25	8.52	12.65	22.82	9.95	9.96	8.33	12.22	10.09
Central region	3.13	5.00	7.91	11.39	19.42	9.60	9.41	7.55	10.97	9.37
Western region	1.97	2.85	4.32	6.03	9.87	7.38	8.60	6.81	9.92	8.16

China. Meanwhile, the Ministry of Railways and the Ministry of Transport submitted the 'Mid-to Long-Term Railway Network Plan' and the 'National Expressway Network Plan' in 2004 to promote the development of the railway and expressway networks. During this period, the national economy had recovered from the economic regression caused by the Asian financial crisis and the GDP increased from 5.003 5 × 10^{12} yuan in 2001 to 7.969 2 × 10^{12} yuan in 2005, or by 47.06%. The annual economic growth rate increased from 8.3% in 2001 to 11.31% in 2005. The railway and highway networks increased by 530 km and 164 720 km, with annual increase rates of 1.47% and 14.5%, respectively. The mileage of expressways increased from 19 400 km to 41 000 km, with an annual increase rate of 16.14%. The increased expressway was mainly distributed in the eastern and central regions, which made the expressway network much denser in these regions, but had little impact on accessibility. The railway lines upgraded during the fourth and fifth 'speed up' campaigns were also mainly distributed in the eastern and central regions. Following these campaigns, the average operating speed of trains on conventional railways increased to 70.2 km/h, and about 1960 km was upgraded to lines that could carry trains with speeds of more than 200 km/h. In addition, the first HSR between Shenyang and Qinhuangdao opened in 2003, symbolizing the start of the 'HSR period'. As the increased expressway and upgraded railway networks were chiefly concentrated in the main transport corridors of China's eastern and central regions, the average value of accessibility increased by just 7.52% annually. The eastern region was also the largest beneficiary in terms of accessibility.

3.1.4 2006–2010

During the Eleventh Five-Year Guideline, China experienced a large economic fluctuation, caused by the global financial crisis in 2008. The economic growth rate dramatically reduced from 14.16% in 2007 to 9.63% in 2008, and then to 9.21% in 2009. To deal with this economic regression, a 4 × 10^{12} yuan investment plan for 2009–2010 was designed to sustain economic growth, and about 40% was used to construct infrastructure, especially HSR and expressway. The Ministry of Railways also altered the 'Mid-to-Long-Term Railway Network Plan', with the target length of passenger rail lines increasing from 12 000 km to 16 000 km to further promote the development of the railway in 2008. Overall, GDP increased from 8.9794 × 10^{12} yuan in 2006 to 1.3557 × 10^{13} yuan in 2010; the railway and highway networks increased from 77 100 km and 3 457 000 km to 91 200 km and 4 008 200 km, respectively. The expressway increased to 74 100 km in 2010 and formed a complete network at the national level. Another significant achievement during this period was the rapid development of HSR. During the sixth 'speed up' campaign in 2007, about 6849 km of railway was upgraded to lines accommodating the speed of over 200 km/h, and most of these upgraded lines were located along the Beijing-Harbin corridor, the Beijing–Guangzhou corridor, the Beijing-Shanghai corridor, the Beijing–Jiulong corridor, the Longhai corridor (Lianyungang–Lanzhou corridor), and the Qingdao–Jinan corridor. Also, there were some newly built HSR tracks with operating speeds of over 250 km/h, such as the Beijing–Tianjin intercity line, the Wuhan–Guangzhou passenger-dedicated lines, and the Shanghai–Nanjing intercity line. By 2010, the mileage of HSR in China had reached 8358 km, comprising the largest network of its type in the world. The average accessibility of cities increased most rapidly during this period, with an annual increase rate of 10.97%.

Overall, the development of China's highways and railways followed the development of its economy, which means that the economy achieved a higher growth rate and the railway and highway networks achieved a higher rate of increase one or two years later. There were also some exceptions, which were influenced by the financial crises in 1998 and 2008. The financial crises generated economic regression, but increased investment in transport, which largely promoted the development of transport network. Specifically, the annual percentage increase of the railway network rose from 1.18% in 2008 to 7.28% in 2009, while the annual economic growth rate decreased from 14.16% to 9.21%; the annual percentage increase rate of the highway network increased from 3.42% in 1997 to 5.72% in 1999, while the economic growth rate decreased by 1.68%. Clearly, transport investment in China is an important measure to deal with economic regression caused by global or regional financial crisis.

3.2 Accessibility and economic growth

3.2.1 Positive statistical correlation in cross-section regions

Transport accessibility and economic growth had a positive statistical correlation for all the selected years. The correlation coefficients of accessibility and economic growth measured by double logarithmic value were much higher than those measured by single logarithmic and real values. For instance, the PCC measured by logarithmic value in 2010 was 0.662 (Table 3), which was 1.68 times and 1.43 times that measured by single logarithmic and real values, respectively. As transport and the economy developed, the relationship between accessibility and GDP became much closer. Here, the PCC measured by the logarithmic value of potential value and economic growth increased from 0.576 in 1990 to 0.662 in 2010. That is to say, in 2010, accessibility was the most explanatory and statistically significant indicator for economic distribution. Approximately 66.2% of economic distribution can be explained by accessibility in 2010. The results of the regression analysis also showed that transport accessibility and economic growth had a statistically significant correlation, based on the *P*-values of *F*-statistics for all selected years. The correlation coefficients (R^2) also showed an increasing trend, from 0.332 in 1990 to 0.438 in 2010 (Table 3). Meanwhile, the slope of regression increased from 1.414 in 1990 to 1.460 in 1995, and then steadily decreased to 1.240 in 2010. That is to say, a 1% increase in the logarithmic value of accessibility corresponded to a 1.414% increase in the logarithmic value of GDP using the cross-section data for 1990, while there was an increase of only 1.240% for 2010.

3.2.2 Strong positive correlation in panel analysis

The panel regression results (Table 4) imply a significant positive relationship between accessibility and economic growth. All the analysis—according to the pooled panel, fixed effect, and random effect models—was statistically significant, based on *p*-values and *F*-statistics. Because of the largest R^2, the relationship between the logarithmic value of economic growth (ln*y*) and accessibility (ln*x*) has greater explanatory importance, similar to PCC and regression analysis. In all three panel models, the coefficients of potential value are significantly positive, implying a positive relationship between accessibility and economic growth. By contract, the fixed effects model of accessibility and GDP generates a higher value of R^2 than the other combinations.

3.2.3 Spatial patterns

The local advantages of accessibility and GDP were distributed unevenly, but the spatial disparity of these local advantages presented a decreasing trend during 1990–2010. For instance, the coefficients of variation (CV) decreased from 1.32 in 1990 to 1.03 in 2010. The cities showing the highest values for local advantage were the Ngari Area in Tibet Autonomous Region in 1990 and 1995, and then the Gouluo Autonomous Prefecture in Qinghai Province in 2000, 2005, and 2010; while the cities with the lowest values were Shanghai during 1990–2005 and then Chongqing in 2010. The average value for local advantage of all 337 cities increased from 2.25 in 1990 to 2.52 in 1995, and then

Table 3 Pearson's correlation coefficients of accessibility and economic growth, and their annual increasing rate

		Accessibility and economic growth					Annual increasing rate of accessibility and GDP				
		1990	1995	2000	2005	2010	1995/1990	2000/1995	2005/2000	2010/2005	2010/1990
x vs *y*	*a*	**21.644**	**25.610**	**24.360**	**32.870**	**32.190**	**0.826**	−0.180	−0.301	−0.044	**0.424**
	b	−7.547	−19.930	−20.930	−69.720	−105.000	2.486	**11.370**	**13.410**	**13.040**	**6.833**
	R^2	0.102	0.138	0.128	0.140	0.189	0.065	0.002	0.006	0.001	0.035
	PCC	**0.319**	**0.372**	**0.357**	**0.374**	**0.435**	**0.255**	−0.048	−0.077	−0.031	**0.187**
ln(*x*) vs *y*	*a*	**48.940**	**90.460**	**138.500**	**258.800**	**429.400**	**8.029**	−1.560	1.790	−0.292	**3.879**
	b	6.294	−32.590	**−104.800**	**−306.400**	**−709.400**	**−7.542**	**13.160**	**15.660**	**13.250**	2.159
	R^2	0.097	0.126	0.118	0.123	0.156	0.071	0.002	0.005	0.003	0.034
	PCC	**0.311**	**0.355**	**0.343**	**0.351**	**0.395**	**0.266**	−0.042	−0.069	−0.017	0.184
ln(*x*) vs ln(*y*)	*a*	**1.414**	**1.460**	**1.370**	**1.360**	**1.240**	**1.136**	−0.080	−0.615	−0.036	**0.425**
	b	**2.154**	**1.950**	**1.930**	**1.970**	**2.160**	**−0.390**	**2.320**	**3.530**	**2.580**	**1.407**
	R^2	0.332	0.380	0.394	0.414	0.438	0.078	−0.002	0.019	0.001	0.049
	PCC	**0.576**	**0.616**	**0.628**	**0.644**	**0.662**	**0.280**	−0.022	**−0.137**	−0.027	**0.222**

Notes: numbers in bold are statistically significant in 0.01 based on p-value; *x* and *y* are the accessibility and GDP of 337 cities in selected years or the annual increase rates of accessibility and GDP

Table 4 Panel analysis of accessibility and economic growth

		Pooled panel model			Fixed effects model			Random effects model		
		a	*b*	R^2	*a*	*b*	R^2	*a*	*b*	R^2
Accessibility and economic growth	*x* vs *y*	**2.947**	**−4.318**	0.028	**2.894**	**−3.883**	0.746	**2.904**	**−3.963**	0.393
	ln(*x*) vs *y*	**22.146**	**−19.912**	0.215	**23.409**	**−22.171**	0.697	**29.041**	**−32.248**	0.090
	ln(*x*) vs ln(*y*)	**1.249**	**−0.095**	0.569	**1.157**	**0.070**	0.972	**1.046**	**0.269**	0.405
Accessibility improvement and economic growth rate	*x* vs *y*	**0.230**	**8.720**	0.010	**0.171**	**9.259**	0.254	0.139	**9.555**	0.003
	ln(*x*) vs *y*	**2.561**	**5.223**	0.012	**2.044**	**6.356**	0.255	1.968	**6.522**	0.005
	ln(*x*) vs ln(*y*)	**0.354**	**1.475**	0.016	**0.242**	**1.721**	0.219	**0.263**	**1.674**	0.006

Notes: numbers in bold are statistically significant in 0.01 based on p-value; *x* and *y* are the accessibility and GDP of 337 cities in selected years or the annual increase rates of accessibility and GDP; *a* is the coefficients of the independent variable; *b* is constant coefficients

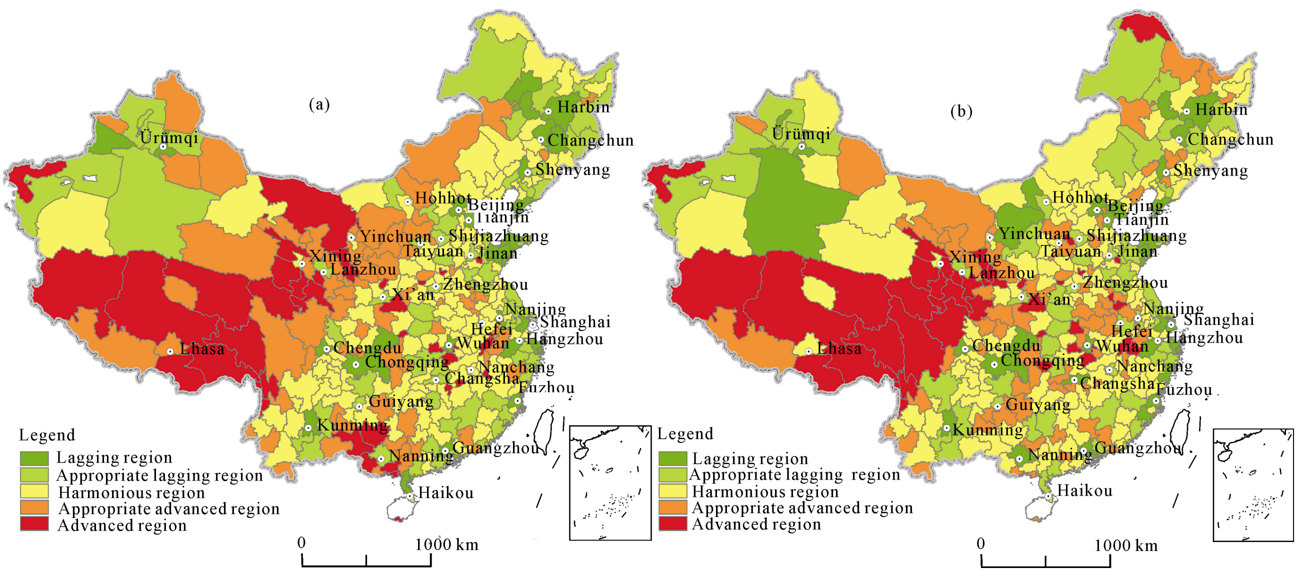

Fig. 3 Spatial distribution of local advantages between potential value and economic growth, 1990 (a) and 2010 (b)

decreased to 2.18 in 2010, which suggests that most of the cities had a higher advantage value for transport than for GDP at the national level. Figure 3 plots local advantages of accessibility and GDP in 1990 and 2010 to illustrate the relationship between transport and economic growth in the cross-section regions.

As shown in Fig. 3, the study's 333 cities and 4 municipalities were categorized according to level of local advantage: 1) a 'lagging region', with a local advantage value of lower than 0.5; 2) an 'appropriate lagging region', with a local advantage value of between 0.5 and 1; 3) a 'harmonious region', with a local advantage value of between 1 and 2; 4) an 'appropriate advanced region', with a local advantage value of between 2 and 4; and 5) an 'advanced region', with a local advantage value of greater than 4 (Table 5).

Table 5 Statistical characteristics of five regional categories classified by local advantage value (GDP, accessibility)

Category	1990		1995		2000		2005		2010	
	Number of cities	%	Number of cities	%	Number of cities	%	Number of cities	%	Number of cities	%
Lagging region	28	8.31	34	10.09	31	9.20	32	9.50	32	9.50
Appropriate lagging region	70	20.77	58	17.21	54	16.02	52	15.43	59	17.51
Harmonious region	128	37.98	116	34.42	120	35.61	111	32.94	128	37.98
Appropriate advanced region	73	21.66	88	26.11	92	27.30	98	29.08	80	23.74
Advanced region	38	11.28	41	12.17	40	11.87	44	13.06	38	11.28

In cities with a local advantage value for accessibility and GDP of lower than 0.5 (i.e., lagging regions), the development of rail and highway transport lags far behind GDP, compared with the national level. Most of these cities were located in the eastern coastal region, were provincial capitals in the western and central regions, or were resource-dependent cities. The number of cities belonging to this category increased from 28 in 1990 to 32 in 2010. Compared to 1990, there were ten new cities, and, of these, three (Quanzhou, Dongguan and Wenzhou) were located in the eastern coastal region, two were the capitals of the Guangxi Autonomous Region and Hunan Province, and the other five cities (namely Karamay, Baotou, Tangshan, Bayinguoleng Autonomous Prefecture, and Xilingol League) were resource-dependent cities, which had a higher increase in growth for GDP than accessibility during this period. The GDP of approximately 92.85% cities (1990) and 93.75% cities (2010) in the lagging regions was much higher than the national average level.

Transport in the appropriate lagging regions (cities with a local advantage value of between 0.5 and 1) also fell behind the corresponding level of economic growth, compared with the national average level. The number of cities belonging to this region decreased from 70 in 1990 to 59 in 2010. Compared with 1990, there were 19 newly increased cities, including 6 cities belonging to the lagging region in 1990, and with the other 13 cities mainly located around the provincial capitals. The cities belonging to this region mostly had a higher GDP value than the national average level. These cities mainly located near to the lagging regions, especially in the eastern and central regions. Meanwhile, only about 25.71% of cities in 1990 and 38.98% of cities in 2010 had a GDP lower than the national average level, and most of these cities were located in the Yunnan Province and Xinjiang Autonomous Region, in which the cities have a less-developed economy and much less-developed transport infrastructure.

Transport in the harmonious regions (cities with a local advantage value of between 1 and 2) has a slightly larger advantage over the economy, compared with the national average level. As most Chinese local governments consider transportation to be an appropriate extra development, in order to make the transport and economy of a region much more harmonious, the cities in this region should be able to develop their economy and transport together. The cities belonging to this region were mostly located east of the ′Aihui–Tengchong Line′ (also named the ′Huhuanyong Line′).

Transport in the appropriate advanced region (with a local advantage value of between 2 and 4) has greater advantage over the economy, compared with the national average level. Most of the cities belonging to this region were located in the central and western regions. Although the cities in the central regions mainly had higher accessibility and GDP values than the national average and those in the western region mostly had lower accessibility and GDP values than the national average, all of these cities had better transportation than the national average level.

Transport in the advanced region (with a local advantage value greater than 4) has far greater advantage over the economy, compared with the national average level. Most of the cities in this region were located in the western region, especially in the Xizang Autonomous Region and Qinghai Province, in which the accessibility and GDP of cities were much lower than the national average level. Specifically, the average GDP value and accessibility of cities in the advanced regions in 2010 were just 15.33% and 79.53% of the national average level, respectively. There were also some cities located in the central and eastern regions. Although most of them had high accessibility, GDP of these cities was much lower than the national average level.

3.3 Accessibility improvement and economic growth rate

3.3.1 No significant relationship in cross-section regions

The annual percentage changes for accessibility and economic growth presented a positive relationship in 1990–1995, but had no significant correlation in 1995–2010. That is to say, during 1990–1995, improvement in accessibility was mainly concentrated in the regions with rapid economic development, which was not evident during 1995–2010 (Table 3). For instance, during 2005–2010, there were four cities with a positive improvement in accessibility and a negative economic growth rate. Hengshui in Hebei Province had a high annual improvement in accessibility of 7.25%, accompanied by an annual economic growth rate of −2.43%. Also, cities located along the trunk transport corridors or around cities with a much more developed economy and dense population had greater improvement in accessibility but relatively lower annual economic growth rate than the others. A case in point was the city of Linfen in Shanxi Province, which had an annual improvement in accessibility of 10.2% and a low economic growth rate of just 0.002% during 2005–2010.

3.3.2 Weak correlation in panel analysis

The panel regression results for annual percentage change in accessibility and GDP suggest that there is weaker significant relationship between the increase rate in accessibility and economic growth rate. The random effects model using simple and single logarithmic values failed the significance test, while the fixed effects and pooled panel models passed the significance test, with a goodness of fit of between 0.010 and 0.255. The fixed effects model also generated a higher value of R^2, which was much lower than that for accessibility and GDP.

3.3.3 Spatial patterns

Figure 4(a–e) plots local advantage by annual percentage changes in accessibility and GDP in 1995/1990, 2000/1995, 2005/2000, 2010/2005, and 2010/1990, respectively, to identify the geographic relationship between increase rate in accessibility and economic growth rate. The spatial distribution of local advantage during the study period was quite uneven. Like that by accessibility and GDP, the spatial disparity of local advantage by their annual percentage changes also presented a decreasing trend, with CVs declining from 2.840 during 1990–2005 to 0.408 during 2005–2010. The spatial distribution of local advantage was also quite different for each study period. The cities with high local advantage were mainly located in the northeastern and western regions and Hunan, Shanxi Province during 1990–1995; this changed to the eastern and central regions during 1995–2000, to the North China during 2000–2005, and along the trunk transport corridors during 2005–2010. Although the cities in the western and northeastern regions had little improvement in transport and economy during 1990–1995, the average annual percentage change of accessibility was higher than that of economic growth, which led to a high local advantage in these regions. During 1995–2000, the highways had formed a complete network in the eastern and central regions, and the upgraded railway lines of the first three 'speed up' campaigns were also located in the eastern and central regions, which led to great improvement in the accessibility of cities in these regions. The difference between the distribution of local advantage during 2000–2005 and 2005–2010 might have been caused by the economic center tending to moving to the north, as North China had far more resources and cheaper labor. The cities located along the HSR in South China also had higher value for local advantage than the others during 2005–2010. Although the distribution of cities with high local advantage altered a lot during different periods, the cities with low local advantage were mainly distributed in the western region. Overall, the cities with high local advantage during 1990–2010 were mainly located along the trunk transport corridors, and the distribution of local advantage was determined by the distribution of economy and transport, especially HSR and expressways.

Overall, the results for the annual percentage change in accessibility and GDP are different from those for accessibility and GDP, which might be caused by the following reasons. There are many factors influencing the development of transport and economic growth, including natural conditions, increasing labor costs, progress in technologies, and national macroeconomic policies. These might lead to different results for relationships between transport and the economy in various areas. For example, cities in the eastern region usually have good natural conditions and high technologies, and many macroeconomic policies have been published since 1978, which has led to higher locational advantage in GDP over land transport. Besides this, the relationship between transport and GDP is caused by long-term interactions between transport expansion and economic development, while the relationship of their annual percentage changes reflects only short-term interactions.

4 Conclusions

The existing literature on the relationship between transport and economic growth in China has mainly taken transport investment to be the dominant aspect of transport, which has neglected the impacts of transport structure. Therefore, this paper has chosen accessibility and GDP to be the dominant aspects of transport and economic growth, respectively, in order to examine the relationship between transport and economic growth during 1990–2010, exploring bivariate analysis including PCC, regression analysis, local advantage and panel analysis.

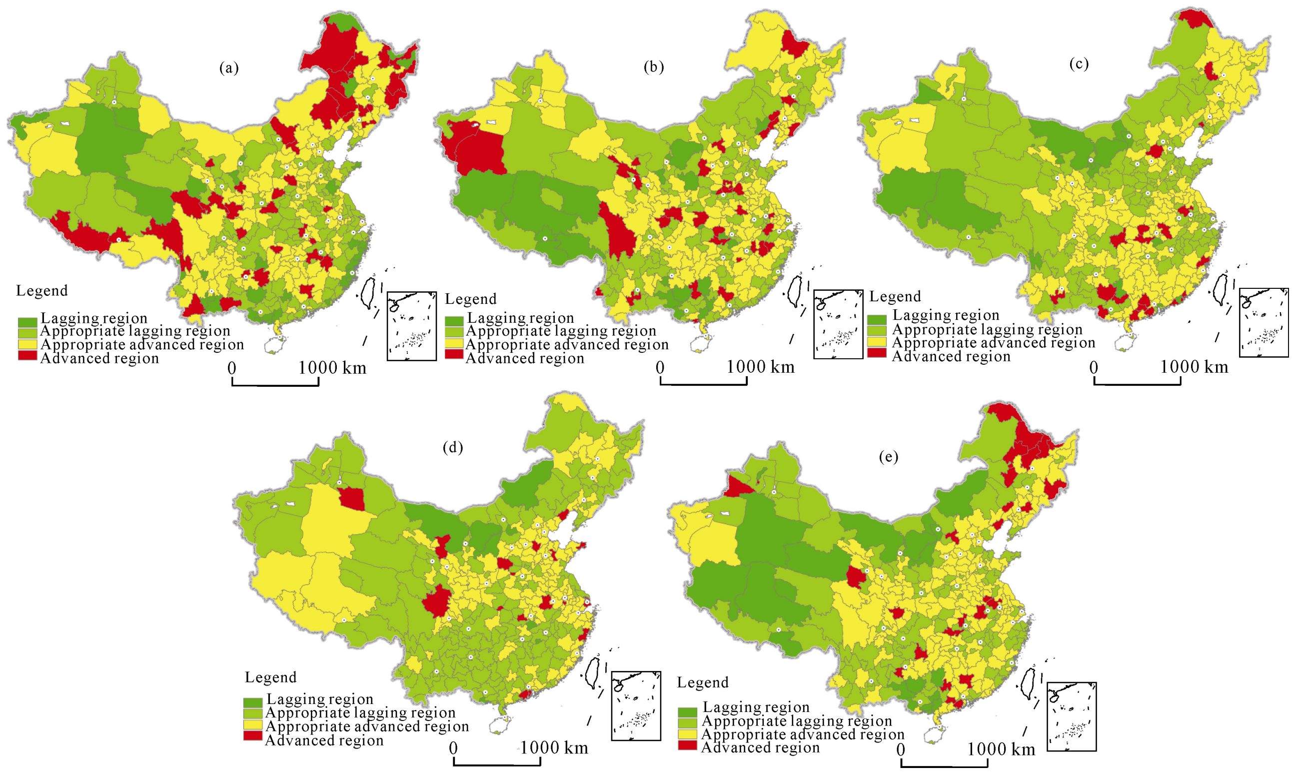

Fig. 4 Spatial distribution of location quotient of improvement in accessibility and economic growth rate, 1990–2010, (a) 1995/1990, (b) 2000/2005, (c) 2005/2000, (d) 2010/2005, (e) 2010/1990

Three main conclusions are obtained from the study. First, the expansion of China's transport network is largely influenced by its economic growth, national planning and strategies (e.g., 'Western Development Plan', 'Rise of Central China Plan' and 'Stimulating Economic Development by Investment'). However, expansion of highway and railway networks in terms of mileage lagged one or two years behind economic growth. Second, transport and economic growth presented a positive relationship from the perspective of accessibility and GDP. However, if it was evaluated with annual percentage change rate of accessibility and GDP, there was no significant relationship when using cross-section data and a weak positive relationship when using panel data. Third, the spatial distribution of local advantage was uneven. The cities with low local advantage in terms of accessibility and GDP were mainly located in the eastern coastal region or the provincial capitals, while those in terms of their annual percentage change rates were mostly located in the western region. The distribution of local advantage had little change in terms of accessibility and GDP, but large changes in terms of their annual percentage change rate. Furthermore, the distribution of local advantage in terms of annual percentage change rate was largely influenced by the distribution of expressway and HSR networks.

This research enriches the study methods, perspectives and scales of transport economy and transport geography, especially in the efficiency and fairness of transport distribution. Although the cities in the eastern region had greatly improved transport and economy, the efficiency (evaluated by accessibility) of highways and railways still lagged behind that of economic growth compared with the national average level according to the local advantages of accessibility and GDP for transport during 1990–2010. In consideration of the harmonious development of transport and the economy, high-level highways and the railway network should also be distributed within the eastern region. For example, the Beijing–Shanghai HSR line, Shanghai–Nanjing, and the Shanghai–Hangzhou intercity railway were opened after 2010. The highways and railways in the western region—especially in the Tibet Autonomous region and Qinghai Province—improved ahead of economic growth during the past 20 years, although the cities in the western region had low values for accessibility and GDP. In terms of fairness, highways and railways are also needed in the western region. According to transport plans such as the 'Mid-to Long-Term Railway Network Plan' and the 'National Expressway Network Plan' (2013), China's transport network should expand to the western region to realize the fairness of transport across different regions. The national planning and strategies of transport should reconcile efficiency with transport fairness in the long term.

This research opens up some important avenues for future research. First, the accessibility indicator is derived by using geographic land transportation, including railways and highways, which neglect air transport and water carriage. A comprehensive study of transportation would provide a stronger foundation for future accessibility analysis. Second, future research could analyze the influence of the integration of transportation and other factors on economic growth.

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