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Using dynamic simultaneous-equation model to estimate the regional impacts of high-speed rail in Spain

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Abstract

The objective of this paper is to investigate the impacts of the HSR network on the regional development of the Spanish provinces from 1990 up to 2010, by applying a simultaneous-equation modeling approach. The proposed model possesses a systematic perspective, the relationships between HSR and the various aspects of the regional development interact with each other in a more realistic manner. The model intends to estimate the quantitative relationships between all the variables, where accessibilities by road and by HSR, employment, GDP, population and number of firms at province level are treated endogenously, and education level is the exogenous variable used to control for the impacts from education policies. The model estimates the reverse causality from the economic development to the investment in transport infrastructure, which is an issue not explicitly modeled in previous research. Besides, the model captures also dynamic effects, by the use of a lag-adjustment framework, implying that the initial levels of the variables are important in determining their subsequent changes. The empirical results concur that the investment in HSR together with education policies has positive impacts on stimulating GDP growth, establishing new firms, increasing employment levels and attracting population at provincial level in Spain.

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1. Introduction

Over the past three decades, substantial literature has focused on the role of public infrastructure in affecting economic growth, private sector productivity and location decisions of firms (Aschauer, 1989; Fujita and Thisse, 2002; Graham, 2007; Martin and Rogers, 1995; Munnell, 1990). Following this stream of literature, a fairly large amount of studies have focused on the economic impacts of transport infrastructure. Improvements in transport infrastructure are seen as a means of stimulating production and influencing the location decisions of firms, which then induce more employment and investment by expanding the existing businesses and attracting new economic activities (Button, 1998; Rietveld and Bruinsma, 1998; Rietveld and Nijkamp, 2000; SACTRA, 1999). It has been acknowledged that investment on transport infrastructure increases the accessibility to resources, goods and markets, and thus improves the competitiveness of a region (Dodgson, 1974) and enhances its economic integration (Blum, 1982; Rietveld, 1989). Reductions in travel time and travel costs can also give rise to productivity growth through reinforcing agglomeration benefits (Graham, 2007; Venables, 2007).

Adopting the traditional production function approach, Aschauer (1990, 1989) argued that core infrastructures have the strongest statistical significance in estimated productivity relations. Positive impacts of transport infrastructure on the production levels, in particular, were also found in several studies, e.g. Munnell (1990), Nijkamp (1986) and Andersson et al. (1990). The robustness of the empirical results from the studies of Aschauer (1989) and Munnell (1992) have raised various criticisms on its methodological drawbacks, firstly, the omitted variable bias. By refining the econometric structure using panel models incorporating state and time fixed- and random effects, some researchers found weakened and insignificant effects of public infrastructure investment on private productivity (Evans and Karras, 1994; Garcia-Mila et al., 1996; Holtz-Eakin, 1994; Holtz-Eakin and Schwartz, 1995). The criticisms relative to ignoring spillover effects of transport infrastructures have also been proven to be important. A municipality may not have the direct access to a transport infrastructure, such as a highway, but can still benefit from the one in an adjacent municipality (Pereira and Andraz, 2006). But the conclusions about the relevance and importance of spillover effects have been mixed, with studies arguing for positive and significant effects (Cohen and Paul, 2004; Dalenberg et al., 1998; Jiwattanakulpaisarn et al., 2012, 2011; Pereira and Andraz, 2006; Pereira and Roca-Sagalés, 2003; Rietveld and Wintershoven, 1998), and negative or insignificant ones spillover effects (Boarnet, 1998; Cohen and Paul, 2004; Holtz-Eakin and Schwartz, 1995b; Jiwattanakulpaisarn et al., 2009a; Kelejian and Robinson, 1993). Concerning the potential existence of a lagged response of economic and demographic aspects to the changes in the provision of transport infrastructure, a more dynamic panel formulation has been applied in the studies of Khadaroo and Seetanah (2008), Berechman et al. (2006), Ozbay et al. (2007), Jiwattanakulpaisarn et al. (2011), Jiwattanakulpaisarn et al. (2012), and Na et al. (2013) etc. Jiwattanakulpaisarn et al. (2009b) found that when the dynamic adjustment issue is properly modelled, the results show that improvements in highways have no discernible impact on employment. In another study by Jiwattanakulpaisarn et al., (2011), the same approach was used and they found that the effects of highway capital on the state output level are positive but fairly small.

Moreover, the potential endogeneity of transport infrastructure investment has been also the subject of dicussion. So far, the results have been mixed. Duffy-Deno and Eberts (1991), Thompson et al. (1993) and Rietveld and Boonstra (1995) provide evidence of a reverse link from economic development to public infrastructure including transport infrastructure. Jiwattanakulpaisarn et al. (2009a) revealed that increases in employment activity could lead to the expansion of roadway capacity, but it depends on the type of highways and the model specifications considered. Boarnet (1998), Bollinger and Ihlanfeldt (2003) found no evidence that changes in output or employment cause highway improvements. Other studies, such as Dalenberg et al. (1998) and Kemmerling and Stephan (2002) found that the feedback effects from economic development to public/transport infrastructure are negligible.

A major shortcoming of the single equation framework is that it tends to neglect the problem of endogeneity arising from the explanatory variables. Several studies use cross-sectional models to examine the impacts of transport infrastructure on population and employment in a simultaneous equations framework, considering that the location decisions of firms and households are simultaneous (Boarnet, 1994; Carlino and Mills, 1987; Clark and Murphy, 1996; Duffy-Deno, 1998; Luce, 1994). Besides the simultaneity between population and employment, more recently, a cross-sectional simultaneous equation model has been used by Yamaguchi (2007) to analyse the impacts of infrastructure development in air transport, during 1990s, on GDP per-capita growth for core and peripheral areas in Japan. Kemmerling and Stephan (2002) proposed a simultaneous-equation approach to the estimation of the contribution of infrastructure accumulation to private production in large German cities, suggesting that public capital is a significant factor in private production. In summary, the works of Carlino and Mills (1987), Boarnet (1994) and Clark and Murphy (1996) are important and inspirational for this paper. One has to note that, using a systematic perspective to examine regional economic development, the incentives for the growth in various economic aspects are not always directly derived from the infrastructure investment. The indicators such as productivity, employment, active population, education level, income level, transport investment, etc., are all interrelated and interdependent on each other, and the causal direction is not always unambiguous. A single-equation framework ignores the fact that transportation and the socioeconomic variables interact in a simultaneous and systematic way.

In this paper, we aim to enhance the current state of knowledge on the relationship between transportation investment and regional development by extending the application of a simultaneous equation modelling in the following aspects. First, an accessibility indicator is used to measure transport infrastructure effects. The use of an accessibility indicator not only captures the network effects of the transport infrastructures, but also the attractiveness of the regions. According to the literature, the measures usually applied for representing transport infrastructure are restricted to the capital stock, the length or density of transport network, the expenditures and the presence of transport infrastructure, etc. (Cohen and Paul, 2004; Dalenberg et al., 1998; Jiwattanakulpaisarn et al., 2011b, 2009b; Lichter and Fuguitt, 1980; Seitz and Licht, 1995). But this type of measurement has the major disadvantage of not reflecting the spatial components, such as the amount, distribution and type of the activities in the destination areas. Second, we extend the application of the simultaneous equation model to a dynamic lag-adjustment framework, implying that the initial levels of the explanatory variables are important in determining their subsequent changes. Besides the consideration of the lagged variables as regressors, the model also endogenizes the railway and road accessibilities. By endogenizing HSR accessibility and road accessibility, we can examine whether the evolution of employment and number of firms causes additional investments of transport infrastructure or not. To estimate the simultaneous municipal economic models, we use a two-stage least square (2SLS) estimator with instrumental variables, accounting for the endogeneity among the dependent variable that might bias the estimated coefficients. Third, the results of education policy are also included as a variable that fosters the regional growth to control for the impacts from the road and railway infrastructures. Educational attainment is considered as a factor contributing to the economic growth (Barro, 1991; Di Liberto, 2008; Machin et al., 2012), however, including education policy or its results in the assessment of economic impacts of transport infrastructure is rarely found. Fourth, the model provides a comprehensive set of quantitative relationships between the accessibility by road, accessibility by railway, education level, GDP, employment, population and number of firms at provincial level, through estimating the five-period panel data for Spain in 1990, 2000, 2005 and 2010.

2. Methodology

The unit of observation is provinces; the sample size is 47 provinces in the continental Spain. The small sample size does not allow the estimation of a significant panel model that permits lagged dependent variables and the time invariant observed variables in a fixed effects model fashion (see Table A.1 in Appendix). Therefore, we only managed to estimate a simultaneous equation model with the pooled data using 2SLS estimator. The inclusion of the education level and road accessibility is to control the effects brought by HSR and prevent the overestimation of its impacts. The rationale behind this model structure is that, the construction of the HSR network directly impacts the level of provincial accessibility, which plays a role of trigger to the proposed system together with the variable of higher education level. Increased access due to HSR improves the attractiveness and competitiveness of a region, which is an important factor for firm location decisions, which then increases the labor demand. Road accessibility broadens the job catchment area, thus increases the labor supply. Employment growth thus occurs as a result of the interaction between the demand for labor stimulated by growth of number of firms and the supply of available labor brought by the higher accessibility to the labor market (Dodgson, 1974). High employment level is a critical factor for attracting in-migrants, which potentially enhances the population growth. Higher population level functions as a base of inducing new economic activities, thus strengthening economic growth in the region. The growth in GDP and number of firms in turn induces more demand of transport services, thus increases the accessibility levels.

The model aims to capture the causal influences (regression effects) among the exogenous variable education level and the endogenous variables, accessibility, population, employment, number of firms and GDP. The variables used were collected between 1990 and 2010 with 5-year time interval. The data structure allows the modeling of a lagged effects model to account for the fact that regional development does not respond instantaneously to changes in transport infrastructure improvements. It implies that the initial levels of the variables are important in determining the subsequent changes. The inclusion of current and lagged values of socioeconomic and transport variables as regressors accounts for not only the potential persistence in the process of economic development but also the timing of the impact of highways and HSR. To endogenize the improvement in railway networks, the levels of railway and road accessibilities are hypothesized as functions of their lagged values and as well as number of firms and GDP respectively. To account for the potential for a lagged response in the four endogenous variables, we consider a simple dynamic specification for our equations,

$$Ln_{GDP_{it}} = \tau_1 + \delta_1 * Ln_{GDP_{it-1}} + \beta_1 * Ln_{POP_{it}} + \varepsilon_1 \tag{1}$$

$$Ln_{POP_{it}} = \tau_2 + \delta_2 * Ln_{POP_{it-1}} + \beta_2 * Ln_{EMP_{it}} + \varepsilon_2 \tag{2}$$

$$Ln_{EMP_{it}} = \tau_3 + \delta_3 * Ln_{EMP_{it-1}} + \beta_3 * Ln_{ACCROAD_{it}} + \beta_4 * Ln_{EDU_{it}} + \beta_5 * Ln_{NOF_{it}} + \varepsilon_3 \tag{3}$$

$$Ln_{NOF_{it}} = \tau_4 + \delta_4 * Ln_{NOF_{it-1}} + \beta_6 * Ln_{ACCHSR_{it}} + \beta_7 * Ln_{GDP_{it}} + \beta_8 * Ln_{NOF_{it}} + \varepsilon_4 \tag{4}$$

$$Ln_{ACCHSR_{it}} = \tau_5 + \delta_5 * Ln_{ACCHSR_{it-1}} + \beta_9 * Ln_{EMP_{it}} + \varepsilon_5 \tag{5}$$

$$Ln_{ACCROAD_{it}} = \tau_6 + \delta_6 * Ln_{ACCROAD_{it-1}} + \beta_{10} * Ln_{GDP_{it}} + \varepsilon_6 \tag{6}$$

In the model framework, “railway accessibility (ACCHSR)”, “road accessibility (ACCROAD)”, “GDP”, “employment (EMP)”, “number of firms (NOF)” and “population (POP)” are the 6 endogenous variables interacting with each other and with the exogenous variable “education level” . Each of them is logarithmized, and represented as, Ln_{ACCHSR_it}, $Ln_{ACCROAD\_it}$, Ln_{GDP_it}, Ln_{EMP_it}, Ln_{NOF_it}, Ln_{POP_it}, *and* Ln_{EDU_it}, respectively, where t represents the year of observation, which are 1990, 1995, 2000, 2005 and 2010. The inclusion of the lagged level of the endogenous variables allows for potential persistence in the process of adjustment towards an equilibrium meaning that the current development situation could affect their future levels, which is reflected by the parameter δ. The regression weights are represented by the parameter β.

3. Data and Variable Description

The data items that used in the model are:

- Total population by province (POP);
- Number of firms by province (NOF);
- Number of employed population by province (EMP);
- Number of population graduated from high-school or above by province (EDU);
- Gross Domestic Product (GDP) by province;
- Calculated provincial accessibility by HSR (ACCHSR) and by road (ACCROAD): this index is a gravity-based measure that has been used extensively in accessibility studies. The accessibility is measured at municipality level and then aggregated to the provincial level. Here, this index uses an exponential distance–decay function as a weight for each municipality-pair in order to take into consideration the possible interaction between the municipal populations.

$$A_i = \sum_j A_{ij} = \sum_j Pop_j * \exp(-\beta * tt_{ij}) \tag{7}$$

$$A_m = \sum_m A_i^m \tag{8}$$

Where, A_i is the accessibility of municipality i, Pop_j is the population of municipality j, tt_{ij} is the travel time from municipality i to municipality j, β is the calibrated coefficient for the impedance function using GIS, with the parameter value equal to 0.1. A_m is the accessibility of province m. The equation takes into account the travel time by road from the origin to the nearest railway station $TT_C(i, E_i)$, the travel time by railway $TT_R(E_i, E_j)$, and the travel time by road from the station nearest the destination to the destination centroid $TT_C(E_j, j)$,

$$TT_{ij} = TT_C(i, E_i) + TT_R(E_i, E_j) + TT_C(E_j, j) \tag{9}$$

In the railway network, each link is given a commercial speed according to the characteristics of the infrastructure and quality of service. For simplicity, we did not include the transfer time between road and railway, between HSR and conventional rail and the frequency of the HSR service. Travel times from the centroid to the closest railway station by car is calculated using the free-flow speed without taking into the consideration of congestion, because in Portugal, most of the municipalities do not have sufficient congestion level to reduce the travel speeds except in the major urban areas, such as Lisbon and Porto. Therefore, for analytical purpose, we used the free-flow travel time for car. The travel times are calculated using a GIS-based network with network analyst tool box in ArcGIS®.

The descriptive statistics of the variables is presented in Table 1.

Table 1 Description of Variables and Descriptive Statistics for Case Study (Spain)

	Min	Max	Mean	St. Dev.		Min	Max	Mean	St. Dev.
ACCROAD90	96179,28	4931821,20	778845,02	941302,51	EMP90	33000	1718300	258798	330775,01
ACCROAD95	93408,94	5047831,38	788301,50	956643,79	EMP95	32325	1702675	249361	325252,15
ACCROAD00	91472,65	5230537,43	801845,05	983549,80	EMP00	36925	2211975	306540	420093,44
ACCROAD05	92309,33	5880445,66	861142,74	1088587,35	EMP05	37975	2858825	374915	522799,74
ACCROAD10	93554,91	6359702,77	912397,73	1165293,88	EMP10	38200	2875100	365257	509739,18
ACCHSR90	95647,07	4931870,27	776917,78	941607,45	GDP90	831,07	52451,01	6419,14	9454,44
ACCHSR95	92821,12	5047840,22	786320,66	956935,09	GDP95	1115,02	74857,79	8895,72	13473,28
ACCHSR00	90867,12	5230551,50	799828,97	983865,96	GDP00	1412,67	111204,52	12478,49	19646,54
ACCHSR05	91629,19	5881537,76	859149,37	1089076,57	GDP05	1817,88	160663,30	18006,26	28191,20
ACCHSR10	92811,01	6360828,98	910260,50	1165858,24	GDP10	2121,44	186630,31	20876,28	32409,71
EDU90	22789	1143423	134225	205087,56	NOF90	4964	325630	42698	57744,13
EDU95	27911	1856137	211266	316160,39	NOF95	5980	366193	49127	67226,24
EDU00	30531	2314634	276785	403519,56	NOF00	6312	411809	56722	78665,11
EDU05	34943	2835122	346920	498432,35	NOF05	6700	493400	66616	94894,38

EDU10	45194	3156015	367063	540292,53	NOF10	6992	548663	72832	103694,73
POP90	95647	4931541	776808	941615,84					
POP95	92821	5047413	786170	956951,32					
POP00	90867	5230106	799674	983879,95					
POP05	91629	5879766	858664	1089037,13					
POP10	92809	6358587	909598	1165825,99					

4. Empirical Findings

Table 2 presents the estimated coefficients of the model. The t-values of all the regression weights are greater than 1.96, which means that all are statistically significant for an α of 5%. All the coefficients possess the hypothesized signs, and all the models have an adjusted rho-square of higher than 0.99, meaning an excellent model fit. Due to the logarithm nature of the formulation, the estimated coefficients actually reflect the elasticity between the variables, meaning that 1% increase in HSR accessibility and road accessibility contributes to the growth in number of firms and employment by 0.20% and 0.15% respectively. Besides the accessibilities, higher education qualifications contributes positively to the employment level and GDP is also an important factor for further investment in the establishment of the firms in that region. A higher number of firms means more job opportunities, hence higher number of employed population, thereby attracting more households and labors into the region. The elasticity of employment with respect to the population is 0.14%. The variable population has small effects on GDP, but 1% growth in population still explains the 0.075% increase in GDP. In the meantime, the null hypothesis of no reverse causality cannot be rejected at the 5% level.

The reverse causal links from GDP and number of firms to HSR and road accessibilities are also statistically evident, meaning that higher levels of GDP and number of firms stimulates higher demand in the transport service investment, thus contributing to the growth of HSR accessibility and road accessibility endogenously with the elasticity of 0.08 and 0.05 respectively. The implication from these findings support the view that government's decisions to expand and improve the road and railway capacities are often taken in response to the derived demand from the growth in the economic activities, suggesting that new construction and expansions for roads are likely undertaken in order to serve growing volumes of individual and business journeys. The growth in GDP permits the public investment in the transport projects.

The lagged five-year effects shows that, all the endogenous variables in year t significantly affect their levels after 5 years, especially for GDP, population and accessibilities with the elasticity values higher than 0.9, slight lower effects found for employment and number of firms, 0.43 and 0.70 respectively.

Table 2 Estimates of Simultaneous-Equation Model (Pooled 2SLS) for Spain

	Dependent Variables					
Explanatory Variables	GDP	EMP	NOF	POP	ACCHSR	ACCROAD
ACCHSR			0.149			
t-value			*11.88*			
ACCROAD		0.196				
t-value		*5.29*				
EDU		0.118				
t-value		*4.10*				
GDP			0.142			0.052
t-value			*8.55*			*5.041*
EMP				0.137		
t-value				*6.05*		
NOF		0.288			0.0787	
t-value		*7.30*			*4.468*	
POP	0.075					
t-value	*8.90*					
GDP (lag)	0.920					
t-value	*73.14*					
EMP (lag)		0.425				
t-value		*7.75*				

NOF (lag)			0.700			
t-value			*27.71*			
POP (lag)				0.875		
t-value				*41.77*		
ACCHSR (lag)					0.939	
t-value					*66.585*	
ACC (lag)						0.967
t-value						*137.12*
R-squared	0.992	0.988	0.995	0.994	0.994	0.994
Adjusted R-squared	0.992	0.987	0.995	0.994	0.994	0.994

** values in italics are the t-stats*

According to the standardized coefficients in Table 3, the evidence of HSR accessibility, road accessibility and education qualification are shown to be slightly higher, but the changes are very small, almost negligible. The contribution of road and HSR accessibilities to the economic development has been confirmed in the case of Spain. The variables representing transportation infrastructures exhibited relatively smaller yet statistically significant effects on the economic variables.

Table 3 Standardized Coefficients of Simultaneous-Equation Model (Pooled 2SLS) for Spain

	Dependent Variables					
Independent Variables	GDP	EMP	NOF	POP	ACCHSR	ACCROAD
ACCHSR			0,144			
ACCROAD		0,191				
EDU		0,124				
GDP			0,150			0,057
EMP				0,114		
NOF		0,292			0,082	
POP	0,067					
GDP (lag)	0,916					
EMP (lag)		0,417				
NOF (lag)			0,696			
POP (lag)				0,702		
ACCHSR (lag)					0,925	
ACCROAD (lag)						0,952

** values in italics are the t-stats*

5. Conclusions

The empirical results aim to verify our hypothesis if the investment in HSR has positive impacts on stimulating GDP, employment, number of firms and population growth at provincial level. The findings reinforce also the concern that the transport investment of one province is endogenously related with its economic development. Both the findings of endogeneity and reverse causality provide a justification for the use of econometric techniques 2SLS which controls for the existence of endogenous variables.

The obtained results are more suggestive than conclusive. The extent to which these rates of increase can be applied to the general population remains unclear but, in terms of policy, it is important to make the point that investment in HSR construction in Spain had positive impacts on the economic growth of its provinces. The findings also reinforce the concern that the provincial GDP level and the number of firms also play an important role in the transport infrastructure improvement.

By taking into account the potential reverse causation, we can empirically identify that the relationships between GDP, number of firms and transport infrastructure are bi-directional, suggesting that growth in number of firms and GDP could stimulate demand for travel and hence the decision of the regional government to investment in the railway and road networks.

Overall, the results presented in this model are fairly strong evidence in favour of concluding that HSR investment has wider economic impacts on the provincial development. However, there are an important issues that need to be solved in the future research. It is related to sample size, which has to be bigger, or in other words, the methodology has to be tested on analysing the impacts of HSR both at municipal and regional levels. Bigger sample increases the variations within the variables and reduces the collinearity among them, and thus helps to improve the reliability of the estimates.

Appendix

Table A.1 Estimates of Simultaneous-Equation Model (FE 2SLS) for Spain

	Dependent Variables					
Independent Variables	GDP	EMP	NOF	POP	ACCHSR	ACCROAD
ACCHSR			0,455			
t-value			*6,26*			
ACCROAD		0,313				
t-value		*5,12*				
EDU		0,066				
t-value		*1,70*				
GDP			0,423			0,285
t-value			*1,36*			*0,07*
EMP				0,415		
t-value				*0,60*		
NOF		0,571			0,413	
t-value		*3,45*			*0,20*	
POP	0,155					
t-value	*0,20*					
GDP (lag)	0,857					
t-value	*0,04*					
EMP (lag)		0,043				
t-value		*0,25*				
NOF (lag)			0,127			
t-value			*0,40*			
POP (lag)				0,561		
t-value				*0,81*		
ACCHSR (lag)					0,542	
t-value					*0,26*	
ACC (lag)						0,643
t-value						*0,16*
R-squared	-15,051	0,983	0,948	0,592	-1,782	-8,630
Adjusted R-squared	-15,492	0,982	0,947	0,581	-1,858	-8,894

** values in italics are the t-stats*

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