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Does the expansion of a motorway network lead to economic agglomeration? Evidence from China

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ABSTRACT

In contrast to most existing studies examining the generative effects of transport infrastructure, this paper addresses the distributive effects of transport infrastructure in China. Using panel data from 274 Chinese municipalities in the 2000–2010 period, our study explores the role of motorway network in the evolution of spatial economic agglomerations. Our results confirm the existence of a distributive effect of road infrastructure in China, and show that an improvement in the motorway network leads to a higher degree of geographic concentration of economic activities. However, in our simulation new motorway construction appears to facilitate spatial dispersal when transport costs fall below a critical level. Moreover, the improved road network has led to a loss of industry in China's lagging areas. Accordingly, current transport investment policy, especially in lagging western areas, has not contributed to spatial equity in China, which contrasts with investment in education, for example.

1. Introduction

China has witnessed growing coastal–interior and urban–rural inequity in terms of average income and other economic or social welfare indicators during its recent decades of rapid economic growth. The manufacturing sector is also highly concentrated in East China, where nine coastal provinces accounted for 69 percent of the manufacturing output value in 2012[1]. The spatial development pattern of core–periphery (coast–interior) has already firmly taken shape in China, and how to narrow the coast–inland gap is therefore an acute question for the Chinese administration. Government officials have been wrestling with this problem for many years. For instance, with the implementation of the 'Western Development Strategy' in 1999 (Yao and Ren, 2009), the central government significantly stepped up its investment in public infrastructure, particularly in the construction of the road network in western regions. From 2000 to 2010, a total of 874,984 km of new roads (including motorways and paved roads) were built in western China, which has greatly improved interregional transportation conditions in western regions (Ministry of Transportation, 2011; SSB, 2001–2011a). The benefits of these transport infrastructure investments have mainly been verified in empirical studies, which report a positive generative effect of transport investment on economic growth (Hong et al., 2011; Liu and Xu, 2010; Yu et al., 2012, 2013). However, few studies have provided an answer to the question whether the improvement in roads has helped reduce China's spatial disparity. This might be because evidence of an impact on spatial inequity is hidden when the economic effect of transport investment is demonstrated on the national or regional scale (Holl, 2004a, 2007; Teixeira, 2006; Meijers et al., 2012).

Indeed, at a detailed geographical level, the effect of transport improvement on the local economy is often obscured because some effects induced by transport infrastructure will extend outside the limits of this area, generating spillover effects (Boarnet, 1998). Negative output spillovers can result when mobile factors of production transfer to more developed locations and away from unattractive areas (Boarnet, 1998). It could well be that transport infrastructure investment leads to more economic growth in one place at the expense of less growth or even decline in another, probably due to the migration of production factors induced by the decreasing transportation costs (Vickerman, 1996; Boarnet and Haughwout, 2000; Ottaviano, 2008; Banister, 2012). This effect of transport infrastructure on the relocation of economic activities

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[1] Data are collected from National Bureau of Statistics of the People's Republic of China.

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has been identified as the 'distributive effect' (Banister and Berechman, 2001; Lopez et al., 2008; Meijers et al., 2012).

A greater understanding of this distributive effect is essential given that balancing the spatial distribution of economic development resulting from transport facilities development is often a major rationale for investment decisions (Chandra and Thompson, 2000; Holl, 2004a,b; Banerjee et al., 2012; Roberts et al., 2012). Much of the evidence for the existence of such a distributive effect has been obtained from developed countries in recent years, such as Spain (Holl, 2004a, 2007; Lopez et al., 2008), Portugal (Teixeira, 2006; Holl, 2004b), The Netherlands (Meijers et al., 2012; Louw et al., 2013) and the US (Funderburg et al., 2010). For instance, Lopez et al. (2008) explored the impact of transport infrastructure investment on the spatial distribution of accessibility in Spain and found that regional disparity has increased due to rail infrastructure. Holl (2004a,b, 2007) examined the impact of road infrastructure on the location and relocation of firms from Spain and Portugal, and the results showed that new motorways affected the spatial distribution of manufacturing establishments, but the impact differed across sectors and space. Some of these studies of European countries also confirmed an inverted U-shaped relationship between transport improvement and economic concentration, as predicted by the theoretical models of New Economic Geography (Fujita and Thisse, 2002; Ottaviano and Thisse, 2004; Ottaviano, 2008). For instance, Teixeira (2006) reported empirical evidence of a bell-shaped relationship between transport costs and agglomeration in Portugal. Holl (2004a) examined the impact of road infrastructure on the relocation of firms from Spain, and found that the new road infrastructure appeared to facilitate economic concentration which later on was followed by geographic dispersal. For emerging economies, Bird and Straud (2014) measured the impact of the road network on Brazil's growth and the spatial allocation of population and economic activity, and revealed a dual pattern of spatial development (the main centers in the South and the emergence of secondary economic centers in the less-developed North) induced by road improvement.

To summarize, most of these studies confirmed the existence of a distributive effect of transport infrastructure in EU countries or the US. However, to our knowledge, there have been very few empirical studies investigating this distributive effect of transport infrastructure in China, despite China having invested heavily in its transport facilities in recent years.

The objective of this paper is to advance our understanding of the role of transport infrastructure planning in China's economic geography. We therefore study how and to what extent motorway network contributes to the agglomeration and dispersal of economic activity across Chinese regions. Furthermore, to highlight the role of road infrastructure in narrowing China's spatial inequity, we also separately evaluate the impact of transport facilities on economic agglomeration or dispersal in China's lagging western areas. This paper provides a thorough analysis of current transport investment policy based on our empirical findings, the results of which could be very significant for China's future transport-infrastructure investment policy. Specifically, we explore:

a. *To what extent and in which direction the spatial patterns of economic distribution in China have changed by virtue of motorway network improvement.*
b. *Whether the relationship between road improvement and economic concentration is bell-shaped, as predicted by New Economic Geography (Fujita and Thisse, 2002).*
c. *Whether motorway infrastructure construction in the lagging areas has contributed to China's spatial equity.*

To this end, we conducted analyses using panel data for Chinese municipalities covering the period 2000–2010, during which Chinese road infrastructure expanded rapidly. This paper differs from earlier studies in three important ways. First, we use data from more-detailed geographic units (municipal level). Geographically detailed studies can reveal spatial distributive patterns, as these tend to be lost at the aggregated scale (Banister and Berechman, 2001; Holl, 2007). Second, we evaluate the distributive effect of motorway network in the poor western regions separately to confirm the impact of transport infrastructure on China's inequity. Third, we apply a computer-simulation method to better forecast the transport–agglomeration nexus in the long run in China.

The rest of the paper proceeds as follows. The next section describes the development of the motorway network and the evolution of spatial distribution patterns of economic activity in China. Section 3 introduces the model, variables and data for an empirical contribution on the distributive effects of road infrastructure in China. Our empirical results are reported in Section 4, along with a detailed discussion. We end with concluding remarks and a number of suggestions for future planning and policy design.

2. Transport improvement and changes in spatial development patterns in China

2.1. Motorway network extension in China

Transport infrastructure has played an instrumental role in China's 'growth miracle'. Out of all the infrastructure sectors, the effort to improve the country's roads has received the strongest impetus and investment from the Chinese government since China's economic reform. Take highway construction, for instance. In the early 1990 s, China's motorway network was basically nonexistent (147 km in 1989); the first highway (Hu-Jia) was only completed in October 1988 (China Transportation Statistical Yearbook, 2001). Since then, China has witnessed dramatic development in its motorway construction. By 2000, the total Chinese highway transportation network had increased to 16,314 km, making it the third largest highway network in the world (China Transportation Statistical Yearbook, 2001). The principal motorway network has been largely completed, linking the main transportation hubs such as Beijing, Shanghai and Shenyang. The regional density and overall highway coverage has also been optimized.

Undoubtedly, China witnessed a considerable road-building boom from 2000 to 2010. The tenth Five-Year Plan (2001–2005) saw the completion of 24,691 km of highways, which was 1.5 times the combined length of all the highways constructed under the seventh to ninth five-year plans (1985–2000). During the eleventh Five-Year Plan (2006–2010), a total of USD 1586.5 billion was poured into transport network construction.[2] Since 2000, China's motorway network has been growing at an average of 20 percent per year. In doing so, the country has moved to second place globally in terms of motorway network (96,200 km in 2012), only behind the US. All provincial capitals, autonomous municipalities and major cities have been linked, as shown in Fig. 1. The accessibility of Chinese cities has been much improved.

Lagging western China is the focal point in the construction of this network, with both the number of new projects and the total mileage under construction there being much higher than the national average (Lin, 2010). Indeed, during the period 2000–2010, the average rate of motorway growth in the western region stood

[2] Data are collected from China Statistical Yearbook (2001–2011a)

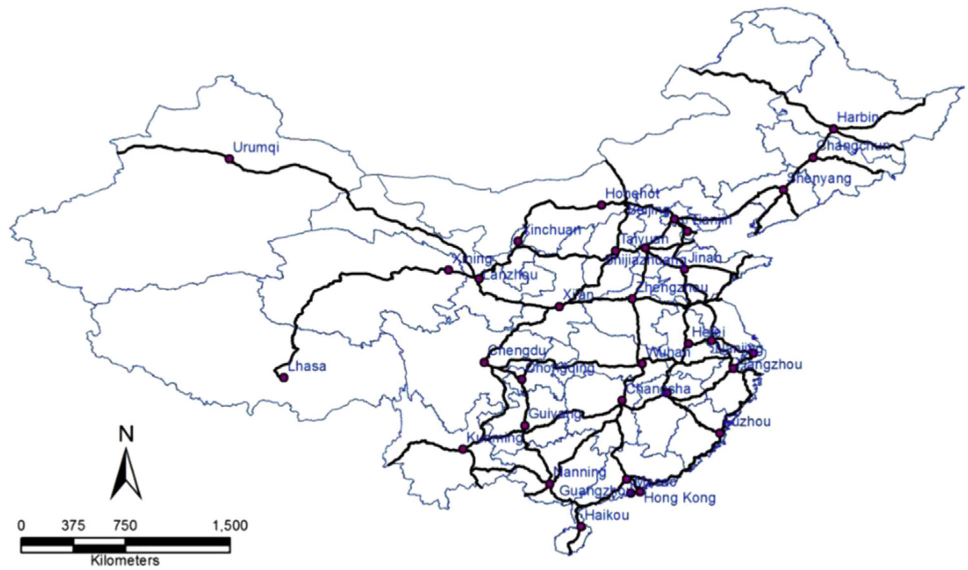

Fig. 1. The Chinese motorway network in 2010.
Source: Highway network map data are collected from China Foundational Geography System.

at 15.9 percent, while the rate in the eastern and central regions was only 4.7 and 6 percent, respectively.[3] Both central and local government hope the rapidly improving road network will spur the economic development of the western region.

2.2. The evolution of a spatial economic development pattern in China

We will start with a brief introduction of the evolution of the regional distribution of GDP in People's Republic of China since its foundation. Table 1 reports the changes in GDP share in China's main regions from 1952 to 2010. As the table shows, the spatial development pattern did not change significantly from 1952 (the foundation years of the People's Republic of China) to 1978 (the year of economic reform). However, as China's growth miracle started in the coastal regions, these regions' share of aggregate GDP significantly increased from the 1980s onwards, and especially after 1990. This obviously meant that the shares of the other interior regions declined. Fig. 2 also shows that economic activity in this decade continued to grow increasingly concentrated and expanded more rapidly in the coastal regions. Accordingly, the pronounced disparity between the coastal and inland provinces in China has grown further since economic reform.

In part (a) of Fig. 2, the Choropleth mapping shows the change in percentages of industrial GDP between 2000 and 2010.Obviously, the coastal and central areas have experienced a higher industrial GDP growth during the last years. As a result, more and more economic activities gathered in the eastern region. Part (b) of Fig. 2 displays the spatial distribution of industrial GDP per capita at the municipal level in 2010. Two clear features of the spatial distribution in China's current economic development can be seen on this map. First, China's economic activities are mainly concentrated in the eastern coastal region, such as the Yangtze River Delta, the Pearl River and the Bohai Baky region. Second, the clusters of economic activity are like stairs descending from the higher eastern China to the lower western China (Liu et al., 2011). Thus, the core (coastal eastern region) to periphery (interior central and western region) pattern in the distribution of economic development is obvious in China.

[3] Authors' calculation based on data from China Transportation and Communication Yearbook, 2001–2011.

However, the reasons for these patterns of geographic agglomeration are complex, since they are the outcome of a variety of natural, policy and other factors. For instance, China has long followed a biased development policy, the so-called 'Coastal Priority Development Strategy' since the beginning of economic reform. Concentration of both capital and human resources in the eastern (coastal) provinces was encouraged at the initial stage of economic reform. Meanwhile, the large demand induced by exportation is also a potential reason for the industries concentration in the coastal provinces. By contrast, in the western region, most provinces have suffered from drought, difficult climatic and geographic conditions, which resulted the production factors migrating to much better and developed locations.

Focusing on our main research goal, a central question is whether motorway network improvements lead to a higher concentration or dispersal of economic activities in China. The New Economic Geography theory suggests that transport infrastructure improvement could lead firms to relocate due to changes in accessibility. This relocation could lead to more concentration and hence regional divergence (Fujita et al., 1999; Holl, 2004a,b, 2007). The answer to this question is important for investment policies aiming at balanced development across Chinese regions.

3. Methodology and data

3.1. Model specification

In order to analyze the role of motorway networks in the process of agglomeration or dispersal of China's economic activities, a detailed geographic analysis follows in this section.

We describe the spatial development pattern by location quotient (*LQ*), which is a way of quantifying concentrated industries or clusters in an area compared with the national pattern (average). The *LQ* measures the level of industrial agglomeration in one region (Liu, 2008), and the *LQ* in region i is calculated as follows:

$$LQ_i = \frac{IY_i/Y_i}{IY/Y} \tag{1}$$

where *IY* is the industrial GDP and Y indexes the total GDP in the whole nation. Given the focus of this paper, motorway network density (*Road*) and education attainment level (*Edu*) are regarded

Table 1
Changes in GDP and the share of Chinese regions.
Source: Authors' calculation based on data from the People's Republic of China's Statistical Series of Sixty Years (SSB, 2010) and the China Statistical Yearbook (SSB, 2011a).

		1952	1980	1990	2000	2010
North-coastal	GDP	104.98	703.77	1702.95	5628.32	19277.70
	Share	17.84%	17.84%	17.47%	18.56%	18.81%
	Growth rate	–	7.03%	9.24%	12.70%	13.10%
East-coastal	GDP	109.60	773.83	1989.13	7206.99	24826.04
	Share	18.62%	19.61%	20.41%	23.77%	24.23%
	Growth rate	–	7.23%	9.90%	13.74%	13.17%
South-coastal	GDP	42.25	335.20	1080.40	4369.81	14929.29
	Share	7.18%	8.50%	11.08%	14.41%	14.57%
	Growth rate	–	7.68%	12.42%	15.00%	13.07%
Center	GDP	146.17	890.75	2133.42	5938.66	19830.14
	Share	24.83%	22.58%	21.89%	19.58%	19.35%
	Growth rate	–	6.67%	9.13%	10.78%	12.81%
Northeast	GDP	84.00	552.80	1199.24	2874.59	9628.57
	Share	14.27%	14.01%	12.30%	9.48%	9.40%
	Growth rate	–	6.97%	8.05%	9.14%	12.85%
West	GDP	101.60	688.76	1641.44	4305.03	13985.16
	Share	17.26%	17.46%	16.84%	14.20%	13.65%
	Growth rate	–	7.07%	9.07%	10.12%	12.50%

Note: Here, we define the northeastern region as including Jilin, Liaoning and Heilongjiang. The hinterland of China (Center) consists of Henan, Jiangxi, Hunan, Anhui, Hubei and Shanxi. The north-coastal region includes Beijing, Tianjin, Shandong and Hebei, and the south-coastal region Fujian, Guangdong and Hainan. The east-coastal region comprises Shanghai, Jiangsu and Zhejiang. The western region consists of Yunnan, Guizhou, Sichuan, Chongqing, Guangxi, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang and Inner Mongolia. The unit of GDP is 10^2 million yuan at constant prices of 1978.

as the main explanatory variables, while other agglomeration determinants could also be distinguished following Holl (2004a,b, 2007) and Meijers et al. (2012). These include measures of market demand – which can be proxied using municipality population (*Pop*) and GDP per capita (*GDP*), market accessibility potential (*ACC*)[4], wage costs (indexed by the average wage, *Wage*), and measures of economic agglomeration (proxied using degree of specialization, *Spe* and the amount of exports, *Exp*). As a result, a basic empirical model can be constructed as follows:

$$LQ = f(Road, Edu, Pop, GDP, ACC, Wage, Spe, Exp) \qquad (2)$$

In addition to these main explanatory variables, several regional dummies were added to the model to control for the geographic difference between municipalities, including a provincial capital dummy to distinguish the political center from other municipalities, a resource-oriented city dummy to highlight this type of city's development characteristics and a coastal city dummy to emphasize its locational advantage.[5] In 2008, 38 percent of the RMB 4 trillion yuan Chinese stimulus package was earmarked for infrastructure construction. Thus, a dummy variable to cover the 2008–2010 period was also added to control for the temporary shocks induced by policy changes. Furthermore, in order to test the theoretical hypothesis of an inverted U-shaped relationship between transport improvement and a geographic agglomeration of economic activities, a quadratic road network term was included in the model.

Moreover, regarding the small size of the spatial units (especially in the eastern region) considered in this paper, we also added a spillover variable of motorway network (W_*Road), in order to control for the effects of this key factor on spatial concentration of industries driven by transport improvement in surrounding units. A binary contiguity matrix is used to construct the spatial weighted matrix (W_{ij}), which assumes only contiguous provinces can influence each other.[6] Therefore, a symmetric spatial matrix of the 274 Chinese municipalities can be obtained based on our observations.

Thus, the following empirical model based on the panel data considering the fixed effect can be estimated:

$$LQ_{it} = \nu_i + \xi_t + \beta_{1i} Road_{it} + \beta_{2i} \log Edu_{it} + \beta_{3i} \log Pop_{it} + \beta_{4i} \log GDP_{it} + \beta_{5i} ACC_{it} + \beta_{6i} \log Wage_{it} + \beta_{7i} Spe_{it} + \beta_{8i} Exp_{it} + \beta_{9i} W_{ij} Road_{it} + \beta_{10i} Road_{it}^2 + \gamma_{it} Dummies_{it} + \varepsilon_{it} \qquad (3)$$

Here, all the explanatory variables are defined as above; ε_{it} is the stochastic error; and ν_i and ξ_t are municipality- and time-specific parameters, respectively. The former takes into account unmeasured characteristics of municipalities and the latter is introduced to control for temporary shocks or policy changes that might have affected all municipalities at the same time.

3.2. Data collection and description

This study uses data from multiple sources, including China

[4] Market accessibility potential reflects the size of the potential market area a given location has access to after taking into account the cost of overcoming distance

[5] The lists of provincial capitals, resource-oriented cities and coastal cities are not provided in this paper due to word limits, but are available from the authors upon request. The list of resource-oriented is collected from 'Planning for the Sustainable Development of National Resource-oriented Cities', which is available on line: http://wenku.baidu.com/link?url=iniWQy8fx3Lkud0Bi1CvHlVJwmf2Sc1DmRjUJ_3fqyZhwL9O_jBO9z8S0ilU9rkYpL30U–jssTfQ9XY5zd00ct9t_G6jPv3-l7J61RBiQK

[6] In this study, we adopt a binary contiguity matrix to construct the spatial weighted matrix: w_{ij} equals to 1 if the city i has a border with city j otherwise equals to zero, and $\sum_{j=1}^{N} w_{ij} = 1$.

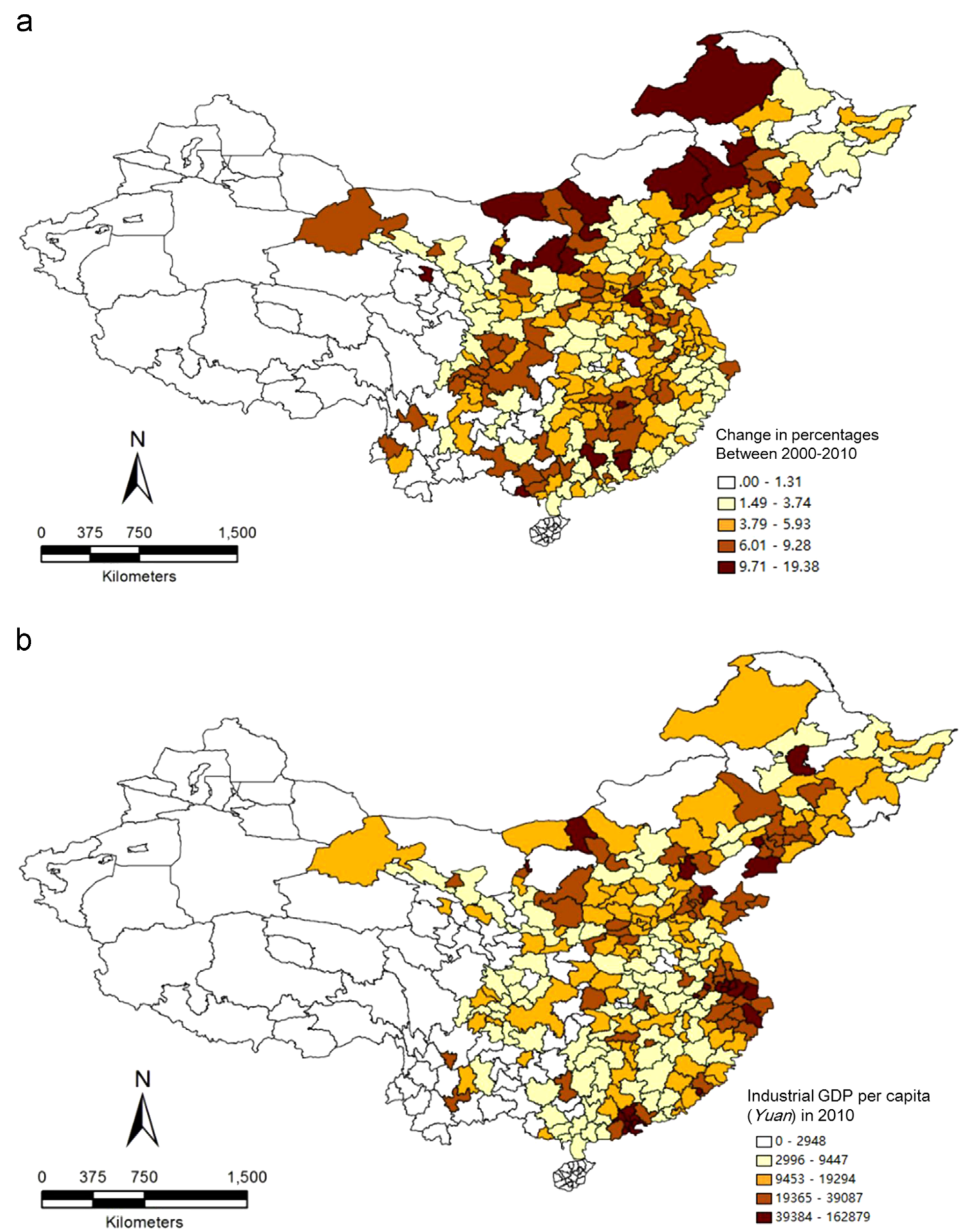

Fig. 2. (a) Changes in China's industrial geography 2000–2010; (b) China's industrial geography in 2010.
Note: Part (a) presents the change in percentages (%) of industrial GDP between the periods of 2000–2010 and part (b) shows municipal industrial GDP per capita at current price in *Yuan*. The data are from the authors' own calculations based on data from the China City Statistical Yearbooks (SSB, 2001-2011b). Map data are from the China Foundational Geography System.

Regional Economic Statistical Yearbooks and the China City Statistical Yearbook from 2001 to 2011. Complementary data was obtained from the Provincial Statistical Yearbooks from 2001 to 2006. Geographic measures were constructed using ArcGIS software based on the basic map data from the National Fundamental Geographic Information System of China. This paper follows Head and Mayer (2004)[7] in using GIS data to calculate market accessibility. Since the road network in China is quite dense, the distance between an arbitrarily defined centroid and the nearest road is not a meaningful measure of access to roads. Following Banerjee et al. (2012), our proxy for access to roads is instead the density of roads in each city. Therefore, we compute road density by taking the total length of highways (multi-lane highways) in each city and dividing it by its land area. The average educational attainment level is proxied using the average years of schooling in the population over six years old. The data on investments, wages and GDP are converted to constant 2000 prices. Due to limited data availability, data on education, export and specialization are chosen at the provincial level.

The autonomous regions of Tibet and Xinjiang are special areas in China, subject to different policies because of their location and religion. The construction of infrastructure in these areas is guided by different considerations from those that guide infrastructure investment in the rest of China. We therefore exclude these two autonomous regions from our sample for both economic and non-economic reasons. Hainan province is an island, which cannot be connected to the other provinces by a road network, so samples from Hainan province are also excluded. Having excluded some

[7] This paper follows Head and Mayer (2004) in using the 'geographic center index' to index the potential market accessibility, which can be calculated by $GC_i = \ln \sum_{i \neq j} d_{ij}^{-1}$, where d_{ij} is the physical distance between region *i* and region *j*.

Table 2
Statistical description of the main variables.

Variables	Description	Max.	Min.	Mean	Std. dev	Expected sign
Population size (Pop)	The total population in a city (10,000s)	3303.45	39.17	427.93	292.79	+
GDP per capita (GDP)	The total GDP in a region divided by local population (10,000 yuan)	14.99	0.11	1.46	1.26	+
Road density (Road)	Total road mileage in a region divided by its land area	3.41	0.01	0.56	0.40	+/−
Educational level (Edu)	Average years of schooling per person	11.52	6.41	8.19	0.60	+/−
Potential market accessibility (ACC)	Index of potential market accessibility	5.23	1.02	3.41	0.45	+
Export (Exp)	The amount of exports in each municipality (10,000 yuan)	4531.91	1.12	404.21	837.07	+
Specialization (Spe)	Share of manufacturing employment in total regional employment	0.52	0.11	0.26	0.09	+/−
Average wage (wage)	The average annual wage in one area (10,000 yuan)	7.27	0.44	0.87	0.30	+/−

Note: Here we measure the average years of schooling in the total population aged six and over using $EL = \sum_1^5 p_i NY_i$, where pi is the share of population with education level i, and NY_i is the average years of schooling associated with the ith education level. More details are available from the authors.

municipalities due to missing data, we end up with a data panel of 274 municipalities for the period 2000–2010. Together, these consist of a total of 3014 observations in our empirical study. Table 2 provides a basic statistical description of the main variables in our empirical study.

Following NEG theory, we provide the expected signs for the main explanatory variables. Market demand is expected to positively affect economic concentration because higher demand is very attractive to the industry (Holl, 2007). Potential market accessibility is the key indicator in the process of economic clustering, the positive effect of which has been widely accepted for theoretical and empirical reasons (Lopez et al., 2008; Puga, 2008). We expect the amount of exports to have a positive effect on industrial concentration due to higher market demand. The expected signs for infrastructure (transport and education) are uncertain, because theoretical models indicate that the role of these variables in explaining geographic concentration correspond with the level of economic development in a region (Holl, 2007; Ottaviano, 2008; Puga, 2008). The higher average annual wage can disperse industry due to high costs (Fujita et al., 1999), but at the same time, higher wages mean greater market demand: the impact of a higher wage is therefore not clear a priori, because it can motivate firms to move away (because of higher costs) or attract new firms to the region (because of higher market demand). Meanwhile, the effect of specialization is also unsure: on the one hand, the traditional industrial areas are prone to attract more industry to a region because of the home market effect, but on the other hand, more industry in one area means fiercer industrial competition (Fujita and Thisse, 2002).

3.3. Estimation strategy

In order to implement a convincing empirical test, the following econometric issues are taken into account.

The first concern is related to the problem of potential multicollinearity of the explanatory variables. A symmetric matrix of correlation coefficients can be constructed[8]. The results show that the ordinary correlation coefficient between *Spe* and *Export* is 0.77, higher than 0.5, indicating the existence of multi-collinearity between independent variables in our empirical model. Econometric theory tells us that differencing variables can reduce the multicollinearity in one model (Pedroni, 2007). Thus, we choose differenced *Exp* instead of the original series. The correlation coefficient between *Spe* and *Diff.(Exp)* is 0.02. Thus, the variables of specification and (differenced) exports can be estimated in the same model.

Secondly, in estimating the impact of transport improvement on industrial concentration, endogeneity may arise because it is not unreasonable to assume that the State prefers to build more roads in more developed areas. So as to ensure that results are not driven by reverse causation, our empirical estimation relies on the Generalized Method of Moments (GMM) method for dynamic panel models (Arellano and Bover, 1995; Blundell and Bond, 1998), which combines a system of equations that include regressions in differences and regressions in levels. The Generalized Method of Moments (GMM) estimators are generally designed for situations with 'small T, large N' panels, meaning few time periods and many individuals, with independent variables that are not strictly exogenous, which perfectly fit our case. Although a first-differenced GMM could be regarded as an alternative, the system GMM estimator that combines moment conditions obtained from equations in first differences with additional moment conditions exploited from the levels equations can be expected to provide more efficient estimates (Blundell and Bond, 1998; Jiwattanakulpaisarn et al., 2010). For GMM estimation of the differenced equations, we use restricted sets of instruments so as to avoid overfitting problems. Two specification tests including the Arellano–Bond test for serial correlation and the Sargan test for overidentifying restrictions are employed to assess whether the instruments are exogenous and thus valid to be used in the system GMM estimation.

Moreover, we transferred the natural logarithm form for some variables in our estimation (population size, GDP per capita, Export and Average wage) in order to narrow the absolute value of the original data, which is convenient for the further estimation. This transformation could not significantly affect the regression results (no effect on signs at all).

Finally, in order to check the robustness of our empirical results, an OLS estimation was also adopted since in these models, the relevant regional dummies could be included simultaneously.

4. Results and discussion

4.1. The distributive effect of transport infrastructure

Table 3 provides both Sys-GMM and OLS estimation results for Eq. (3) for all samples and for poor areas. Starting with the result for all samples in columns 1–4, most variables have the signs theoretically predicted. The positive signs for GDP per capita show that market demand is an important factor in the clustering of economic activity. This would seem to makes sense, because if the purchasing power in one area is much higher than in neighboring areas, more industry will want to relocate to this area due to the greater demand and larger market. Consistent with previous studies (Holl, 2004a, 2007; Lopez et al., 2008), the positive impact of potential market accessibility can be verified in our study (the coefficient is statistically significant and positive). The significantly positive regressor of average wage can be obtained, suggesting

[8] We did not present the correlation coefficients matrix due to the words limitation, however, more calculation details are available from the authors upon request.

Table 3
Main estimation results.

	All samples				Poor regions	
	Sys-GMM		OLS		Sys-GMM	OLS
	(1)	(2)	(3)	(4)	(5)	(6)
LQ(-1)	0.485(17.23)***	0.552(17.64)***	–	–	0.527(50.12)***	–
Road (Road)	0.121(5.75)***	0.709(5.76)***	0.102(6.40)***	0.208(5.07)***	−0.571(−11.62)***	−0.163(−2.12)*
Education (Edu)	0.065(3.15)***	0.093(4.29)***	−0.047(−4.44)***	−0.046(−4.39)***	0.016(1.18)	0.085(2.15)**
Population (Pop)	0.045(0.14)	−0.029(−0.09)	0.006(0.62)	0.001(0.14)	0.189(0.86)	0.005(0.16)
GDP per capita (GDP)	0.137(3.40)***	0.204(4.69)***	0.335(26.20)***	0.331(25.73)***	0.463(16.79)***	0.385(8.55)***
Potential market accessibility (ACC)	0.472(5.24)***	0.249(3.42)***	0.351(6.36)***	0.324(4.63)***	0.201(1.42)	0.293(2.75)***
Export (Exp)	−0.001(−0.73)	−0.011(−1.06)	−0.026 (−1.12)	−0.029(−1.24)	0.058(5.50)***	−0.086(−1.14)
Specialization (Spe)	0.417(3.01)***	0.086(0.35)	−0.197(−2.48)**	−0.215(−2.70)***	−0.304(−1.88)	0.454(0.65)
Average wage (Wage)	0.461(5.99)***	0.502(5.90)***	0.090(3.27)***	0.087(3.15)***	0.911(11.19)***	0.034(0.28)
W*Road	0.104(6.32)***	0.039(4.72)***	0.163(2.98)***	0.117(4.01)***	–	–
Road^2	–	−0.352(−4.69)***	–	−0.062(−2.79)***	–	–
Dummy coastal	–	–	−0.037(−2.22)*	−0.039(−2.34)**	–	–
Dummy capital	–	–	−0.256(−12.16)***	−0.254(−12.10)***	–	−0.239(−3.52)***
Dummy resource	–	–	0.122(10.45)***	0.122(10.51)***	–	0.168(4.12)***
Dummy period	–	–	−0.075(−5.47)***	−0.078(−5.66)***	–	0.012(3.21)***
Observations	2466	2466	2740	2740	495	550
Sargan test	[0.17]	[0.35]	–	–	[0.14]	–
AR(2)	[0.53]	[0.62]	–	–	[0.51]	–
Effects specification	Cross-section fixed	Cross-section fixed	No effects	No effects	Cross-section fixed	No effects
R^2	–	–	0.42	0.39	–	0.36

Note: *T*-statistics appears in parenthesis; *p*-statistics are shown in the square brackets. We define poor areas as the cities in the western provinces, including Gansu, Ningxia, Shaanxi, Yunnan, Guizhou, Sichuan, Chongqing, Guangxi and Qinghai. In all estimations, we transferred the natural logarithm form for population size (Pop), GDP per capita (GDP), Export (Exp) and Average wage (Wage) in order to facilitate further estimation.

*** Denotes statistical significance at 1%.

** Denotes statistical significance at 5%.

* Denotes statistical significance at 10%.

that the relatively higher wage in the coastal region has not constrained the development of Chinese firms until now. The greater market demand induced by the higher wage led more industries to relocate. The regression coefficient of export is not significant, probably because the share of international business is limited compared to China's huge domestic market demand. We also found that the traditional industrial areas (higher specialization) do not attract more industry to a region because two opposing effects (home market effect and higher competition) cancel each other out in practice (Fujita and Thisse, 2002).

Interestingly, as a typical social infrastructure, education has very different distributive effects on geographic concentration. On the national scale, the level of educational attainment has no stable impact on economic concentration (the sign of coefficient turns out not to be negative when dummies are added), but a positive effect on the lagging areas can be observed, as shown in columns 5 and 6 of Table 3. This finding conflicts with Liu (2008), probably because of methodology we adopted in this study (the potential endogeneity of independent variables has been conquered by Sys-GMM), and also because of the data-we used average schooling years as a proxy for education attainment level, which we consider more appropriate than literacy rate.

With respect to the regional dummies, some conclusions can be drawn from our empirical study. The coefficient of the resource-oriented municipalities dummy is significantly positive, suggesting the concentration of economic activity in these areas. This is in line with a fundamental insight from NEG, namely that natural resource endowments are the 'first geography', which provide regions with an initial comparative advantage in resource-oriented activities and lead to clustering in these activities (Fujita et al., 1999; Ottaviano, 2008). However, the industries did not cluster in the provincial capitals as we expected, as the provincial capital dummy is found to be statistically insignificant. The effect of this dummy is likely overwhelmed by the impact of other main explanatory variables on economic agglomeration (for instance, assuming that capital cities on average have denser motorway networks and higher education attainment level).

Focusing on the motorway network – the variable we are most interested in – there would appear to be a stable, statistically significant positive relationship between spatial economic agglomeration and road network improvement in China. This finding remains robust no matter which method we adopted or after the introduction of additional dummies, as seen in columns 1–4 of Table 3. These results definitely confirm the existence of a distributive effect of transport infrastructure in China, and imply that road infrastructure currently plays an essential role in changing China's spatial development patterns. An improvement in the road network could accelerate the spatial agglomeration of economic activities when all other things being equal. Moreover, the significantly positive coefficients of the spillover effect of motorway network suggest that motorway construction in the neighboring units also contributes to local industrial clusters.

In order to distinguish between the motorway networks in developed and less-developed regions, we also ran the empirical model for the lagging areas separately. The results are reported in columns 5 and 6 of Table 3. However, the coefficient for the road infrastructure changed to significantly negative, suggesting a loss of industry in these regions due to improvement to the motorway construction. This can help explain the puzzling widening gap between coastal and western regions in the last decade in the face of the considerable investment in transport facilities in poorer western provinces.

These findings may disappoint Chinese government officials who believe that investment in transport infrastructure is a key policy tool to stimulate growth and reduce regional disparity. In contrast, our empirical results show that improvement in transport facilities lead to greater concentration, mainly in the coastal provinces, as discussed in Section 2. Contrary to the expectations policymakers have, the undeniable coastal–interior disparities have grown further since the poor western areas have become more accessible.

However, it is worth noting that the relationship between these two variables is complex and not constant over time. One strand of literature connects the evolution of the spatial distribution of industries to the various stages of economic development (Ottaviano and Thisse, 2004; Ottaviano, 2008). We will therefore examine below how the transport–agglomeration nexus changes with better road infrastructure endowment.

4.2. The bell-curve of spatial development

The bell-shaped relationship between the degree of spatial concentration of economic activity and transport costs predicted by NEG theory has been empirically observed in many studies (Combes and Lafourcade, 2001; Holl, 2007; Teixeira, 2006). These authors argue that a high degree of core concentration occurs in the early phases of economic growth along with a widening rich-poor wage differential (Fujita and Thisse, 2002), and that as development proceeds, spatial de-concentration of industries and a narrowing wage differential follows. The emergence of a core-periphery structure is therefore expected to be followed by a phase of interregional convergence (Teixeira, 2006).

To examine this argument in the context of China, we added a quadratic road network term to our empirical model to examine the presence of this kind of bell-shaped relationship in China. We found a non-linear link between economic agglomeration and the road networks in China, as an inverted U-shaped relationship could be discerned from the positive sign of the road network term and the negative sign of the quadratic term from our regression results (columns 2 and 4 of Table 3). When the geographic concentration is relatively low, improvement in the road network appears to accelerate the spatial agglomeration of economic activity, whereas when the concentration is high, decreasing transportation costs help industries disperse to the peripheral regions. This phenomenon is in line with NEG theory models. However, to our knowledge, this paper is the first to report this result for the People's Republic of China.

In order to assess the possible implications of the planned transport policy, we used MATLAB to simulate the degree of concentration and fit for the transport–concentration nexus, as displayed in Fig. 3. In the short term, the fitted curve shows that economic agglomeration is positively associated with improvement in the road network (the peak value of motorway network density is 1.52). However, if we forecast this curve for the long term, we find that the pattern comes to resemble an inverted U. Improvement in the road network (reduction in transport costs) is likely to cause substantial spatial dispersal of economic activity when the transport costs fall below a critical level. The fitted result of the quadratic function is satisfactory (the coefficient of the quadratic term has a p-value of 0.03, and R^2 is 0.37).

Some European scholars also confirmed this bell-shaped relationship between transport costs and agglomeration by examining the distributive effects across several sub-periods or in simulation, as discussed in the introduction (Teixeira, 2006; Holl, 2004a). The countries they examined – such as Spain and Portugal – witnessed the dispersal of industries before 2010 because of their relatively higher developmental stage. China, however, will need to wait several decades for this dispersal to occur. If we look at the simulation results from Fig. 3, the massive dispersal looks likely to occur when the road network density is approximately three times greater than its current level. This is obviously an ambitious target, especially at a time when growth in China has already slowed in pace. Moreover, wages in the developed coastal regions are not very high compared with those in interior regions, mainly because of the seemingly 'endless' supply of cheap labor in China. The advantage of lower wages is expected to be too small to induce firms to relocate outside East China for a long period to come (Yu et al., 2013). It therefore seems likely that the spatial concentration and inequality in China will further intensify in the coming decades.

4.3. Transport infrastructure investment policy in China

In order to highlight the role of road infrastructure in China's economic development and regional disparity, we performed a further analysis of transport investment policy based on our empirical findings, as represented in Table 4.

Although policymakers and planners in China have neglected the impact of transport infrastructure on economic activity agglomeration in the decision-making process, the distributive effect of transport infrastructure is by no means insignificant. Our empirical results show that road infrastructure will increase the agglomeration of economic activities, thus widening coastal–inland disparity. Moreover, the negative impact of transport facilities on poor regions also indicates the outflow of industry over the last ten years. Accordingly, the increased industrial agglomeration in

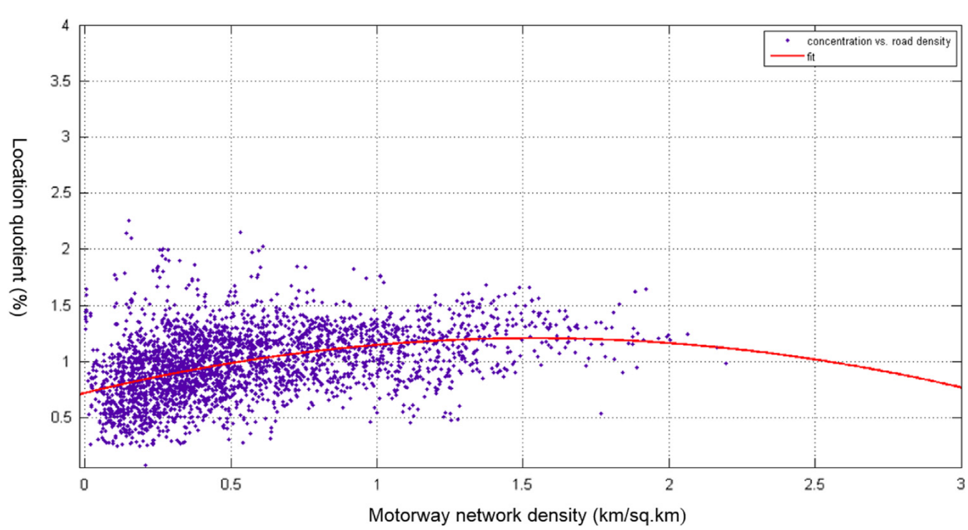

Fig. 3. Fitting the road improvement–agglomeration nexus in the long term.
Note: The x-axis denotes road network density (negatively associated with transportation cost), and the y-axis represents the location quotient, which measures the degree of economic concentration. We simulated the road–agglomeration nexus using quadratic polynomial fitting.

Table 4
Transport infrastructure investment policy analysis.

Aim of investment policy	Economic growth	√
	Relocation of economic activity	×
	Spatial equity	√
Result of investment policy	Economic growth	Higher growth rate with increased concentration of economic activity Modest growth in economic dispersal
	Relocation of economic activity	At the national level, transport infrastructure improvements leads to greater geographic concentration For the lagging areas, transport facilities facilitates spatial dispersal
	Spatial equity	In the short term, greater concentration brings greater economic growth with a widening gap between rich and poor In the long term, the inverted U-shaped relationship can be verified
Investment policy design	Spatial growth and equity	Trade-off between spatial growth and spatial equity

the coastal areas has resulted in growing spatial inequity in China. Nevertheless, we should also note that the higher degree of geographic concentration will lead to a higher national economic growth rate due to industrial specialization and technological innovation (Fujita and Thisse, 2002; Liu, 2008).

As the national government has invested heavily in road and railway construction in underprivileged West China, it is not surprising that more industry has relocated to the more developed areas in recent decades. In other words, the nation has achieved a higher economic growth rate at the expense of widening regional disparity. Current transport investment policy therefore appears to be faced with a trade-off between *spatial efficiency* (greater geographic concentration of industry and a higher growth rate) and *spatial equity* (more even spatial distribution of economic activities) (Zheng and Kuroda, 2013).

From a national perspective, transport infrastructure construction is necessary for China's growth goals; however, reducing urban–rural, coastal–inland disparity is another key policy objective of the Chinese government, as important as economic growth in recent years. It is therefore necessary for policymakers to intervene in the economic concentration process to narrow spatial inequality among Chinese regions. For instance, investment in education could counteract the trade-off between spatial equity (education did not exhibit a significant impact on economic concentration in our empirical findings) and spatial growth (the importance of education has been underlined in many studies, such as Fleisher et al., 2010). In particular, investment in education in poor areas could facilitate agglomeration in these regions, which would help strengthen these areas. From this perspective, improving education could be a valuable strategy for decision-makers wishing to promote spatial equity in China.

5. Conclusion

Transport infrastructure has played an instrumental role in the ascent of the China to global economic power status. The generative effects of transport infrastructure development measured on the macro-spatial scale often obscure distributive effects on the highly localized micro-spatial scale (Holl, 2007; Meijers et al., 2012). In this paper, we focused on such distributive effects and used municipal level panel data to empirically estimate the role of motorway network in the evolution of China's geographic distribution.

Overall, this study confirms the existence of such distributive effects of road infrastructure in China, suggesting that an improvement in transport facilities would accelerate geographic concentration on the national scale, which means greater growth according to the NEG theories (Fujita and Thisse, 2002). Even though this belief is widely supported by the observations of developed countries during the developmental process, very limited evidence on the developing countries have been provided. The findings of our study provides important implications of policy design for other emerging countries like China. To achieve the goal of fast growth, transport-oriented development strategy seems to be one possible solution to the developing countries at the take-off stage such as India and Brazil, with empirical support indicating that transport infrastructure could generate increases in output and reshape economic activities as well.

Moreover, our empirical results show the impact of the motorway network on economic agglomeration in the lagging western areas is negative, indicating a loss of industry in these poorer regions during the observed period. This means that the less-developed regions in China have become relatively more peripheral due to their increased accessibility by road, which is probably contrary to the original intention of the policymakers (Banerjee et al., 2012; Yu et al., 2013). Furthermore, consistent with the predictions of NEG models (Fujita et al., 1999; Ottaviano, 2008), the bell-shaped relationship between transport improvement and geographic agglomeration can be observed in our simulation of China, indicating that industry will spread to peripheral areas if transport costs are lowered sufficiently. However, this dispersal will require some time, due to China's developmental stage and unique social features. During this period, investment in transport infrastructure would allow more firms to further concentrate in the better-developed East China, which would widen the spatial inequity in China. These findings have implications for China's long term policy in terms of public funding and negative externalities. The result of investment in transport infrastructure represents a trade-off between spatial equity (more even spatial distribution of economic activities) and spatial growth (greater concentration and higher growth rate), while investment in education could offer an alternative to this trade-off (spatial equity and spatial efficiency). Given the political aim of reducing spatial inequity, the appropriateness of the current 'transport-infrastructure-stressed' investment policies in these areas should be questioned, especially for the lagging western areas (Yu et al., 2013), and investment in education would be strongly recommended, since improved education could stimulate economic growth in China and cause a more even pattern of development across regions.

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