



The nexus of transport infrastructure and economic output in city-level China: a heterogeneous panel causality analysis

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Abstract

The nexus between transport infrastructure and economic output has been subject to heated debates. Existing studies investigating their nexus between transportation and economic growth tend to focus on macroscales and utilize panel data but assume homogeneity across individual units. This paper aims to handle the problem of geographic heterogeneity and panel heterogeneity embedded in Granger causality between transportation and economic growth in China. According to a panel data of 216 cities from 1999 to 2014, heterogeneous Granger non-causality model at the nation level and region-specific heterogeneous Granger non-causality models are established. Results show that the heterogeneity of their mutual causality across cities cannot be neglected. In the direction from transport infrastructure to economic output, this paper finds homogeneous causality in all geographic regions except central China and it proves that the pulling effect of transportation on economic growth is positive in China but relatively marginal in eastern and western regions. In the reverse direction, heterogeneous causality can be found in all geographic regions. However, western region finds negative impact of economic growth on transportation. Overall, bidirectional causality is observed in 53.24% of the cities (115 out of 216) in the panel. Unidirectional causality is observed in about 39.35% (85 out of 216) and no causality in 7.41% (16 out of 216). This paper concludes with some main findings and region-specific policy implications.

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1 Introduction

Transportation and economic growth are closely linked. On the one hand, economic growth stimulates transportation demand. On the other hand, transportation improvement can drive economic growth by unlocking new sites for development, enlarging the existing product and labor markets and opening up new and larger markets (Rietveld and Nijkamp 1992; Vickerman et al. 1999), although these benefits cannot guarantee increased economic development. China's economy has gained astonishing growth in the last few decades, which catapulted the country to its current status as the world's second largest economy. However, investment-led growth has long been criticized as a key development strategy in China (Qin et al. 2006). In 2008, approximately USD 220 billion was spent on transport-related projects to counter the global economic crisis. In 2014, the total investment amount for highway, railway and waterway transportation stood at USD 393.25 billion in China to promote employment and grow investment circles (Xinhuanet 2015).¹ However, many critiques have been raised as to this investment-led economy and whether these projects are economically reasonable with enough considerations of travel demand (Martinsons 2008). Thus, the necessity of understanding the mutual impact of transportation in terms of transport supply as well as travel demand and economic growth is of considerable significance.

Although previous studies have emphasized on the economic effect of transport infrastructure at macrolevels since the ground-breaking study by Aschauer (1989), mixed results are shown in Table 1 because of different methodologies, geographical scales, time coverage and study contexts (Blum 1982; Boopen 2006; Farhadi 2015; Fujita and Krugman 2004; Lall 2007; Lall et al. 2004; Pradhan et al. 2013). On the US aggregate economy, transport infrastructure being viewed as public capital (Garcia-Mila et al. 1996), can promote specialization and long-run economic growth with the elasticity of 0.24, although its impact on the latter is not monotonic over time (Bougheas et al. 2000; Aschauer 1989). Tatom (1993) used the corrected statistical data and showed no evidence that an increasing public capital could produce higher private productivity. Fernald (1999) and Jiwattanakulpaisarn et al. (2010) find that when the growth of road infrastructure changes, the productivity growth disproportionately changes in different sectors of the economy in US. Crescenzi and Rodrigues-Pose (2012) took the European as the example and confirmed that transport infrastructure endowment cannot predict regional growth efficiently. Besides the direct effect, transport infrastructure would bring spatial spillover effect (Esfahani and Ramirez 2003) and agglomeration economies (Chatman and Noland 2011), which is conducive for increasing agricultural output (Crihfield and Panggabean 1995; Lall et al. 2004; Tong et al. 2013). However, clear evidence indicates a negative employment spillover from interstate lane-mile additions (Jiwattanakulpaisarn et al. 2010).

¹ The data source is from <http://www.chinanews.com/cj/2015/04-30/7245191.shtml>.

Table 1 Review of selected literature on the nexus between transportation (*T*) and economic growth (*D*)

Study	Country	Period	Results	Method	Variables (<i>T</i>)	Variables (<i>D</i>)	Geographic scales
Jiwattanakulpaisarn et al. (2010)	US	1984–1997	$T \rightarrow D$ $D \rightarrow T$ (both positive in services sector; both negative in manufacturing; spillovers both positive and negative)	VAR with spatial spillovers	Roadway lane miles	Real gross state product	48 US states
Jiang et al. (2017)	China	1986–2011	$T \rightarrow D$ (both positive and negative)	Structural equation model	The total length of the routes of highway, railway and waterway	GDP, income and consumption	29 provinces
Tatom (1993)	US	1949–1990	$D \rightarrow T$	Granger causality	Public capital investment	TFP	Nationwide
Zhao et al. (2018)	China	2012	$T \rightarrow D$ (air and land transport)	Spatial autoregressive regression	Both passenger traffic and freight volume of each mode of land, air, and water	GDP	277 cities
Fernald (1999)	US	1953–1989	$T \rightarrow D$	Seemingly unrelated regression	Public investment in roads	TFP growth	29 sectors of the US economy
Saidi and Hammami (2017)	75 countries	2000–2014	$T \rightarrow D$	Dynamic panel data models in simultaneous equations	Freight transport	Per capita GDP	Countries
Tong et al. (2013)	US	1981–2004	$T \rightarrow D$	Spatial Durbin panel data model	Road disbursement and railroad mileage	Physical quantities and market prices of crops and livestock	44 states

Table 1 (continued)

Study	Country	Period	Results	Method	Variables (<i>T</i>)	Variables (<i>D</i>)	Geographic scales
Shi et al. (2017)	China	1990–2013	$T \rightarrow D$ (negative)	VECM	Roadway/railway per worker, electricity generating capacity per worker, urban telephone landline subscribers per worker	Real GDP per worker	Provinces
Kim (2002)	Korea	1975–1992	$T \leftrightarrow D$	The recursive general equilibrium model	Transportation capital stock	GDP	Nationwide
Bougheas et al. (2000)	US	1970–1985	$T \rightarrow D$	Romer models	Paved roads per 1000 km	Per capita GDP growth	Nationwide
Fedderke et al. (2006)	South Africa	1875–2001	$T \leftrightarrow D$	Structural model	Public expenditure in transportation	GDP	Nationwide
Groote et al. (1999)	Netherlands	1853–1913	$T \rightarrow D$	VAR and impulse response analysis	Transport infrastructure investment	GDP	Nationwide
Cullison (1993)	US	1955–1992	No causality	Granger-causality test	Public investment in roads	Private GDP growth	Nationwide
Bose and Haque (2005)	32 developing countries	1970–1987	$D \rightarrow T$	The block Granger non-causality test	Expenditure in transportation and communication	Per capita GDP	Countries
Haque and Kim (2003)	15 developing countries	1970–1987	$T \rightarrow D$	Bivariate dynamic panel model	Public investment in transportation and communication	GDP Growth rate	Countries
Zhang and Fan (2004)	Rural India	1971–1994	$T \leftrightarrow D$	Panel causality test	Road length	Total factor productivity	District level

Table 1 (continued)

Study	Country	Period	Results	Method	Variables (T)	Variables (D)	Geographic scales
Fernandes and Pacheco (2010)	Brazil	1966–2006	$D \rightarrow T$	Granger's causality test	Total domestic passenger-kilometers	GDP	Nationwide
Iacono and Levinson (2016)	US	1988–2007	No causality	Granger's causality test	Road miles per square mile	The ratio of employment to workers	Minnesota counties
Sahooet al. (2010)	China	1975–2007	$T \rightarrow D$	Vector Error Correction Model (VECM)	Infrastructure index ^a	GDP	Nationwide
Fleisher and Chen (1997)	China	1978–1993	No causality	Regression model	Transportation route length per square kilometer	GDP	Provinces
Démurger (2001)	China	1985–1998	$T \rightarrow D$	Random-effects panel data	Transportation network length per square kilometer	GDP per capita	Provinces
Sturm et al. (1999)	Netherlands	1853–1913	$T \rightarrow D$	Granger-causality tests	Kilometer	GDP	Nationwide
Pradhan and Bagchi (2013)	India	1970–2010	$T \leftrightarrow D$ (road) $T \rightarrow D$ (rail)	VECM	Transport infrastructure investment	GDP	Nationwide
Fujita and Krugman (2004)	European Union 15 countries	1970–2008	$T \leftrightarrow D$ (heterogeneously)	Granger causality in panel data with fixed coefficients	TRP, PAS, GAS ^b	GDP per capita	Countries
Wang et al. (2016)	China	1978–2014	Positively correlated	Linear regression	Freight traffic, freight turnover	GDP	Nationwide

Table 1 (continued)

Study	Country	Period	Results	Method	Variables (<i>T</i>)	Variables (<i>D</i>)	Geographic scales
Arvin et al. (2015)	G-20 countries	1961–2012	No causality in the developed group $T \rightarrow D$ for the developing group	Panel VAR	Utilization rates per capita of air-passenger and air-freight transport facilities	Per capita economic growth	Countries
Pradhan et al. (2013)	India	1970–2012	$T \rightarrow D$	Autoregressive distributed lag (ARDL) and VECM	Road and rail length	GDP	Nationwide
Herranz-Loncán (2007)	Spain	1850–1935	$T \rightarrow D$ (weak)	Cointegration and VAR	Infrastructure capital	GDP	Nationwide
Farhadi (2015)	18 OECD countries	1870–2009	$T \rightarrow D$	Endogenous growth model	Public infrastructure expenditure	Labor productivity and total factor productivity	Countries
Song and van Geen-huizen (2014)	China	1999–2010	$T \rightarrow D$	Production function	Port infrastructure capital stock	GDP	Regions and provinces
Yu et al. (2012)	China	1978–2008	$T \rightarrow D$ (spatially varied)	Production function	Transport capital stock	GDP	Provinces
Liddle and Lung (2013)	107 countries	1971–2009	$D \rightarrow T$ (heterogeneous)	Error correction model	Transport energy per capita	GDP per capita	Countries

^aA principal component analysis is utilized to build an infrastructure index by considering six major infrastructure indicators, such as per capita electricity power consumption, per capita energy use, telephone line, rail density, air transport and paved roads, as a percentage of the total road

^bTRP refers to inland freight transportation per capita in ton-km; PAS refers to inland passenger transportation per capita in passenger-km; GAS refers to road sector gasoline fuel consumption per capita in kg of oil equivalent

Methodologically, the cost function approach is employed by most recent approach to examine whether and how transport infrastructure affects economic growth. Both positive and negative impacts of public capital on economic growth are described in related research (Seitz 1993; Vijverberg et al. 1997; Jiang et al. 2017) and the output elasticity is estimated from -0.92 to 0.27 (Jiang et al. 2017). However, this method is inadequate in uncovering their reverse causality from transport infrastructure to economic growth, thus producing biased estimates of the structural parameters because of the endogeneity problem (Beyzatlar et al. 2014; Fujita and Mori 2005; Pradhan 2019). Unlike the cost function approach, the production function approach as well as the OLS estimation, the causality models such as vector auto-regression, are able to investigate their mutual interaction between transport infrastructure and economic growth with the estimated elasticity from -0.31 to 0.52 (Berndt and Hansson 1991; Boarnet 1996; Randolph et al. 1996). The results about the sign, elasticity and the direction are inconsistent in related studies as seen in Table 1.

To date, these techniques have been utilized mostly to analyze macroeconomic time series. Panel data turns out to be more popular than time series data or cross-sectional data since it shows more accuracy such as increasing the degrees of freedom and reducing the collinearity among independent variables (Erdil and Yetkiner 2004). Some techniques examining panel data causality have been constructed and widely used, because they allow for nonstationary individual effects in the panel data sets (Holtz-Eakin et al. 1988). Zhang and Fan (2004) conducts a Granger causality test to examine their relation between road density and agricultural productivity in 290 districts of rural India and finds a unidirectional causality from the former to the latter. Using Vector Error Correction Model (VECM), Pradhan and Bagchi (2013) find different causality relations, respectively, for road and rail transport with taking India as a case study for 1970–2010. Mutual causality is more frequently existent for road infrastructure despite a unidirectional causality from rail infrastructure to economic growth. By running a panel vector autoregressive model, Arvin et al. (2015) prove that their causality relationship is also closely correlated with economic conditions for G-20 countries for 1961–2012, namely no causality for the developed group and only a unidirectional causality from transport infrastructure to economic growth for the developing group.

The panel causality model proves to be effective and practical to examine the direction of causality. However, the use of cross-sectional information in panel data implies to consider the heterogeneity across individuals in defining the causal relation (Venet and Hurlin 2001), which has been neglected in most previous studies. Following Erdil and Yetkiner (2009) and Beyzatlar et al. (2014), this paper proposes an extension of conventional Granger causality—a Granger non-causality test for heterogeneous panel data models. The extension of Granger causality allows considering both the heterogeneity of the causality and the heterogeneity of the data generating process (Hurlin 2004a, b). Erdil and Yetkiner (2009) used the Granger non-causality analysis to investigate the Granger-causality relation between health care expenditure and output. The results indicated the bidirectional causality is the dominant type and the pattern of unidirectional causality is not homogenous, that is, one-way causality generally is from health to income in high-income countries

while the reverse holds for low- and middle-income countries. Beyzatlar et al. (2014) investigated the Granger-causality relation between GDP and transportation of EU-15 countries in 1970–2008. They verified the dominant type of bidirectional causality, but found instances of one-way or no Granger-causality in countries with the lowest income. A heterogeneous bias is easily introduced if the use of panel data assumes a homogeneous relationship across individuals in defining causal relationships (Pesaran and Smith 1995). Venet and Hurlin (2001) proposed an extension of the Granger causality definition to test homogeneous causality against heterogeneous causality. This method has been applied to investigate the causality between carbon emissions and economic growth (Maddison and Rehdanz 2008), between government expenditure and growth (Gregoriou and Ghosh 2009), between exports and economic growth (He and Zhang 2010) and between energy consumption and GDP (Akkemik and Göksal 2012). Therefore, the heterogeneity problem in examining the causal relationship in panel data should be paid enough attention.

Many studies have analyzed the influence of transport infrastructure on economic output in China at the national level or regional level or provincial level. Sahoo et al. (2010) justified China's high investment on infrastructure since the early 1990s by confirming the unidirectional causality from infrastructure development to regional growth. Based on a panel data of 31 provincial units in China for 1978–2008, Yu et al. (2012) proved that the effect of transport infrastructure on productivity is spatially varied. Specifically, the estimated elasticity parameters of transport infrastructure are 0.09, 0.24 and 0.08, respectively, in the eastern, central and western regions. The study of Song and van Geenhuizen (2014) indicates the positive effect of port infrastructure on economic growth in China's four regions by performing the production function although the elasticity varies considerably among four regions of China. Using the technique of VECM, Shi et al. (2017) found that the contribution of infrastructure investment to regional growth demonstrates significant regional differences and temporal effect. Their study further verified the inverse U-shaped relation between infrastructure investment and growth which supposes a "crowding-out effect" of private capital. Using a panel dataset across regions of China for 1986–2011, Jiang et al. (2017) concluded that the magnitude of transport infrastructure on economic growth is sensitive to spatial scales. These differences could be explained by phases of development, transport investment policies, local spatial spillovers from neighboring areas as well as reform institutions from the central Chinese government.

Overall, it is of vital significance to understand their interplay between transport infrastructure and economic output in the context of a growing economy like China for the necessity of formulating appropriate transport policies (Soja 2009). This paper aims to provide a comprehensive empirical analysis of the speculated nexus between transport infrastructure and economic output observed in city-level China during 1999–2014. This study tries to contribute in the following aspects. First, we employ the extended panel Granger non-causality model to examine the heterogeneity problem embedded in their causal relation between transport infrastructure and economic output. Moreover, four types of causality relations are also examined. Second, empirical analysis at the city-level China is conducted and transport supply as well as travel demand represents major components of transport infrastructure.

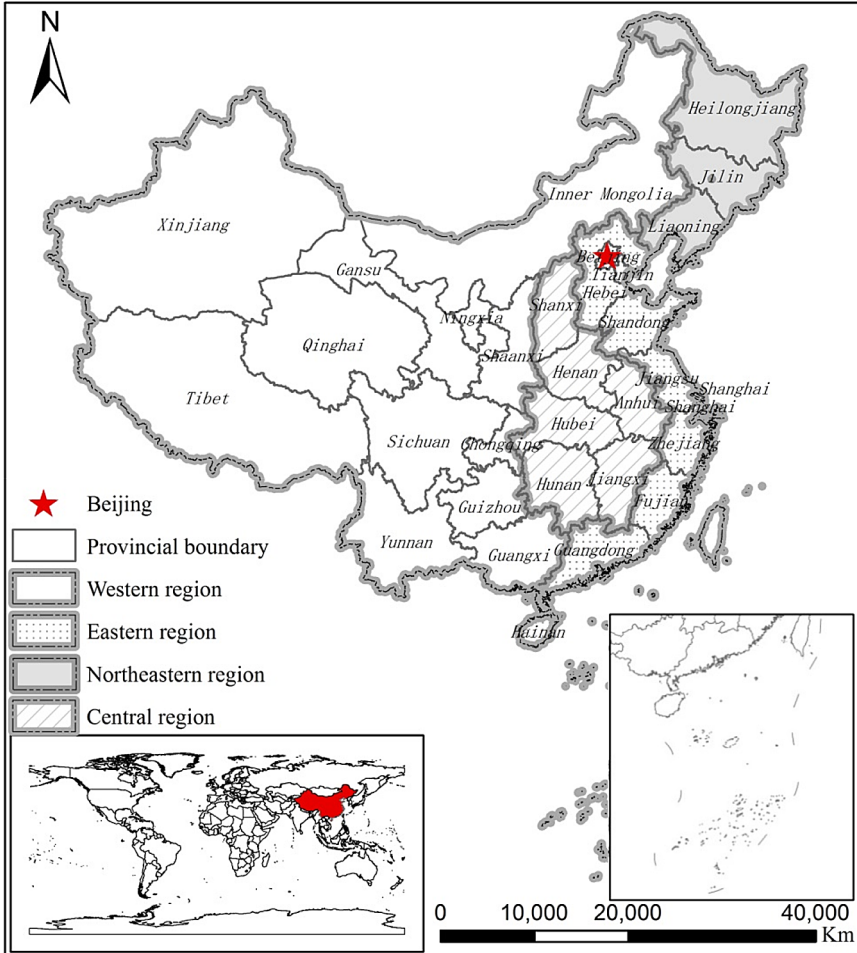


Fig. 1 The study area

Third, regional differences of their mutual causality are discussed and further investigation of transport-led growth or growth-led transport infrastructure in four regions of China is made to formulate some policy implications.

The remaining content of this paper is organized as below: Sect. 2 presents the data sources and study area. The methodology and testing procedures are explained

in Sect. 3. Section 4 describes the results and Sect. 5 clarifies the main findings. Section 6 concludes with the main findings and policy implications.

2 The study area and data description

2.1 The study area

China is often known for undergoing fast economic growth stimulated by the reform and opening-up policy since 1978. According to official statistics, from 1978 to 2013, the country achieved an annual growth rate of Gross Domestic Product (GDP) of 9.77% and an annual growth rate of per capita GDP (PCGDP) at 8.67% (CSB 2014). Transport infrastructure also expanded significantly during the same period (Chinahighway.com 2011), with the national total length of highway growing at an average rate of 4.64% per annum. Yet such economic and transportation progress has been made in a geographically highly uneven manner. Taking differences in geographical context and level of development into account, China can be divided into four regions as seen in Fig. 1: eastern, central, western and northeastern.² In terms of economic growth, the eastern and western regions are on the lead. The growth rate of GDP for the same period is 10.40% in eastern region, 9.72% in central region, 9.82% in western region and 8.43% in northeastern region.

However, in terms of transport development, infrastructure is slightly improved more quickly in the central and western regions. From 1982 to 2013, while highway length has grown at an average annual rate of 5.55% in the central region, 5.21% in the western region, it was only 4.97% in the eastern region, and 4.17% in the northeastern region. There does not seem to be any one-to-one correspondence in the pace of transport infrastructure and economic output. This raises the question of whether transport improvement equally facilitates economic growth in different regions.

2.2 Data sources and data description

In this study, we collected data on GDP, population, transport infrastructure, capital input and labor input for the 1999–2014 period across cities. The data source is mainly from the China City Statistical Yearbook and the China Statistical Yearbook. Our database includes 216 cities from across China. We categorized these cities into four groups by geographical location to ascertain whether any structural differences exist

² The eastern region encompasses the economically developed areas along the coast, including three provincial-level municipalities (Beijing, Tianjin and Shanghai) and seven provinces (Hebei, Jiangsu, Zhejiang, Shandong, Fujian, Guangdong, and Hainan). The other regions are inland areas with relatively lagging economies. The central region includes six provinces (Shanxi, Anhui, Jiangxi, Henan, Hubei and Hunan). The western region includes one provincial-level municipality (Chongqing) and eleven provinces (Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang, Guangxi and Inner Mongolia). The northeastern region includes three provinces (Liaoning, Jilin and Heilongjiang).

Table 2 Descriptive statistics for variables about transport infrastructure, economic output, capital and labor

Variables	Mean	Median	Minimum	Maximum	SD
<i>All cities</i>					
$T(\ln T)$	5.35 (1.30)	3.59 (1.28)	0.22 (-1.53)	85.70 (4.45)	6.03 (0.85)
$D(\ln D)$	45.37 (3.29)	26.11 (3.26)	0.84 (-0.18)	589.96 (6.38)	57.71 (1.03)
$K(\ln K)$	24.82 (2.49)	12.86 (2.55)	0.25 (-1.40)	247.29 (5.51)	32.61 (1.28)
$L(\ln L)$	78.25 (4.06)	55.01 (4.01)	5.86 (1.77)	903.11 (6.81)	77.43 (0.74)
<i>Eastern region</i>					
$T(\ln T)$	7.30 (1.63)	4.92 (1.59)	0.56 (-0.58)	85.70 (4.45)	7.68 (0.83)
$D(\ln D)$	69.04 (3.79)	45.10 (3.81)	1.27 (0.24)	589.96 (6.38)	75.26 (0.96)
$K(\ln K)$	33.02 (2.94)	20.88 (3.04)	0.55 (-0.59)	213.78 (5.36)	34.89 (1.13)
$L(\ln L)$	103.11 (4.33)	73.02 (4.29)	8.83 (2.18)	903.11 (6.81)	99.58 (0.76)
<i>Central region</i>					
$T(\ln T)$	4.54 (1.25)	3.51 (1.26)	0.50 (-0.70)	25.93 (3.26)	3.73 (0.72)
$D(\ln D)$	33.72 (3.13)	22.29 (3.10)	2.08 (0.73)	355.58 (5.87)	38.04 (0.86)
$K(\ln K)$	21.09 (2.35)	10.90 (2.39)	0.25 (-1.40)	247.29 (5.51)	28.77 (1.23)
$L(\ln L)$	66.30 (3.98)	53.80 (3.99)	9.13 (2.21)	428.05 (6.06)	52.74 (0.64)
<i>Western region</i>					
$T(\ln T)$	4.55 (1.11)	3.04 (1.11)	0.22 (-1.53)	58.25 (4.06)	5.87 (0.87)
$D(\ln D)$	28.06 (2.87)	17.24 (2.85)	0.84 (-0.18)	355.12 (5.87)	34.73 (0.97)
$K(\ln K)$	18.68 (2.16)	8.78 (2.17)	0.28 (-1.27)	234.16 (5.46)	28.08 (1.28)
$L(\ln L)$	58.60 (3.76)	44.09 (3.79)	5.86 (1.77)	515.56 (6.25)	58.57 (0.76)
<i>Northeastern region</i>					
$T(\ln T)$	3.32 (0.86)	2.30 (0.83)	0.28 (-1.27)	20.57 (3.02)	3.22 (0.81)
$D(\ln D)$	34.51 (2.97)	17.86 (2.88)	2.41 (0.88)	275.57 (5.62)	45.30 (1.03)
$K(\ln K)$	20.73 (2.13)	8.34 (2.12)	0.54 (-0.62)	240.39 (5.48)	35.44 (1.36)
$L(\ln L)$	68.48 (3.99)	46.34 (3.84)	15.58 (2.75)	378.33 (5.94)	60.82 (0.62)

D denotes gross domestic product, representing economic output (the unit is billion RMB); T denotes the weighted summation of three normalized transport variables, representing transport infrastructure; L denotes labor input represented by the number of employed persons (the unit is ten thousand persons); K denotes capital input represented by the fixed asset investment (the unit is billion RMB); $\ln T$, $\ln D$, $\ln K$ and $\ln L$ are, respectively, the natural logarithm of T , D , K and L

at the subnational scale. These groups are the eastern region (78 cities), central region (58 cities), western region (47 cities) and northeastern region (33 cities) (Fig. 1).

In this paper, we prefer to infer from a theoretical framework instead of unrestricted choice of control variables. Specifically, we employ the widely used production function where economic output can be expressed as a function of capital, labor and transport infrastructure. The variables capital and labor are added to the panel causality regressions as the control variables. By adding these two variables, the impact of transportation as an independent variable to economic output, as well as vice versa, relative to other independent variables can be gauged. In so doing, the multivariate heterogeneous panel Granger causality analysis could more accurately measure their causal relationship (Leightner and Inoue 2012).

Through dynamic factor analysis, transport infrastructure is measured by the weighted summation of the total highway length, the total passengers by rail and highway and the total volume of rail and highway freight, ranging from 0 to 100. The eigenvalues for the above three indicators are all larger than 1. The first indicator namely the total passenger capacity by rail and highway, accounts for 70.18% of transportation development; the second indicator namely the total volume of rail and highway freight, accounts for 17.68% of transportation development; the third indicator namely highway length, accounts for 12.14% of transportation development. Economic output is measured by real GDP in constant 1990 RMB currency. Capital input refers to the fixed asset investment at the comparable price in 1990, while labor input refers to the number of employed persons.

In total, all panel data are available for the time period from 1999 to 2014. Table 2 presents descriptive statistics of all variables, namely T representing transport infrastructure, D representing economic output, K representing capital input and L representing labor input. From a geographic perspective, the eastern region has the highest mean value of all variables, indicating the strength of its economy, adequate provision of transport infrastructure, as well as the well-functioning labor and capital market in the coastal China. However, the north-eastern region has the lowest level of transport infrastructure and the western region has the lowest levels of economic strength, fixed asset and labor supply. Furthermore, the eastern region has the highest standard deviation for transport infrastructure and GDP, indicating the large disparity of transportation and economic output in the coastal China.

3 Methodology

We employ the extended panel Granger non-causality model as developed by Venet and Hurlin (2001). The fixed effect estimator and lagged value of the dependent variable are also included in the panel model. We apply this technique to a balanced panel of 216 cities in China over the 1999–2014 period. The following model is utilized to test the heterogeneous causality from transport infrastructure to economic output:

$$\ln D_{i,t} = \sum_{k=1}^p \gamma^k \ln D_{i,t-k} + \sum_{k=1}^p \beta_i^k \ln T_{i,t-k} + v_{i,t} \quad v_{i,t} = \alpha_i + \varepsilon_{i,t}$$

Likewise, the reverse causality can be elaborated as shown below:

$$\ln T_{i,t} = \sum_{k=1}^p \gamma^k \ln T_{i,t-k} + \sum_{k=1}^p \beta_i^k \ln D_{i,t-k} + v_{i,t} \quad v_{i,t} = \alpha_i + \varepsilon_{i,t}$$

where i refers to the cross-sectional unit; t denotes time; k is the number of time lags; $\varepsilon_{i,t}$ are i.i.d. $(0, \sigma_\varepsilon^2)$; and α, β, γ are the parameters to be estimated. In this model, we assume that the autoregressive coefficient γ^k and regression coefficient slope, or elasticity, β_i^k are constant for $\forall k \in [1, p]$. Therein, γ^k is identical for all

Table 3 Panel unit root test results for $\ln D$, $\ln T$, $\ln L$ and $\ln K$

All cities	ADF test		LLC test	
	Level	1st diff.	Level	1st diff.
$\ln D$	344.67	683.53***	-18.02***	-2.54***
$\ln T$	302.07	1290.60***	-0.79	-26.09***
$\ln L$	178.88	1433.06***	4.07	-24.99***
$\ln K$	316.84	914.48***	-11.69***	-13.43***

$\ln D$ represents economic output, $\ln T$ represents transport infrastructure, $\ln L$ represents labor, $\ln K$ represents capital

***Significant at 1% level, **significant at 5% level, *significant at 10% level

Table 4 Panle cointegration tests

	Pedroni test		Kao test
	Panel ADF	Group ADF	
All cities	-7.49***	-10.40***	-18.52***
Eastern region	-6.10***	-8.70***	-11.30***
Central region	-4.86***	-6.75***	-12.20***
Western region	-2.11**	-2.88***	-7.48***
Northeastern region	-1.98**	-0.85**	-8.32***

***Significant at 1% level, **significant at 5% level, *significant at 10% level

cross sections, whereas β_i^k could be heterogeneous across all individuals. $\ln K$ and $\ln L$ are entered into the equations as exogenous variables.

For a heterogeneous panel data framework, four types of causality hypothesis can be tested: homogenous non-causality (HNC), homogeneous causality (HC), heterogeneous non-causality (HENC) and heterogeneous causality (HEC). In this paper, we test for these hypotheses for each direction of causality between transport infrastructure and economic output of cities in the following order. First comes the test for HNC, which means that transport infrastructure and economic output are causally unrelated for all cities. If the HNC hypothesis is rejected, a second test for HC is followed to determine if transport infrastructure and economic growth has a causal link with homogeneous elasticity among all individuals. If the HC hypothesis is also rejected, a third test is undertaken for HENC. Acceptance of the HENC hypothesis means that the existence of a sub-group of cities for which transport infrastructure does not cause economic growth. On the contrary, if the HENC hypothesis is rejected, it implies a causal relation between transport infrastructure and economic output for all cities of the panel, but the data generating process is still heterogeneous. Then the HEC hypothesis is accepted.

4 Empirical results

4.1 Stationarity test and cointegration test for panel data

In order to examine the stochastic properties of the panel data, panel unit root test such as Dickey–Fuller (ADF) tests and Levin et al. (2002) (LLC) tests, are employed to detect the stationarity of panel data. Table 3 reports the results of ADF and PP tests for four variables (ln*D* representing economic output, ln*T* representing transport infrastructure, ln*L* representing labor, ln*K* representing capital). Results reveal that the panel data is nonstationary in level. However, the first differences for these four variables lead to stationarity.

Furthermore, panel cointegration tests such as Pedroni and Kao tests are employed to detect their long-run or co-movement relation between transportation and economic growth. The result as shown in Table 4 confirms the presence of their long-run co-movement between transportation and economic growth in eastern region, central region, western region and northeastern region. This indicates the strong long-run association between transport infrastructure and economic output in China although further studies are required to clarify the underlying causal mechanisms and causal directions.

4.2 Panel causality analysis from transport infrastructure to economic output

In order to determine the optimal lag length for the dependent variable and independent variables, we utilize the vector autoregressive (VAR) lag length criteria, such as Akaike (AIC), Schwarz (SC) and Hannan–Quinn (HQ) (Lütkepohl 2005). In the VAR model, the variables of transport infrastructure and economic output are entered as endogenous variables while the variables of capital and labor as exogenous variables. In most VAR models, we chose SC information criterion to choose the optimal lag order. Heteroscedasticity in panel data model is corrected using cross section weights estimation method. *F* tests are employed to examine whether each causality hypothesis is accepted or rejected.

Homogeneous (non)causality hypothesis is first tested and the results are shown in Table 5. Homogeneous non-causality hypothesis is rejected at 1% level for all cities and homogeneous causality hypothesis gets rejected as well at 1% level for all cities. According to geographic divisions, homogeneous non-causality hypothesis is rejected at 5% level in these four sub-regions according to F_{HNC} statistics, whereas eastern region, western region and northeastern region accepts homogenous causality hypothesis at 5% level. The fourth column indicates that only central region finds panel heterogeneity.

In the next step, heterogeneous non-causality hypothesis is tested and this hypothesis cannot get rejected for central region at 1% level. Only 18 out of 58 cities exhibit heterogeneous causality from transportation to economic growth in central China. 42 cities from central region demonstrate heterogeneous non-causality. For this sub-group, transportation does not Granger cause economic growth.

Table 5 F statistics for HNC, HC and HENC hypotheses from transportation to economic growth

Type	Lag length	F_{HNC}	F_{HC}	F_{HENC}
All cities	3	1.70***	1.27***	0.87
Eastern region	2	1.25**	1.06	–
Central region	2	2.31***	1.99***	0.59
Western region	1	1.43**	1.34	–
Northeastern region	2	1.47**	1.08	–

HNC denotes homogenous non-causality hypothesis; HC denotes homogenous causality hypothesis; HENC denotes heterogeneous non-causality hypothesis

***Significant at 1% level, **significant at 5% level, *significant at 10% level

Overall our results suggest some evidence of causality from transport infrastructure to economic growth and this causal relation is only heterogeneous in central China. Although homogeneous causality exists in eastern, western and northeastern regions, their elasticity coefficients are different, which is 0.007, 0.006 and 0.053.³ The facilitation of transportation on economic growth is positive and is only statistically significant in northeastern region. As the major heavy-industry base in the past, economic development of northeastern region has been challenged by low marketization, insufficient vitality of state-owned enterprise, single industrial structure, resource depletion, etc., emphasized by President Xi (SinaLiaoning 2016). Therefore, the strategy of reviving northeastern region was proposed in 2004. Therein, improving transport network is recognized to be prerequisite for pulling economic growth. During the 11th 5-year plan (2006–2010) northeastern region totally invested 369 billion yuan in constructing transport infrastructure, accounting for 7.85% of the nationwide.

However, for the eastern and western China, in spite of homogeneous causality, the role of transportation on economic growth is relatively marginal. The eastern region as the mostly developed region in China has sufficient transport supply and transport demand, which plays an important role in strengthening regional economy in coastal cities. However, the continuing investment of transportation may not lead to a sustaining growth of economic development for the eastern region. More development strategies should be oriented at technological innovations, industrial structure upgrading, environmental protection and so on. The western region as the relatively backward area in China is constrained by the mountainous terrain and fragile ecological environment. The findings of this paper imply that the transport infrastructure is adequate for its economic development in western region and further transport investment cannot significantly stimulate its economy.

An important finding of this paper is that the causality from transportation to economic growth is highly heterogeneous in central China. This finding proves the

³ The p values corresponding to these three elasticity coefficients are 0.38, 0.39 and 0.05. Therefore, only the elasticity coefficient in northeastern region is significant in statistics.

Table 6 F statistics for HNC, HC and HENC hypotheses from economic growth to transportation

Type	Lag length	F_{HNC}	F_{HC}	F_{HENC}
All cities	3	2.60***	1.88***	0.59
Eastern region	2	2.24***	1.79***	1.52
Central region	2	1.98***	1.63***	0.76
Western region	1	4.66***	4.42***	0.91
Northeastern region	2	2.69***	2.12***	4.03***

HNC denotes homogenous non-causality hypothesis; HC denotes homogenous causality hypothesis; HENC denotes heterogeneous non-causality hypothesis

***Significant at 1% level, **significant at 5% level, *significant at 10% level

significance of panel heterogeneity since individual predictors for the causal relation differs among panel members. Central region as the major supplier of grains in China, transportation is significant for shipping goods and labors, thus increasing total factor productivity and promoting economic growth in China. As a result of the strategies—“Rise of Central China” in 2004, a continuing large sum of fiscal investment⁴ is flown to transportation industry to conquer the bottlenecks of economic growth in central China. However, although these transport investments have been always believed to be effective, some cities in central China cannot find any causality from transportation to economic growth. This finding point to divergent results in causality studies listed in Table 1. In other words, panel heterogeneity may be an important determinant of the causal relation since the causality relationship only holds for a sub-group of cities in the panel.

4.3 Panel causality analysis from economic output to transport infrastructure

The results for homogenous non-causality test running from economic growth to transportation are shown in the third column of Table 6. This hypothesis gets rejected for all sub-groups at 1% level, which is slightly different from the results for the reverse causality explained in the previous subsection. As revealed in the fourth column of Table 6, homogenous causality hypothesis is rejected as well for all sub-samples at 1% level, indicating no homogeneous (non)causality running from economic growth to transportation.

Consequently, we further look at the causality at the individual level by testing heterogeneous non-causality hypothesis and heterogeneous causality hypothesis. Heterogeneous non-causality is presented in eastern, central, western regions, whereas heterogeneous causality exists in northeastern region. A total of 53 cities, including 11 out of 78 (14.10%) cities from eastern region, 15 out of 58 (25.86%) cities from central region, 27 out of 47 (57.45%) cities from western region, and 18 out of 34 (52.94%) cities from northeastern region exhibit heterogeneous

⁴ A total investment of 854 billion yuan is completed in central China during the 11th 5-year plan (2006–2010).

non-causality, which means economic growth does not Granger cause transportation in these sub-groups.

Overall we find that the causal relationship from economic growth to transportation is highly heterogeneous across each subregion in China. In eastern region, 67 out of 78 cities demonstrate heterogeneous causality mostly with positive elasticity coefficients. The average elasticity coefficient is 1.28 with the highest value of 7.41 in Laiwu City in Shandong province. In central region, 43 out of 58 cities find heterogeneous causality mostly with positive elasticity coefficients. However, the average elasticity coefficient is only 0.29 with the highest value of 1.67 in Wuhan city of Hubei province. In western region, 20 out of 47 cities find heterogeneous causality mostly with negative elasticity coefficients. The average elasticity coefficient is -0.16 with the highest value of 0.80 in Meishan city in Sichuan province. In north-eastern region, 16 out of 33 cities find heterogeneous causality mostly with positive elasticity coefficients. The average elasticity coefficient is 1.31 with the highest value of 4.01 in Baishan city in Jilin province.

Therefore, the significance of economic growth on transport improvement is more evident in developed areas like the coastal/eastern region. Regions with better performance of economic growth have more tendencies to improve transportation, which is understandable that developed regions recognized the pulling effect of transportation and the government is financially capable of providing transportation. The effect from economic growth to transportation is roughly positive but only evident in a few cities of the western China. It may be attributable to the mode of economic growth as well as its insufficient marketization within the western region. The mode of economic growth in western region is still extensive and resource-relied, resulting in increased pollution and environmental destruction. Negative impacts of economic growth and insufficient marketization within the western region cannot promote the flow of labor elements. Overall, this finding provides another evidence for the heterogeneity of the causal relationship in the panel. Appropriate policy-making should stress on both geographical difference and the internal socio-economic differences within each subregion.

5 Discussion

We extend the causality research between transportation and economic growth by introducing panel heterogeneity and apply it to the China context across cities. The panel consists of 216 cities covering the period from 1999 to 2014. Most previous studies tend to assume the homogeneous causality in a panel data framework and the finer-scale research for the causality between transportation and economic growth in China is still lacking. The contribution of this paper is to enrich the existing empirical evidences for their causal relationship by examining how geographic heterogeneity and panel heterogeneity work and to shed some new lights on transportation-led or development-led policy-making for the Chinese government.

Previous studies implicitly assume panel homogeneity and geographic homogeneity in examining the causal relationship between transportation and economic growth. Previous studies in the China context as shown in Table 1 mainly conclude

the unidirectional causality from transportation to economic growth mainly focusing on provinces. Only Yu et al. (2012) mention that their causality from transportation to economic growth is spatially heterogeneous. Our paper tries to enrich existing studies at the city level in four geographic regions by uncovering the sign, elasticity and direction of their causality in mutual directions. This paper verifies the extensive existence of panel heterogeneity in both causality directions between transportation and economic growth, especially in the reverse direction. More specifically, the causal relation between transportation and economic growth differs among four geographic regions. Unlike previous studies, we cannot find homogeneous causality from transportation to economic growth in central China.

Although Beyzatlar et al. (2014) take panel heterogeneity into account when investigating the Granger-causality between transportation and GDP in EU-15 countries, this study only investigate the heterogeneity in the direction of their causality between transportation and economic growth regardless of the sign and the elasticity. This paper tries to enrich existing studies by providing the sign, elasticity and direction of their causality in order to uncover their complex relationship in China context. An important finding of this paper is that the pulling effect of transportation on economic growth is positive in all geographic regions but relatively marginal in eastern and western regions. This partly proves the Chinese slang “pave the road to get rich”. However, to what extent transportation can stimulate economic growth is heterogeneous across geographic regions (He et al. 2017). In the reverse causality, only western region finds negative impact of economic growth on transport improvement. The mode of economic growth in western region is still extensive and resource-relied, resulting in increased pollution and environmental destruction. Negative impacts of economic growth and insufficient marketization within the western region cannot promote the flow of labor elements. Overall, the reverse causality differs among each city and each geographic region. It suggests that we take individual city perspective rather than the aggregated country when devising policy recommendations.

Panel causality tests show that bidirectional causality is observed in 53.24% of the cities (115 out of 216) in the panel. Unidirectional causality is observed in about 39.35% (85 out of 216) and no causality in 7.41% (16 out of 216). We conclude for the 115 cities exhibiting bidirectional causality that there is an interaction between transportation and economic growth. This is called “feed-back hypothesis”, which implies that transportation serves as an engine of economic growth and is also determined by the scale of economic activities. The share of cities with bidirectional causality is mainly from relatively developed eastern and central regions. The interaction between transportation and economic growth is important in this respect. On the one hand, conforming to previous cross-country studies as shown in Table 1, bidirectional causality is likely to occur in developed countries such as US, EU, Netherlands or South Africa. This study proves this viewpoint with taking city-level China as a case study. On the other hand, China’s resource-rich provinces in the under-developing western region exhibit bidirectional causality. Different from eastern region, the construction of transport network in western region is more dependent on fiscal transfers from the central government. This paper finds evidence for the significance of transportation for sustaining economic growth in these

less-developed cities, which is consistent with the studies of Hart (1993) and Zhang et al. (2007) that the local government is motivated to drive economic growth within its jurisdiction in less-developed regions.

There is unidirectional causality from transportation to economic growth in 11 cities in eastern region, 4 cities in central region, 27 cities in western region and 17 cities in northeastern region. The share of cities with unidirectional causality from transportation to economic growth is mainly from western and northeastern regions. Given that these cities are mainly resource-exhausted or topography-constrained; transport infrastructure in this group is relatively lagged, which also reflects the transport inequality in four sub-regions of China. Thus, in order to stimulate their growth, some preferential policies from the central government should target at these cities when proposing transport-related projects. In the case of causality from economic growth to transportation, cities in this group include 26 cities in central China. In these economies, blind investment and repeated construction will result in a waste of resources, traffic jam, even destroying urban landscape and ecology, etc. Even these transport investment cannot see any real economic feedback. A possible solution is to put in place relevant policies to enhance the usage efficiency of transport infrastructure and promote smart transportation and this may rather promote economic development.

There is no Granger causality in either direction in 16 cities in central China. In these cities, transportation and economic growth are independent from each other and investment in transport infrastructure has a neutral effect on economic development. These cities do not seem to share a common characteristic in terms of development trajectories.

6 Conclusions and policy implications

In this paper, heterogeneous Granger non-causality model at the national level and region-specific heterogeneous Granger non-causality models are established with the panel data of 216 cities from 1999 to 2014. The mutual interaction between transportation and economic output are estimated. According to the results of this empirical study, we can conclude the following findings.

First, this paper verifies the extensive existence of panel heterogeneity and geographic heterogeneity in both causality directions between transportation and economic output, especially in the reverse direction. Second, in the direction from transport infrastructure to economic output, this paper finds homogeneous causality in all geographic regions except the central China and it proves that the pulling effect of transportation on economic growth is positive in China but relative marginal in highly developed eastern region and the relatively backward western region. Third, in the reverse direction, heterogeneous causality can be found in all geographic regions. Western region finds negative impact of economic growth on transportation. Four, over a half of cities in China exhibit bidirectional causality and they are mainly from relatively developed eastern and central regions.

This paper tries to enrich existing studies by providing the sign, elasticity and direction of their causality in order to uncover their complex relationship in China context. The presence of geographic heterogeneity and panel heterogeneity sheds

some important insights into devising effective transportation-led or development-led policies. Geographic targeting should be emphasized when making region-specific policies. The following policy implications can be proposed according to the empirical findings. First, although the bidirectional causality is evident in the coastal region, the impact of transportation on economic output is relatively marginal. This implies that the development-led strategies in coastal China should be more oriented at technological innovation and industrial structure upgrading instead of transport investment. Second, the central region as the main supplier of China finds positive causality from economic output to transportation but Granger non-causality in most cities in the reverse direction. Thus, the local government in central China should reduce the continuing transport investment and more fiscal revenue spending should be directed at agricultural mechanization, improving rural environment and stimulating new-type urbanization. Third, the western region as the relatively backward region in China finds negative impacts of economic growth on transportation and marginal influence of transportation on economic growth. Thus, further transport investment cannot significantly stimulate the economy of the western China. The mountainous terrain and fragile ecological environment are still the major constraints for developing the western region. The development-led strategies in western China should pay attention to regional carrying capacity of resources and environments as well as the sustainability of regional economy. Four, the northeastern region as the heavy industrial base in China, finds a significant and positive impact of transportation on economic growth. This indicates that the transport-led development strategies can be effective to stimulate a new-round economic growth in northeastern region.

This paper also has some limitations which can be addressed in the future. First, transport infrastructure can be measured from multiple aspects including waterways and airports. As constrained by data availability, this paper only incorporates three transport variables including highway length, the total volume of rail and highway freight as well as the total passenger capacity by rail and highway. The geographic big data about airlines can be used to enrich the empirical analysis. Second, the high-speed railway network is under rapid construction in China. How the high-speed railways are associated with economic output requires further studies.

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Author contributions According to the contribution of each author during the revision stage, after all authors agreed, we added two new authors because of their substantial contributions. SY mainly contributed to data processing and data analysis and LW restructured the full paper and revised the discussion section greatly. SH drafted the full paper and revised the result analysis greatly.

References

- Akkemik KA, Göksal K (2012) Energy consumption-GDP nexus: heterogeneous panel causality analysis. *Energy Econ* 34:865–873
- Arvin MB, Pradhan RP, Norman NR (2015) Transportation intensity, urbanization, economic growth, and CO₂ emissions in the G-20 countries. *Util Policy* 35:50–66

- Aschauer DA (1989) Is public expenditure productive? *J Monet Econ* 23:177–200
- Berndt ER, Hansson B (1991) Measuring the contribution of public infrastructure capital in Sweden. National Bureau of Economic Research, New York
- Beyzatlilar MA, Karacal M, Yetkiner H (2014) Granger-causality between transportation and GDP: a panel data approach. *Transp Res Part A Policy Pract* 63:43–55
- Blum U (1982) Effects of transportation investments on regional growth: a theoretical and empirical investigation. *Pap Reg Sci* 49:169–184
- Boarnet MG (1996) The direct and indirect economic effects of transportation infrastructure. University of California Transportation Center, New York
- Boopen S (2006) Transport infrastructure and economic growth: evidence from Africa using dynamic panel estimates. *Empir Econ Lett* 5:37–52
- Bose N, Haque ME (2005) Causality between public investment in transport and communication and economic growth. *J Econ Dev* 30:95–106
- Bougheas S, Demetriades PO, Mamuneas TP (2000) Infrastructure, specialization, and economic growth. *Can J Econ/Revue can d'écon* 33:506–522
- Chatman DG, Noland RB (2011) Do public transport improvements increase agglomeration economies? A review of literature and an agenda for research. *Transp Rev* 31:725–742
- Chinahighway.com (2011) The twelfth transportation plan [交通運輸“十二五”發展規劃]
- Crescenzi R, Rodríguez-Pose A (2012) An ‘integrated’ framework for the comparative analysis of the territorial innovation dynamics of developed and emerging countries. *J Econ Surv* 26(3):517–533
- Crihfield JB, Panggabean MP (1995) Is public infrastructure productive? A metropolitan perspective using new capital stock estimates. *Reg Sci Urban Econ* 25:607–630
- Cullison WE (1993) Public investment and economic growth. *FRB Richmond Econ Q* 79:19–33
- Démurger S (2001) Infrastructure development and economic growth: an explanation for regional disparities in China? *J Comp Econ* 29:95–117
- Erdil E, Yetkiner IH (2004) A panel data approach for income-health causality. *The Economics of Health Reforms*. Athens, Greece: Athens Institute for Education and Research, pp 701–724
- Erdil E, Yetkiner IH (2009) The Granger-causality between health care expenditure and output: a panel data approach. *Appl Econ* 41:511–518
- Esfahani HS, Ramírez MAT (2003) Institutions, infrastructure, and economic growth. *J Dev Econ* 70:443–477
- Farhadi M (2015) Transport infrastructure and long-run economic growth in OECD countries. *Transp Res Part A Policy Pract* 74:73–90
- Fedderke JW, Perkins P, Luiz JM (2006) Infrastructural investment in long-run economic growth: South Africa 1875–2001. *World Dev* 34:1037–1059
- Fernald JG (1999) Roads to prosperity? Assessing the link between public capital and productivity. *Am Econ Rev* 89:619–638
- Fernandes E, Pacheco RR (2010) The causal relationship between GDP and domestic air passenger traffic in Brazil. *Transp Plan Technol* 33:569–581
- Fleisher BM, Chen J (1997) The coast–noncoast income gap, productivity, and regional economic policy in China. *J Comp Econ* 25:220–236
- Fujita M, Krugman P (2004) The new economic geography: past, present and the future. *Pap Reg Sci* 83:139–164
- Fujita M, Mori T (2005) Transport development and the evolution of economic geography. *Port Econ J* 4:129–156
- Garcia-Mila T, McGuire TJ, Porter RH (1996) The effect of public capital in state-level production functions reconsidered. *Rev Econ Stat* 78:177–180
- Gregoriou A, Ghosh S (2009) The impact of government expenditure on growth: empirical evidence from a heterogeneous panel. *Bull Econ Res* 61:95–102
- Groote P, Jacobs J, Sturm JE (1999) Output effects of transport infrastructure: the Netherlands, 1853–1913. *Tijdschrift voor econ soc geogr* 90:97–109
- Haque ME, Kim DH (2003) Public investment in transportation and communication and growth: a dynamic panel approach: University of Manchester, Center for Growth and Business Cycle Research Discussion Paper Series, p 31
- Hart T (1993) Transport investment and disadvantaged regions: UK and European policies since the 1950s. *Urban Stud* 30:417–436
- He D, Zhang W (2010) How dependent is the Chinese economy on exports and in what sense has its growth been export-led? *J Asian Econ* 21:87–104

- He S, Bayrak MM, Lin H (2017) A comparative analysis of multi-scalar regional inequality in China. *Geoforum* 78:1–11
- Herranz-Loncán A (2007) Infrastructure investment and Spanish economic growth, 1850–1935. *Explor Econ Hist* 44:452–468
- Holtz-Eakin D, Newey W, Rosen HS (1988) Estimating vector autoregressions with panel data. *Econ J Econ Soc* 56:1371–1395
- Hurlin C (2004a) A note on causality tests in panel data models with random coefficients. *Mimeo*, University of Orléans
- Hurlin C (2004b) Testing Granger causality in heterogeneous panel data models with fixed coefficients. *Mimeo*, University of Orléans
- Iacono M, Levinson D (2016) Mutual causality in road network growth and economic development. *Trans Policy* 45:209–217
- Jiang X, He X, Zhang L, Qin H, Shao F (2017) Multimodal transportation infrastructure investment and regional economic development: a structural equation modeling empirical analysis in China from 1986 to 2011. *Trans Policy* 54:43–52
- Jiwattanakupaisarn P, Noland RB, Graham DJ (2010) Causal linkages between highways and sector-level employment. *Transp Res Part A Policy Pract* 44:265–280
- Kim E (2002) Determinants of optimal level of transportation infrastructure. *J Urban Plan Dev* 128:150–163
- Lall SV (2007) Infrastructure and regional growth, growth dynamics and policy relevance for India. *Ann Reg Sci* 41:581–599
- Lall SV, Shalizi Z, Deichmann U (2004) Agglomeration economies and productivity in Indian industry. *J Dev Econ* 73:643–673
- Leightner JE, Inoue T (2012) Solving the omitted variables problem of regression analysis using the relative vertical position of observations. *Adv Decis Sci* 2012:353
- Levin A, Lin C-F, Chu C-SJ (2002) Unit root tests in panel data: asymptotic and finite-sample properties. *J Econ* 108:1–24
- Liddle B, Lung S (2013) The long-run causal relationship between transport energy consumption and GDP: evidence from heterogeneous panel methods robust to cross-sectional dependence. *Econ Lett* 121:524–527
- Lütkepohl H (2005) *New introduction to multiple time series analysis*. Springer, London
- Maddison D, Rehdanz K (2008) Carbon emissions and economic growth: homogeneous causality in heterogeneous panels. Working paper no. 1437. Kiel Institute for the World Economy, Kiel
- Martinsons MG (2008) Relationship-based e-commerce: theory and evidence from China. *Inf Syst J* 18(4):331–356
- Pesaran MH, Smith R (1995) Estimating long-run relationships from dynamic heterogeneous panels. *J Econ* 68:79–113
- Pradhan RP (2019) Investigating the causal relationship between transportation infrastructure, financial penetration and economic growth in G-20 countries. *Res Transp Econ* 78:100766
- Pradhan RP, Bagchi TP (2013) Effect of transportation infrastructure on economic growth in India: the VECM approach. *Res Transp Econ* 38:139–148
- Pradhan RP, Norman NR, Badir Y, Samadhan B (2013) Transport infrastructure, foreign direct investment and economic growth interactions in India: the ARDL bounds testing approach. *Proc Soc Behav Sci* 104:914–921
- Qin D, Cagas MA, Quising P, He X-H (2006) How much does investment drive economic growth in China? *J Policy Model* 28:751–774
- Randolph S, Bogetic Z, Heffley DR (1996) Determinants of public expenditure on infrastructure: transportation and communication. World Bank policy research working paper
- Rietveld P, Nijkamp P (1992) Transport and regional development. Research Memorandum, p 50
- Sahoo P, Dash RK, Nataraj G (2010) Infrastructure development and economic growth in China. The Institute of Development Economics discussion paper no.261
- Saidi S, Hammami S (2017) Modeling the causal linkages between transport, economic growth and environmental degradation for 75 countries. *Transp Res Part D: Transp Environ* 53:415–427
- Seitz H (1993) A dual economic analysis of the benefits of the public road networks. *Ann Reg Sci* 27:223–239
- Shi Y, Guo S, Sun P (2017) The role of infrastructure in China's regional economic growth. *J Asian Econ* 49:26–41

- SinaLiaoning (2016) Solving the difficulties and problems of developing northeastern China (解决东北地区发展的困难和问题)
- Soja EW (2009) Regional planning and development theories A2—Kitchin, Rob. In: Thrift N (ed) International encyclopedia of human geography. Elsevier, Oxford, pp 259–270
- Song L, van Geenhuizen M (2014) Port infrastructure investment and regional economic growth in China: panel evidence in port regions and provinces. *Transp Policy* 36:173–183
- Sturm J, Jacobs J, Groote P (1999) Output effects of infrastructure investment in the Netherlands. *J Macroecon* 21(2):355–380
- Tatom JA (1993) Paved with good intentions: the mythical national infrastructure crisis. *Water supply* 110(2):8
- Tong T, Yu T-HE, Cho S-H, Jensen K, Ugarte DDLT (2013) Evaluating the spatial spillover effects of transportation infrastructure on agricultural output across the United States. *J Transp Geogr* 30(30):47–55
- Venet B, Hurlin C (2001) Granger causality tests in panel data models with fixed coefficients. Eurisco working paper no. 2001-09. University of Paris-Dauphine
- Vickerman R, Spiekermann K, Wegener M (1999) Accessibility and economic development in Europe. *Reg Stud* 33:1–15
- Vijverberg WPM, Vijverberg C-PC, Gamble JL (1997) Public Capital and Private Productivity. *Rev Econ Stat* 79(2):267–278
- Wang W, Bengler K, Wets G, Shen Y, Jiang X, Gao Y, Zhang Y, Li H, Peng T, Hao S (2016) Green intelligent transportation system and safety study on the relationship between comprehensive transportation freight index and GDP in China. *Proc Eng* 137:571–580
- Xinhuanet (2015) Transportation infrastructure investment this year will exceed 2.5 trillion RMB; railway investment will exceed 800 billion RMB
- Yu N, De Jong M, Storm S, Mi J (2012) The growth impact of transport infrastructure investment: a regional analysis for China (1978–2008). *Policy Soc* 31:25–38
- Zhang X, Fan S (2004) How productive is infrastructure? A new approach and evidence from rural India. *Am J Agr Econ* 86:492–501
- Zhang J, Gao Y, Fu Y, Zhang H (2007) Why does China enjoy so much better physical infrastructure? (中国为什么拥有了良好的基础设施?). *Econ Res J* 3:4–19
- Zhao J, Guo D, Wang J, Yang Z, Zhang H (2018) Examining the Association of Economic Development with Intercity Multimodal Transport Demand in China: A Focus on Spatial Autoregressive Analysis. *ISPRS Int J Geo-Inf* 7(2):56–73

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