Spat. Inf. Res. (2021) 29(1):19–30
https://doi.org/10.1007/s41324-020-00332-y

Spatial effects of transport infrastructure on regional growth: the case of Turkey

Zeynep Elburz[1,2] · **K. Mert Cubukcu**[1]

Received: 26 December 2019 / Revised: 18 April 2020 / Accepted: 25 April 2020 / Published online: 11 May 2020

Abstract The provision of infrastructure is an important policy tool for promoting regional growth and reducing regional disparities. The main reason underlying this approach is the view that transportation promotes mobility, mobility promotes trade, and trade promotes economic growth. Based on this view, Turkey has invested in transportation infrastructure to reduce the regional economic inequalities since the 1960s. Between 2004 and 2014, governments have expended approximately 65 billion dollars for road infrastructure only. We believe that investigating the recent improvements in road infrastructure with a spatial perspective in an emerging economy as Turkey is necessary to generate more effective and practical regional policies. This study attempts to measure the latest developments of transportation infrastructure by analyzing the spatial effects of road transport infrastructure on regional economy in Turkish NUTS 2 regions between 2004 and 2014. We employ an augmented Cobb–Douglas production function model and use spatial Durbin model to estimate spatial effects. Apart from previous studies that employ spatial econometric models, we create a different spatial weight matrix for each year based on inverse distance to capture the change between the years 2004 and 2014. The results reveal that road infrastructure investment has significant and positive spatial spillover effects on regional growth. Any improvement in road transport infrastructure in a region causes a GDP increase in neighboring regions. Essentially the findings expose the importance of indirect effects of road transport infrastructure and contradict with previous non-spatial and overestimated effect results in the literature.

Keywords Spatial Durbin model · Spatial spillover effects · Spatial weight matrix · Road transport

1 Introduction

In the mainstream economic literature, transport infrastructure has been regarded as an important determinant of economic growth due to its effects on reducing transport cost and increasing accessibility. From the policy makers' point of view, the provision of infrastructure is an important policy tool for promoting regional growth and reducing regional disparities. The main reason underlying this approach is the view that transportation promotes mobility, mobility promotes trade, and trade promotes economic growth [1, 2]. For example, European Union Regional Development Fund invests substantially on transportation infrastructure to promote economic growth and to reduce regional disparities. Similarly, Turkey has invested in transportation infrastructure to reduce the regional economic inequalities since the 1960s [3]. According to the statistics of Ministry of Transport and Communication, governments have expended approximately 65 billion dollars for road infrastructure between 2004 and 2014. The highest road infrastructure investment has been made in 2011 with 8.8 billion dollars and has a percentage of 1.06% in Gross Domestic Product (GDP) in the same year (Table 1). The first National Regional Development

✉ Zeynep Elburz
zeynep.elburz@deu.edu.tr; zeynepelburz@iyte.edu.tr

K. Mert Cubukcu
mert.cubukcu@deu.edu.tr

[1] Department of City and Regional Planning, Faculty of Architecture, Dokuz Eylul University, Izmir, Turkey

[2] Department of City and Regional Planning, Faculty of Architecture, IZTECH, Izmir, Turkey

Table 1 Road infrastructure investment expenditures and road length changes (2004–2014). *Source*: General Directorate of Highways

Year	Investment (Billion $)	Percentage of GDP (%)	State highways	Provincial roads	Motorways
2004	2,30	0.46	31,446	30,368	1662
2005	3,15	0.52	31,371	30,568	1667
2006	3,80	0.60	31,335	30,429	1908
2007	4,14	0.53	31,333	30,579	1908
2008	6,30	0.74	31,311	30,712	1922
2009	5,93	0.87	31,271	30,948	2036
2010	8,52	1.05	31,395	31,390	2080
2011	8,88	1.06	31,372	31,558	2119
2012	7,54	0.91	31,375	31,880	2127
2013	7,62	0.90	31,341	32,155	2244
2014	7,24	0.89	31,280	32,474	2278

Strategy which has been prepared by the Ministry of Development [4] also points out the importance of transport infrastructure as a prominent regional development goal by to increasing accessibility. By taking into account this goal, the General Directorate of Highways has launched a highway construction program for building new highways to connect metropolitan cities (İstanbul, Ankara, İzmir) with port cities (Mersin, Rize, Samsun). General Directorate of Highways is planning to reach 8227 km. highway network by constructing 5738 km new highways by the end of 2035. However, this serious change in the transport infrastructure stock has captured little attention in the literature.

To our knowledge, this study is the first attempt to measure the latest developments of transportation infrastructure in 26 NUTS 2 regions in Turkey with a spatial concern. The aim of this study is to examine spatial effects of transportation infrastructure investments on regional economic growth by using spatial econometric models. We believe that investigating the recent improvements in road infrastructure with a spatial perspective in an emerging economy as Turkey is necessary to generate more effective and practical regional policies. As a novel perspective, we create a spatial weight matrix for each year from 2004 to 2014. Taking into account the huge investments on road infrastructure in Turkey since early 2000′s, we believe that relying on one contiguity-based spatial weight matrix would not capture the difference on the distance between the regions and thus would not control the neighborhood criteria. So, we measure the real time distance between 26 NUTS 2 regions in Turkey for each year and create 11 different spatial weight matrices. The objective of using multiple spatial weight matrices is to measure the spatial relation which changes parallel to the changes in the road infrastructure network. Also, this study is the first attempt to measure the latest developments of transportation infrastructure in Turkey from a spatial concern with the latest regional data. Previous studies that investigate the impacts of transport infrastructure on regional economy in Turkey, have largely ignored the spatial spillovers and focused on only the standard econometric models by using provincial data from 2000.

In Sect. 2, previous studies that investigate transport infrastructure and regional growth relation with spatial and non-spatial aspects are reviewed. Section 3 describes the empirical model applied to analyze the spatial effect of transport infrastructure on regional economy and presents the spatial weight matrices that used in this study. Section 3 also introduces the data and the sources of the variables. The findings of the spatial econometric models are reported in Sect. 4. Finally, Sect. 5 contains the main conclusion with several policy recommendations that ensue from the estimated results from the previous chapter.

2 Literature review

It is Aschauer's [5] empirical study that attracted great attention from both academics and policymakers for the relation between public infrastructure and economic growth. According to his results, core infrastructure which includes highways, mass transit, airports, electrical and gas facilities, water, sewer is the biggest explicator of productivity with an elasticity of 0.24 compared to other public capital types. Even though Aschauer's [5] study can be considered as a milestone in the empirical literature on the effects of public infrastructure, Aschauer's highly significant and positive view is far from being the norm [6]. The studies that focus on the effects of public infrastructure at the regional level tend to reach insignificant impacts by taking into account the previous criticism in the early studies. Pereira and Andraz [7] discussed the underlying reason for the different findings between the empirical studies and suggest that spillover effects (indirect effects) are a possible explanation for this, since infrastructure impacts are confined to specific regions only [8]. Holtz-Eakin and Schwartz [9] addressed spillover effects issue by measuring the indirect effect of highway capital stock on neighboring states using panel data from 1969 to 1986. They revealed that highway capital stock has no statistically significant spillover effects on productivity for the US case. In more recent studies [10], the measurement of spillovers effect of transport infrastructure has been developed with adaptation of spatial econometric models (see Table 2). Cohen [11] argued that ignoring spatial effects may cause omitted variable bias, which creates inaccurate estimations of infrastructure effects. He used the US states highway capital stock data for 1996 to investigate the broader benefits, which refers to indirect benefits that may result from spatial interaction of transportation infrastructure. The results based on a spatial lag model with contiguity weight matrix showed a positive effect of transport infrastructure on the output. Jiwattanakulpaisarn et al. [12] suggested using dynamic production function approach with an additional variable to capture spatial spillover effects from highway capital stock to outputs of neighboring states. They used five different spatial weight matrices based on contiguity and distance, since the literature does not point out the correct spatial weight matrix for all studies. Their findings revealed positive spillover effects of highway improvements to the neighbors. It is also underlined that employing distance decay matrix helps to reach higher output elasticities compared to the other four spatial weight matrices.

For the case of European Union regions, Del Bo and Florio [13] preferred to use spatial Durbin model (SDM) with respect to likelihood ratio (LR) tests results with row-standardized contiguity matrix based on inverse of geographical distance. The findings demonstrated that while motorways have positive direct and insignificant indirect effects, other roads have negative direct and positive indirect effects on regional GDP. Xueliang [14] took China as example to examine the role of transport infrastructure to promote regional economic growth using a panel data for 29 Chinese provinces and regions. The model which contains spatial spillover effects of transport infrastructure is estimated with the fixed effects spatial lag model with four different spatial weight matrices. These four spatial weight matrices are created on the basis of binary contiguity, population density, GDP per capita, and transport network. The positive and significant results showed that improvement of transport infrastructure fosters regional

Table 2 Empirical studies with spatial models

	References	Time period	Country	Transportation Measure	Spatial Weight Matrix
1	Boarnet [10]	1969–1988	USA	Street and highway capital stock	Contiguity; similarity matrices based on population, GDP per capita, and employment
2	Cohen [11]	1996	USA	Highway capital stock	Contiguity matrix
3	Jiwattanakulpaisarn et al. [12]	1984–1997	USA	Existing road lane miles	Binary contiguity; inversed distance matrix
4	Del Bo and Florio [13]	2006	EU countries	Length of motorways and regular roads	Contiguity based on inverse distance
5	Yu et al. [18]	1978–2009	China	Transport infrastructure capital stock	Binary contiguity matrix
6	Tong et al. [19]	1981–2004	USA	Road disbursement, rail miles	Queen contiguity matrix
7	Xueliang [14]	1993–2009 2000–2009	China	Km of highways	Binary contiguity; inversed distance matrix; similarity matrices based on population, GDP per capita
8	Chen and Haynes [20]	1991–2009	USA	Highway and railway stock	Queen contiguity matrix
9	Arbues et al. [15]	1986–2006	Spain	Road capital stock	Binary contiguity matrix; contiguity based on inverse distance
10	Li et al. [21]	2005–2014	China	Highway network km/km2	Binary contiguity based on distance
11	Dehghan Shabani and Safaie [16]	2001–2011	Iran	Road length per capita	Inverse distance matrix

economic growth however; ignoring spatial spillover effects in the model causes over-estimation of the role of transport infrastructure. Arbues et al. [15] contributed the literature by estimating a spatial Durbin model (SDM) for 47 Spanish provinces by controlling for endogeneity issue and spatial spillovers. Arbues et al. [15] built two spatial weight matrices based on binary contiguity and physical contiguity matrix. The results indicated that improvement of road infrastructure in Spanish provinces would create a productivity rise in neighboring provinces up to 5.5%. More recently, Dehghan Shabani and Safaie [16] investigated 28 Iranian provinces from 2001 to 2011 to measure direct and spillover (indirect) effects of road transport infrastructure on economic growth with spatial Durbin model (SDM) and maximum likelihood (ML) estimation method. They created spatial weight matrix based on inverse Euclidean distance to capture spillover effects more properly than simple binary contiguity weight matrix. Regarding the results, Dehghan Shabani and Safaie [16] recommended policymakers to increase cross-regional transport networks mostly. The number of studies that focuses on the effects of transportation infrastructure on regional economic growth in Turkey is limited. Recently, Elburz et al. [17] studied the role of transport infrastructure stock in the Turkish regions with different estimation methods. The results confirmed that the road and highway infrastructure have significant and positive effects on Turkish regional GVA.

Based on the review of the transport infrastructure effects literature, it can be said that the results are quite heterogeneous and one of the main reasons for this is the about the measurement of the spatial spillover effects of transport infrastructure. The studies that measure spatial effects of transport infrastructure on regional economy in the economic literature rely on simple spatial weight matrices without any arguments on how to define neighboring regions. As it is underlined in the introduction section, the originality of this study lays in the definition the neighborhoods for spatial weight matrix to have accurate spatial spillover effects by using spatial econometric models.

3 Methodology

We use an augmented Cobb–Douglas production function per capita in which infrastructure has an important role along with other production factors, such as private capital and human capital which enhances the productivity [22]. The basic Cobb–Douglas production function can be expressed as:

$$Y_{it} = AK_{it}^{\alpha}H_{it}^{\beta}T_{it}^{\gamma} \tag{1}$$

where Y, K, H, T, i, and t denote output per capita, private capital per capita, human capital, transport infrastructure stock, region and time respectively, while A, α, β, and γ denote constants. Since infrastructure has gestation period, it may not affect regional economic output simultaneously. We form a model which contains three-year lagged variable of transport infrastructure which has the highest correlation value with dependent variable according to correlation matrix results.[1] The model can be shown as:

$$LnY_{it} = LnA + \alpha LnK_{it} + \beta LnH_{it} + \gamma LnT_{it-3} + \varepsilon_{it} \tag{2}$$

where T_{it-3} is three year lagged transport infrastructure stock variable. We assume that the model does not suffer from reverse causality problem since we use lagged transport infrastructure variables. Clearly, lagged transport variable may have an effect on current output but vice versa is not possible.

3.1 Spatial Econometric Models

Using spatial data with standard econometric models which have the assumption that *outcomes for units are independent of each other* [23] is problematic. Assessing the magnitude and significance of spatial spillovers which is restricted by standard econometric models, are applicable by spatial econometric models [23]. However, selecting the appropriate specification model is quite difficult process for researchers. The researchers need to comprehend the theoretical ground of their study and whether it has local or global spatial spillover before choosing the proper model specification. Global spillover specification is most appropriate when a region has effects on all other regions (e.g. transportation network, river) rather than only on neighboring regions and also global spillovers are best captured using the SDM [24].[2] Thus the model can be shown as follows in a SDM framework:

$$Y_t = \rho WY_t + X_t\beta + WX_t\theta + \mu + \alpha_t\iota_N + u_t \tag{3}$$

where Y is an *Nx1* vector of regional GDP per capita, X is an 1×3 matrix of dependent variables which contains private capital per capita, human capital stock, and transport infrastructure stock; WY is the endogenous interaction effects among the dependent variable; WX is the exogenous interaction effects among the independent variables, ρ is the spatial autoregressive coefficient, θ and β are 3x1 vector of fixed parameters, μ is a vector of spatial fixed or random effects, t is time, α_t is the time period fixed or

---

[1] The results are available upon request.

[2] For more detailed information and discussion about global and local spillovers, see [24] and [25].

random effects, l_N is an *Nx1* vector of ones. Unlike the spatial error model and spatial lag model, coefficients from SDM results cannot interpret as elasticities [15]. Elhorst [26] suggests using direct, indirect (a proper measure of global spatial spillover) and total effects estimates by employing rewritten form of SDM as:

$$Y_t = (I - \rho W)^{-1} \alpha I_N + (I - \rho W)^{-1} (X_t \beta + W X_t \theta) + (I - \rho W)^{-1} \varepsilon \tag{4}$$

where I is the identity matrix, I_N is an *nx1* vector of ones.

3.2 Spatial Weight Matrix

Before applying spatial econometric analyses, the spatial weight matrix (*W*) is to be set. Spatial weight matrix is the simplest measure of spatial influence [27] and entirely depends on the neighborhood definition in the model [28]. There are several ways to construct a spatial weight matrix to formalize the role of space [29]. Mostly, spatial weight matrices are based on geographical arrangements or contiguity (see Table 2). LeSage and Pace [30] criticize contiguity or nearest neighbors with distance function based spatial weight matrices for being intuitive and suggest more elegant ways to generate spatial weight matrix. In parallel with this, Anselin [28] states that contiguity or distance based spatial weight matrices that have only zeros or ones are too general and alternatives, such as inverse distance squared can be considered [31].

In this study, relying on distance decay methods, we create a spatial weight matrix for each year from 2004 to 2014. These spatial weight matrices reflect the change over time, to capture the impacts of recently built-up road infrastructure or extension the existing ones on regional economic growth. Transportation investments have the lion's share of the public investments since 2004 and it is clear that there has been a change in the transport infrastructure stock in terms of length of the state highways, provincial roads and motorways in Turkey between 2004 and 2014 (see Table 1). As expected, building new road network and/or extension of the existing ones cause a reduction of the travel times between regions. Based on this fact, we believe a simple contiguity weight matrix would not reflect the real changes in Turkish transportation infrastructure and thus would not measure the spatial influence properly. Therefore, we use network analysis to calculate the distances in minutes between the regions based on 3 different road categories (Fig. 1). Official speed limits of these three type of road which are motorways, state highways and provincial roads are respectively, 120, 110 and 90 km/h.

First, we start with adjusting road network data obtained from the General Directorate of Highways to measure the quickest route from each origin region to destination region and produce distance matrix by using OD cost matrix analysis extension of network analysis [32]. After obtaining the annual changes in the real distance (in minutes) between regions, we generate inverse distance spatial weight matrices for 26 NUTS 2 regions for each year between 2004 and 2014. The inverse distance spatial weight can be formulated as:

$$W_{ij} = \left(\frac{1}{d_{ij}^2} \right) \tag{5}$$

where W_{ij} reflects spatial interaction between region i and region j, and d_{ij} denotes real distance (in minutes) between i and j. We transform the spatial weight matrices with row-standardization to produce a row-stochastic weight matrix [33] which can be shown as:

$$W_{ij}^s = \frac{W_{ij}}{\sum_j W_{ij}} \quad \sum_j W_{ij}^s = 1 W_{ij} = 0, \quad if \quad i = j \tag{6}$$

Finally, we transform the spatial weight matrices with row-standardization to produce a row-stochastic weight matrix and get 11 different *nxn* (26x26) size non-negative symmetric spatial weight matrices (*W*) with zeros on the diagonals.[3]

3.3 Data

We use macroeconomic panel data at 26 NUTS 2 regions from 2004 to 2014 to measure the role of transport infrastructure on regional economic performance with regional GDP per capita in Turkish Liras (TL) as regional output. GDP deflator which is obtained from Central Bank of the Republic of Turkey is applied to eliminate the inflation impact. Since private capital stock data is unavailable in Turkey, we use industrial electricity consumption per capita as a proxy for private capital stock as proposed in Moody [34]. Following Lucas [22], we add human capital variable to the model which is the proportion of the university graduated to the total population. Finally, we augment the production function by adding a transportation infrastructure variable by adopting physical measurement instead of monetary measures as indicated in Bröcker and Rietveld [35] and Vickerman [36] (see Table 3). Different transport infrastructure investment may have similar monetary values even though the effects on output may be various [37]. Deng [38] also states that physical measurement leads significant and positive results more often than monetary measure by investigating recent studies. Many researchers remark the fact that economic contributions of transport infrastructure vary based on the

---

[3] Eleven spatial weight matrices are available upon request.

Fig. 1 State highways (black), provincial roads (blue) and motorways (red) in 2014

Table 3 Definitions of the variables

Variables	Description	Data source	Unit	Min	Max
Y (GDP per capita)	Gross Domestic Product per capita based on 2009	TurkStat	TL/person	8.027	10.596
K (Private Capital)	Industrial electricity consumption per capita	TurkStat	kWh/person	−3.503	1.5119
H (Human Capital)	University graduates divided by total population	TurkStat	Number of person	−2.656	1.7818
T (Transport Infrastructure)	Divided roads and motorway infrastructure length (km) divided by population	TurkStat and OECD	Km/person	−10.002	−5.641

type of infrastructure e.g. [6, 16, 39, 40]. We inspire the results of Elburz et al. [17] which shows the substantial impact of road infrastructure on regional economic growth in Turkey. By taking into account Turkish governments massive investments on road infrastructure since 2003 and Elburz et al. [17] study results, we prefer to focus on only road infrastructure rather than including all type of transport infrastructure (point and network infrastructure). We employ length (km) of total highway and divide roads which are standardized with total population of a region. Since regional population data is not available between the years 2000 and 2007 at TurkStat, we use the estimated regional population data by OECD regional statistics between 2004 and 2007. It is also important to underline the fact that the effects of transport infrastructure do not emerge immediately. Thus using data for transport infrastructure and regional output for the same year may not reveal the real effects which lead us to consider lagged transport infrastructure variables in our model.

4 Results

Taking into account the spatial spillover effects that highlighted in the previous sections, we test spatial autocorrelation in the model by using Moran's I statistics as a spatial diagnostic test. The findings from Table 4 support the hypothesis that the variables are spatially linked among regions, and omitting spatial effects of transport infrastructure may cause biased estimations. Thus, a simple OLS estimate would be insufficient for the analysis. To decide which spatial econometric model is more appropriate to test for spatial dependence, LM and robust LM tests can be used. LeSage and Pace [30] suggest to choose SDM when LM test is rejected for both spatial lag and spatial error model. According to Table 4, the hypothesis of no spatially lagged dependent variable and the hypothesis of no spatially autocorrelated error term must be rejected at 1 percent significance [26]. These rejected hypotheses and theoretical ground of the study point out to SDM.

Table 5 displays 12 results from SDM with panel data. Each column represents a panel data estimation based on a different spatial weight matrix. First column shows the results from an estimation based on queen contiguity-based spatial weight matrix while the rest demonstrates 11

Table 4 Moran's I statistics results from residuals of OLS estimation and Lagrange multiplier (LM) test results

Year	Moran's I	Spatial Error		Spatial Lag	
		LM	Robust LM	LM	Robust LM
2004	9.323***	82.699***	23.775***	200.158***	141.235***
2005	9.421***	84.420***	23.397***	203.405***	142.382***
2006	9.402***	84.079***	23.279***	203.259***	142.456***
2007	9.492***	85.691***	22.609***	205.817***	142.735***
2008	9.487***	85.587***	22.509***	205.672***	142.594***
2009	9.532***	86.395***	22.227***	207.021***	142.854***
2010	9.533***	86.401***	22.238***	207.047***	142.883***
2011	9.471***	85.285***	22.497***	204.847***	142.059***
2012	9.512***	86.043***	22.527***	206.003***	142.487***
2013	9.512***	86.043***	22.527***	206.003***	142.487***
2014	9.517***	86.138***	22.379***	205.823***	142.064***

Note: *** denotes statistical significance at the 1% level

distance-based spatial weight matrices which are calculated from 2004 to 2014. According to Table 5, the spatial autocorrelation coefficient (rho) is positive and significant for all estimations. Both human capital (*H*) and private capital (*K*) variables are highly significant and affect regional GDP in a positive way. Conversely, transport infrastructure variable (*T*) is not significant in any estimations. While human capital *(H)* is the biggest explanatory of regional GDP, it loses its significance when the spatial effects are considered. It is also noteworthy that the spatial effect of transport infrastructure variable *(W*T)* is significant at 1% ($p < 0.01$) level. When the results from contiguity-based spatial weight matrix ($W_{cont)}$ with 11 distance-based spatial weight matrices (W_{2004}, W_{2005}, etc.) compared, it can be seen that the magnitude of the variables are higher for distance-based spatial weight matrices. To have a better understanding about the magnitude of the results it is needed to consider the direct, indirect and total effects.

Table 6 represents the findings of direct and indirect effects of the model with different spatial weight matrices. Similar to Table 5, first column displays the results from queen contiguity-based spatial weight matrix while the rest demonstrates 11 distance-based spatial weight matrices. According to the results, direct effects of human capital *(H)* and private capital *(K)* are significant while transport infrastructure (T) is not for both contiguity-based and distance-based weight matrices. However, the direct effects of the variables are higher when distance-based spatial weight matrices are considered, especially for human capital *(H)*. A bigger difference can be seen between the contiguity and distance-based weight matrices from indirect effects. While transport infrastructure investments (*T*) at neighboring regions affect regional GDP in a positive and significant way in a range of 0.163-0.168, the magnitude is 0.110 for the first column. The human capital (*H*) and private capital (*K*) variables have also bigger effects on neighboring region's GDP according to the indirect spatial effects from Table 6. It is clear that human capital (*H*), private capital (*K*), and transport infrastructure *(T)* play important roles on neighboring region's output. Similar with direct and indirect effects, total effects are also higher for the distance-based spatial weight matrices. Transport infrastructure *(T)* affects regional GDP in a range of 0.172-0.177 and the magnitude is smaller (0.117) for contiguity-based matrix which is in line with Jiwattanakulpaisarn et al. [15] findings. Lastly, we check the changes of the coefficients of transport infrastructure variable *(T)* to perceive any influence from the different distance-based spatial weight matrices which can be seen at Fig. 2. Based on the trend of the coefficients from the variable, the results are not sensitive but very stable to different distance-based spatial weight matrices, in contrast with our hypothesis.

5 Conclusion

In this study, the effects of transport infrastructure in Turkish regions is estimated by using SDM. The most striking finding of the model is that lagged transport infrastructure variable has highly significant and positive spillover (indirect) effects on the regional output. It can be summarized that the road transport infrastructure investments contribute the regional output indirectly in Turkey in contradistinction to previous studies such as Elburz et al. [17]. While the non-spatial results from the literature are quite encouraging for investing transport infrastructure, our results from spatial econometric models argue that the effects of transport infrastructure are over-estimating which is similar with Xueliang [14]. Yet, the estimation

Table 5 Spatial Durbin model with spatial fixed effects

Variables	$W_{cont.}$	W_{2004}	W_{2005}	W_{2006}	W_{2007}	W_{2008}	W_{2009}	W_{2010}	W_{2011}	W_{2012}	W_{2013}	W_{2014}
H	0.029*	0.054***	0.053***	0.053***	0.053***	0.053***	0.052***	0.052***	0.053***	0.054***	0.054***	0.053***
	0.017	*− 0.017*	*− 0.017*	*− 0.017*	*− 0.017*	*− 0.017*	*− 0.017*	*− 0.017*	*− 0.017*	*− 0.017*	*0.983*	*− 0.017*
K	0.043***	0.050***	0.050***	0.049***	0.049***	0.049***	0.049***	0.049***	0.049***	0.049***	0.049***	0.049***
	0.012	*− 0.012*	*− 0.012*	*− 0.012*	*− 0.012*	*− 0.012*	*− 0.012*	*− 0.012*	*− 0.012*	*− 0.012*	*− 0.012*	*-0.012*
T	−0.002	−0.002	−0.002	−0.002	−0.002	−0.002	−0.002	−0.002	−0.002	−0.002	−0.002	−0.002
	0.003	*− 0.003*	*− 0.003*	*− 0.003*	*− 0.003*	*− 0.003*	*− 0.003*	*− 0.003*	*− 0.003*	*− 0.003*	*− 0.003*	*− 0.003*
W*H	0.047*	0.035	0.038	0.037	0.036	0.037	0.036	0.036	0.034	0.033	0.033	0.034
	0.027	*− 0.031*	*− 0.031*	*− 0.031*	*− 0.031*	*− 0.031*	*− 0.031*	*− 0.031*	*− 0.031*	*− 0.031*	*− 0.031*	*− 0.031*
W*K	0.043***	0.054*	0.053*	0.055*	0.056*	0.056*	0.056*	0.056*	0.057*	0.057**	0.057**	0.057*
	0.021	*− 0.029*	*− 0.029*	*− 0.029*	*− 0.029*	*− 0.029*	*− 0.029*	*− 0.029*	*− 0.029*	*− 0.029*	*0.971*	*− 0.029*
W*T	0.015***	0.024***	0.024***	0.023***	0.023***	0.023***	0.023***	0.023***	0.023***	0.023***	0.023***	0.023***
	0.005	*− 0.008*	*− 0.008*	*− 0.008*	*− 0.008*	*− 0.008*	*− 0.008*	*− 0.008*	*− 0.008*	*− 0.008*	*0.992*	*− 0.008*
rho	0.888***	0.876***	0.876***	0.876***	0.877***	0.877***	0.877***	0.877***	0.877***	0.878***	0.878***	0.877***
	0.017	*− 0.021*	*− 0.021*	*− 0.021*	*− 0.02*	*− 0.02*	*− 0.02*	*− 0.02*	*− 0.02*	*− 0.02*	*− 0.02*	*− 0.021*
Hausman	26.49	43.08	43.65	44.11	46.00	46.16	46.23	46.22	45.81	45.77	45.77	45.67
	0.0004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Log likelihood	533.4080	522.3447	523.9787	523.8467	524.5332	524.6066	524.9853	524.9969	523.6552	523.967	523.967	523.9833
Observations	286	286	286	286	286	286	286	286	286	286	286	286
R-squared	0.812	0.809	0.809	0.809	0.809	0.809	0.809	0.809	0.81	0.81	0.81	0.81

Note: Standard errors are in italics * $p < 0{,}10$, *** $p < 0{,}01$. W_{cont} represent a spatial weight matrix based on first order queen contiguity weight matrix

Table 6 Direct, indirect and total effects

	Var.	$WW_{cont.}$	W_{2004}	W_{2005}	W_{2006}	W_{2007}	W_{2008}	W_{2009}	W_{2010}	W_{2011}	W_{2012}	W_{2013}	W_{2014}
Direct	**H**	0.075***	0.095***	0.094***	0.093***	0.093***	0.093***	0.092***	0.092***	0.093***	0.093***	0.093***	0.092***
		0.023	*− 0.022*	*− 0.022*	*− 0.022*	*− 0.022*	*− 0.022*	*− 0.022*	*− 0.022*	*− 0.022*	*− 0.022*	*0.978*	*− 0.022*
	K	0.096***	0.101***	0.100***	0.100***	0.100***	0.100***	0.099***	0.099***	0.101***	0.100***	0.100***	0.100***
		0.022	*− 0.023*	*− 0.023*	*− 0.023*	*− 0.023*	*− 0.023*	*− 0.022*	*− 0.022*	*− 0.023*	*− 0.022*	*− 0.022*	*− 0.022*
	T	0.006	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009
		0.006	*− 0.006*	*− 0.006*	*− 0.006*	*− 0.006*	*− 0.006*	*− 0.006*	*− 0.006*	*− 0.006*	*− 0.006*	*− 0.006*	*− 0.006*
Indirect	**H**	0.590***	0.613***	0.623***	0.616***	0.614***	0.616***	0.614***	0.614***	0.605***	0.601***	0.601***	0.606***
		0.169	*− 0.178*	*− 0.178*	*− 0.178*	*− 0.179*	*− 0.178*	*− 0.179*	*− 0.179*	*− 0.179*	*− 0.18*	*0.82*	*− 0.179*
	K	0.688***	0.765***	0.756***	0.763***	0.774***	0.772***	0.776***	0.776***	0.787***	0.790***	0.790***	0.788***
		0.199	*− 0.234*	*− 0.235*	*− 0.235*	*− 0.236*	*− 0.236*	*− 0.237*	*− 0.237*	*− 0.237*	*− 0.238*	*0.762*	*− 0.238*
	T	0.110**	0.168***	0.166***	0.165***	0.164***	0.163***	0.163***	0.163***	0.165***	0.165***	0.165***	0.165***
		0.051	*− 0.061*	*− 0.062*	*− 0.062*	*− 0.062*	*− 0.062*	*− 0.063*	*− 0.063*	*− 0.062*	*− 0.063*	*0.937*	*− 0.062*
Total	**H**	0.665***	0.708***	0.716***	0.709***	0.706***	0.709***	0.706***	0.706***	0.697***	0.694***	0.694***	0.698***
		0.186	*− 0.194*	*− 0.194*	*− 0.194*	*− 0.194*	*− 0.194*	*− 0.194*	*− 0.194*	*− 0.195*	*− 0.195*	*0.805*	*− 0.195*
	K	0.785***	0.866***	0.856***	0.863***	0.874***	0.871***	0.875***	0.876***	0.888***	0.891***	0.891***	0.888***
		0.218	*− 0.254*	*− 0.254*	*− 0.254*	*− 0.255*	*− 0.255*	*− 0.256*	*− 0.256*	*− 0.256*	*− 0.257*	*0.743*	*− 0.257*
	T	0.117**	0.177***	0.175***	0.174***	0.173**	0.172**	0.172**	0.172**	0.174***	0.173**	0.173**	0.174***
		0.056	*− 0.066*	*− 0.067*	*− 0.067*	*− 0.067*	*− 0.067*	*− 0.067*	*− 0.067*	*− 0.067*	*− 0.068*	*0.932*	*− 0.067*

Note: Standard errors are in italics ** $p < 0,05$, *** $p < 0,01$. W_{cont} represent a spatial weight matrix based on first order queen contiguity weight matrix

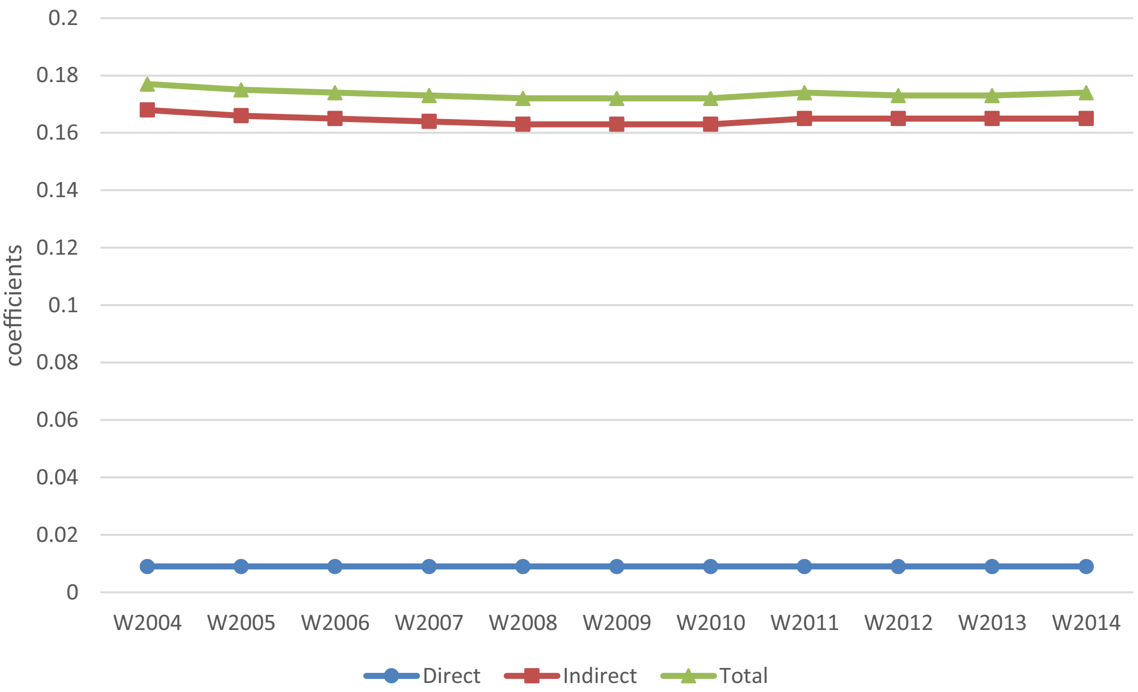

Fig. 2 Changes of coefficients from transport infrastructure (T)

results from spatial econometric models depend on the spatial weight matrices. The findings also give evidence on the impacts of using multiple spatial weight matrices in spatial econometric models. Cleary, the coefficients from the spatial models are stable over different distance-based spatial weight matrices.

These results may have some policy implications. Essentially the findings expose the importance of spillover effects of road transport infrastructure while emphasizing the over-estimated effects. Any improvement in the road transport infrastructure in a region causes a GDP increase in the neighboring regions. Therefore, policymakers may consider the road transport infrastructure network as a whole when deciding the allocation of the investments. Regarding the positive spillover effects of transport, boosting connectivity between developed and less-developed regions may increase growth rate of both regions. However, as Nijkamp [41] noted, an advanced transport infrastructure generates sufficient conditions for regional development, however it is not adequate alone. Since there are no direct effects of transport infrastructure, policymakers need to reflect transport infrastructure not as a major contributor of the regional economy anymore and need to reconsider the transport infrastructure based-regional development policies.

Even though our empirical test results give no evidence on the effects of infrastructure on regional economic inequalities, it is possible to draw attention to prospective role of infrastructure on inequalities in Turkey by taking into account its effect on spatial location of economic activities. Improving road transport infrastructure network and reducing transport costs may or may not lead to convergence [42]. It is clear from the targets of Ministry of Transport and Communication that Turkey encourages intra-core infrastructure by connecting the economic centers with highways. Since many researchers have analyzed the economic disparities in Turkey, such as Gezici and Hewings [43], Filiztekin and Çelik [44], and have underlined the high level of disparities between and within the regions since 1980s, there should be more intra-periphery infrastructure improvements in local infrastructure in the less-developed regions in the eastern part of Turkey to diminish regional disparities.

Author contributions Zeynep Elburz: Literature Search/Review, Analyzing, Manuscript Writing, Content planning. K. Mert Cubukcu: Literature Search/Review, Analyzing, Manuscript Writing, Content planning

Funding This work was supported by the Dokuz Eylul University Department of Scientific Research Projects under Grant 2018.KB.FEN.005

Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

References

1. Vickerman, R. (2002). The role of infrastructure for expansion and integration. In M. M. Fischer (Ed.), *G Atalik*. Berlin, Heidelberg: Regional Development Reconsidered. Advances in Spatial Science. Springer.
2. Button, K. (2005). The economics of cost recovery in transport: introduction. *Journal of Transport Economics and Policy, 39*(3), 241–257.
3. Karadağ, M., Deliktaş, E., & Önder, A. Ö. (2004). The effects of public infrastructure on private sector performances in the Turkish regional manufacturing industries. *European Planning Studies, 12*(8), 1145–1156.
4. Ministry of Development (2015). Bölgesel Gelişme Ulusal Stratejisi (2014-2023). Ankara.
5. Aschauer, D. A. (1989). Is public expenditure productive? *Journal of Monetary Economics, 23*(2), 177–200.
6. Rodríguez-Pose, A., Psycharis, Y., & Tselios, V. (2012). Public investment and regional growth and convergence: Evidence from Greece. *Papers in Regional Science, 91*(3), 543–568.
7. Pereira, A. M., & Andraz, J. M. (2013). On the economic effects of public infrastructure investment: A survey of the international evidence. *Journal of Economic Development, 38*(4), 1–37.
8. Moreno, R., & López-Bazo, E. (2007). Returns to local and transport infrastructure under regional spillovers. *International Regional Science Review, 30*(1), 47–71.
9. Holtz-Eakin, D., & Schwartz, A. E. (1995). Spatial productivity spillovers from public infrastructure: evidence from state highways. *International Tax and Public Finance, 2*(3), 459–468.
10. Boarnet, M. G. (1998). Spillovers and the locational effects of public infrastructure. *Journal of Regional Science, 38*(3), 381–400.
11. Cohen, J. P. (2010). The broader effects of transportation infrastructure: Spatial econometrics and productivity approaches. *Transportation Research Part E: Logistics and Transportation Review, 46*(3), 317–326.
12. Jiwattanakulpaisarn, P., Noland, R. B., & Graham, D. J. (2011). Highway infrastructure and private output: evidence from static and dynamic production function models. *Transportmetrica, 7*(5), 347–367.
13. Del Bo, C. F., & Florio, M. (2012). Infrastructure and growth in a spatial framework: evidence from the EU regions. *European Planning Studies, 20*(8), 1393–1414.
14. Xueliang, Z. (2013). Has transport infrastructure promoted regional economic growth? with an analysis of the spatial spillover effects of transport infrastructure. *Social Sciences in China, 34*(2), 24–47.
15. Arbués, P., Banos, J. F., & Mayor, M. (2015). The spatial productivity of transportation infrastructure. *Transportation Research Part A: Policy and Practice, 75,* 166–177.
16. Dehghan Shabani, Z., & Safaie, S. (2018). Do transport infrastructure spillovers matter for economic growth? Evidence on road and railway transport infrastructure in Iranian provinces. *Regional Science Policy & Practice, 10*(1), 49–63.
17. Elburz, Z., Nijkamp, P., & Pels, E. (2017). Public infrastructure and regional growth: evidence from Turkey. *European Journal of Transport & Infrastructure Research, 17*(4), 1–8.
18. Yu, N., De Jong, M., Storm, S., & Mi, J. (2013). Spatial spillover effects of transport infrastructure: evidence from Chinese regions. *Journal of Transport Geography, 28,* 56–66.
19. Tong, T., Yu, T. H. E., Cho, S. H., Jensen, K., & Ugarte, D. D. L. T. (2013). Evaluating the spatial spillover effects of transportation infrastructure on agricultural output across the United States. *Journal of Transport Geography, 30,* 47–55.
20. Chen, Z., & Haynes, K. E. (2015). Public surface transportation and regional output: A spatial panel approach. *Papers in Regional Science, 94*(4), 727–751.
21. Li, J., Wen, J., & Jiang, B. (2017). Spatial spillover effects of transport infrastructure in Chinese new silk road economic belt. *International Journal of e-Navigation and Maritime Economy, 6,* 1–8.
22. Lucas, R. E. (1988). On the mechanics of economic development. *Journal of Monetary Economics, 22,* 3–42.
23. Halleck Vega, S., & Elhorst, J. P. (2012). On spatial econometric models, spillover effects, and W. University of Groningen, Working paper.
24. LeSage, J. P. (2014). What regional scientists need to know about spatial econometrics. *The Review of Regional Studies, 44*(1), 13–32.
25. Lacombe, D. J., & McLntyre, S. G. (2016). Local and global spatial effects in hierarchical models. *Applied Economics Letters, 23*(16), 1168–1172.
26. Elhorst, J. P. (2012). *Spatial panel data models*. Berlin, Heidelberg: Springer.
27. Bavaud, F. (1998). Models for spatial weights: a systematic look. *Geographical Analysis, 30*(2), 153–171.
28. Anselin, L. (2001). Spatial Econometrics. In B. H. Baltagi (Ed.), *A companion to theoretical econometrics, (310-330)*. Malden: Blackwell Publishing.
29. Anselin, L. (1988). *Spatial econometrics: Methods and models*. Dordrecht: Kluwer.
30. LeSage, J. P., & Pace, R. K. (2009). *Introduction to Spatial Econometrics*. FL: CRC Press Boca Raton.
31. Anselin, L. (1999). Spatial Econometrics, Retrieved February 10, 2018, from https://pdfs.semanticscholar.org/47be/74ada1f72cb5fd50e45ba4e448afc74c7cf8.pdf.
32. Environmental Systems Research Institute (2018). OD cost matrix analysis. Retrieved February 01, 2018, from http://desktop.arcgis.com/en/arcmap/latest/extensions/network-analyst/od-cost-matrix.htm.
33. LeSage, J. P. (2004). Lecture 1: Maximum likelihood estimation of spatial regression models, Retrieved February 10, 2018, from http://www4.fe.uc.pt/spatial/doc/lecture1.pdf.
34. Moody, C. E. (1974). The measurement of capital services by electrical energy. *Oxford Bulletin of Economics and Statistics, 36*(1), 45–52.
35. Bröcker, J., & Rietveld, P. (2009). Infrastructure and regional development. In R. Capello & P. Nijkamp (Eds.), *Handbook of Regional Growth and Development Theories, (152-181)*. Massachusetts: Edward Elgar Publishing.
36. Vickerman, R. (2007). Recent evolution of research into the wider economic benefits of transport infrastructure investments. OECD Discussion Paper, 2007-9.
37. Melo, P. C., Graham, D. J., & Brage-Ardao, R. (2013). The productivity of transport infrastructure investment: A meta-analysis of empirical evidence. *Regional Science and Urban Economics, 43,* 695–706.
38. Deng, T. (2013). Impacts of transport infrastructure on productivity and economic growth: Recent advances and research challenges. *Transport Reviews, 33*(6), 686–699.
39. Gómez-Antonio, M., & Garijo, A. A. (2012). Evaluating the effect of public investment on productivity growth using an urban economics approach for the Spanish provinces. *International Regional Science Review, 35*(4), 389–423.
40. Bronzini, R., & Piselli, P. (2009). Determinants of long-run regional productivity with geographical spillovers: the role of R&D, human capital and public infrastructure. *Regional Science and Urban Economics, 39*(2), 187–199.
41. Nijkamp, P. (1986). Infrastructure and regional development: a multidimensional analysis. *Empirical Economics, 11*(1), 1–21.

42. Puga, D. (2002). European regional policies in light of recent location theories. *Journal of Economic Geography, 2*(4), 373–406.
43. Gezici, F., & Hewings, G. J. (2004). Regional convergence and the economic performance of peripheral areas in Turkey. *Review of Urban & Regional Development Studies, 16*(2), 113–132.
44. Filiztekin, A., & Çelik, M. A. (2010). Regional income inequality in Turkey. *Megaron, 5*(3), 116–127.