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Estimating the provincial economic impacts of high-speed rail in Spain: An application of structural equation modeling

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Abstract

This paper presents the preliminary steps on an investigation about the impacts of the Spanish high-speed rail (HSR) network on the provincial economic development from 1990 to 2010 using a panel Structural Equation Modeling (SEM) formulation. The SEM model incorporates education level (proxied by number of people finished high-school or above) as the exogenous variable, endogenizes provincial accessibility brought by the introduction of the HSR service, and analyzes its long term impacts on the endogenous variables, employment and GDP, as well as the causal relationships among them. Panel structure helps to reveal the temporal effects with a time lag of 5 years. Comparison between SEM formulation and single-equation formulation is carried out in the paper as well to reveal the applicability and advantages of SEM formulation.

Keywords: High-speed Rail; economic development; panel model; structural equation modeling.

1. Introduction

The investment on High-Speed Rail (HSR) infrastructure has been widely encouraged and supported in Europe due to the firm belief that transport infrastructure has spatial, social and economic impacts on urban/regional development, such as increase in employment, income, production and changes in land use patterns (Vickerman, 1997; Banister and Berechman, 2000). It is commonly acknowledged that investment on transport infrastructure increases the accessibility to resources, goods and markets, and thus improves the competitiveness of a region (Dodgson, 1974; Gutiérrez, 2001; Levinson, 2012) and enhances economic integration (Blum, 1982; Rietveld, 1989). Reductions in travel time and travel cost can also give rise to productivity growth through reinforcing the agglomeration benefits (Venables, 2007; Graham, 2007; Hensher et al., 2012). The improvement in transport infrastructure is seen as a means of stimulating production and

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influencing the location decisions of firms, which then induce more employment and private investments through expanding the existing businesses and attracting new economic activities (Button, 1998; Rietveld and Bruinsma, 1998; Rietveld and Nijkamp, 2000).

Despite the ample and extensive literature about the contribution of transport infrastructure to the economic development, the magnitude and significance of the economic effects have been continuingly inconclusive and controversy. The empirical findings from the existing literature vary severely, from no significance to strong significance, according to the geographical scale of analysis, employed data set, modeling frameworks etc. (Holtz-Eakin, 1994; Garcia-Mila et al., 1996; Boarnet, 1998; Jiwattanakulpaisarn et al., 2011). For the case of HSR, although in general the spatial impacts of investments in HSR networks on development are proven to be positive (Martin, 1997; Vickerman, 1997; Gutiérrez, 2001; Levinson, 2012), there has been no clear consensus on their magnitudes or scopes. Nakamura and Ueda (1989) found a high correlation between high growth rate of population and employment and the presence of HSR stations. Bonnafous (1987) argued that the arrival of the TGV in Lyon strengthened the city's business base. But Facchinetti-Mannone (2009) reached disappointing results that exurban HSR stations failed to act effectively as polarizing infrastructures and accentuated centrifuge forces in small towns in France. This accentuates the complexity and challenges in examining the links between HSR and economic development. One has to note that, from a systematic perspective, the incentives for the growth in various economic aspects are not always directly derived from the transport infrastructure. The indicators such as production, employment, population, education level, income level, transport investment, etc., are in fact interdependent on each other, and the causal direction is not always unambiguous. In the big pool of literature, rather few researchers focused on exploring the impacts induced by HSR quantitatively and analyze the relationship between HSR and regional development holistically. To avoid potentially misleading model estimates, an obvious and important improvement is to estimate the joint evolution of transport infrastructure, population, private investment, employment and other related socioeconomic aspects, in the context of a more interactive and realistic model.

Structural equation modeling (SEM), one of the approaches employed for this paper, is a modeling technique capable of dealing with several difficult modeling challenges, unobservable or latent variables, endogeneity among variables, and complex underlying data structures often found in the social phenomena, such as transportation applications (Washington et al., 2003). Most of SEM applications have been in psychology, sociology, the biological sciences, educational research, political science, and market research. In transportation field, numerous studies using SEM methods have been conducted on travel demand and travel behavior (Golob, 2003; de Abreu e Silva et al., 2012); Aditjandra et al., 2012). Several authors used simultaneous equation models in transportation related issues (Fujii and Kitamura, 2000; Sakano and Benjamin, 2011). To our knowledge, there are no applications of SEM on the assessment of the economic impacts of HSR investment. Furthermore, panel data modeling is one possible application for SEM. Models can be specified with repeated variables variables joined by lagged causal effects and possibly autocorrelated error structures. Moreover, time-invariant individual-specific terms can be incorporated in error structures, and period effects can be isolated with certain types of panel data (Bollen and Brand, 2010).

The objectives of this paper are two-fold. Firstly, it is to explore the applicability of the SEM approach on the estimation of the economic impacts of transport infrastructures, particularly HSR in this case. Secondly, it is to preliminarily investigate the impacts of the Spanish HSR network on the provincial economic development from 1990 to 2010, through a panel model with fixed effects using SEM approach (Bollen and Brand, 2010). The SEM model endogenizes provincial accessibility brought by the introduction of HSR service, analyzes its long term impacts on the other endogenous variables of provincial development, employment and GDP, and as well as the causal relationships among them. Education level, proxied by number of people finished high-school or above, is included exogenously to control the effects of accessibility. A fixed effects panel structure was adopted to reveal the temporal effects with a time lag of 5 years, and as well as the reverse direction of how provincial employment is affecting the accessibility level in 5 years.

2. Methodology

SEM is used to capture the causal influences of the exogenous variables on the endogenous variables and the causal influences of endogenous variables upon on another (Golob, 2003). SEM with latent variables is known as the full model, however, the SEM model presented in this paper mainly deals with observed variables, only includes the latent time-invariant variables for the time-varying covariates (Bollen and Brand, 2010). A measured variable is a variable that can be observed directly and is measurable. They are also known as observed variables, indicators or manifest variables. A latent variable is a variable that cannot be observed directly and must be inferred from measured variables. The basic equations of the structural and measurement models are the following (Muthén, 2002):

The measurement part of the SEM model is defined as:

$$y_i = \nu + \Lambda \eta_i + \mathrm{K} x_i + \varepsilon_i \tag{1}$$

Where η is an m-dimensional vector of latent variables, x is a q-dimensional vector of covariates, ε is a p-dimensional vector of residuals or measurement errors which are uncorrelated with other variables, ν is a p-dimensional parameter vector of measurement intercepts, Λ is a p×m parameter matrix of measurement slopes or factor loadings, and K is a p × q parameter matrix of regression slopes.

The structural part of the model is defined in terms of the latent variables regressed on each other and the q-dimensional vector x of independent variables,

$$\eta_i = \alpha + \mathrm{B}\eta_i + \Gamma x_i + \varsigma_i \tag{2}$$

Here, α is an m-dimensional parameter vector, Γ is an m × q slope parameter matrix for regressions of the latent variables on the independent variables, B is an m×m parameter matrix of slopes for regressions of latent variables on other latent variables, and ς is an m-dimensional vector of residuals.

3. Case Study

Spain is one of the earliest European countries to enter the high-speed rail era. The first Spanish HSR line was inaugurated in 1992, connecting Madrid to Seville. In 2000s, more HSR lines are opened, under construction or planned. The lines from Madrid to Valladolid, Barcelona and Valencia were respectively inaugurated in 2007, 2008 and 2010. By the end of 2011, the 2,665-km HSR network is the second longest in the world. Adopting the proposed path diagram, the case study assesses the economic impacts of the HSR investment at provincial level in Spain.

3.1. Data Description

The model is estimated based on the data of 47 provinces of Spain in the year 1990, 1995, 2000, 2005 and 2010. The data items that used in the model are:

- Number of employed population by province (*Emp*);
- Number of population graduated from high-school or above by province (*H_Edu*);
- Gross Domestic Product (*GDP*) by province;
- Calculated accessibility by HSR (*Acc_HSR*): this index is a gravity-based measure that has been used extensively in accessibility studies. In this paper, this index uses a distance–decay function as a weight for each province-pair in order to take into consideration the possible interaction between the populations.

$$A_i = \sum_j A_{ij} = \sum_j Pop_j * \exp(-\beta * tt_{ij}) \tag{3}$$

$$tt_{ij} = tt_{im} + tt_{mn} + tt_{nj} \tag{4}$$

Where, A_i is the accessibility of province i, Pop_j is the population of province j, tt_{ij} is the travel time from province i to province j, β is the calibrated coefficient for the impedance function using GIS. tt_{ij} consists of the travel time from the centroid of the origin province to the closest railway station m by car, denoted as tt_{im}, the travel time from the origin railways station to the destination railway station n, denoted as tt_{mn} and the travel time from the destination railway station to the centroid of the destination province, denoted as tt_{nj}.

Table 1. Descriptive Statistics of Data

	MIN	MAX	MEAN	STDEV.		MIN	MAX	MEAN	STDEV.
HSR_ACC_1990	95647,07	4931870,30	776917,78	941607,45	H_Edu_1990	28317	1456383	171016	257188
HSR_ACC_1995	92821,12	5047840,22	786320,66	956935,09	H_Edu_1995	27911	1856137	211266	316160
HSR_ACC_2000	90867,12	5230551,50	799828,97	983865,96	H_Edu_2000	30531	2314634	276785	403520
HSR_ACC_2005	91629,19	5881537,75	859149,37	1089076,57	H_Edu_2005	34943	2835122	346920	498432
HSR_ACC_2010	92811,01	6360829,01	910260,50	1165858,24	H_Edu_2010	45194	3156015	367063	540293
Emp_1990	33000	1718300	258798	330775	GDP_1990	831,07	52451,01	6419,14	9454,44
Emp_1995	32325	1702675	249361	325252	GDP_1995	1115,02	74857,79	8895,72	13473,28
Emp_2000	36925	2211975	306540	420093	GDP_2000	1412,67	111204,52	12478,49	19646,54
Emp_2005	37975	2858825	374915	522800	GDP_2005	1817,88	160663,30	18006,26	28191,20
Emp_2010	38200	2875100	365257	509739	GDP_2010	2121,44	186630,31	20876,28	32409,71

3.2. Model Specification

The model aims to capture the causal influences (regression effects) among the exogenous variable education level and the endogenous variables, accessibility, employment and GDP. The variables used were collected for five year periods between 1990 and 2010. The data structure allows the modeling of lagged effects to account for the fact that provincial 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 the social economic 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 accessibility is hypothesized as functions of the lagged employment level. We develop a panel model that permits lagged dependent variables and as well permits the time invariant observed variables in a fixed effects model fashion. The inclusion of the education level as an exogenous variable 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 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. Better accessibility to resources, goods and markets improves the competitiveness of a region, which then stimulates the production level (Erenburg, 1993; Guild, 2000). Higher GDP levels then functions as expanding the existing economic scale and inducing new economic activities, thus strengthening economic growth and creating more employment opportunities in the region. Employment growth thus occurs as a result of the GDP and accessibility, due to the interaction between the demand for labor stimulated by GDP growth and the supply of available labor brought by the higher accessibility to the labor market (Dodgson, 1974).

The final path diagram of the model is presented in Figure 1. In the model framework, “Accessibility”, “Employment” and “GDP” are the 3 endogenous variables interacting with each other and with the exogenous variable “Higher Education Level”. Each of them is logarithmized, and represented as, “*Ln_Acc_HSR_t*”, “*Ln_Emp_t*”, “*Ln_GDP_t*” and “*Ln_H_Edu_t*”, in which *t* represents the year of observation, which are 1990, 1995, 2000, 2005 and 2010 respectively. In the model formulation, the covariance among the exogenous variables “*Ln_H_Edu_t*” is as well included (but omitted for easy reading). The time-specific fixed effects for the endogenous variables are modeled too, denoted as “*Fix_Emp*”, “*Fix_Acc*” and “*Fix_GDP*”, in which “*Fix_GDP*” is correlated with “*Ln_H_Edu_t*”(also omitted from the diagram for the same reasons). Besides, the path diagram also shows the lagged five year effects of Education Level on GDP, GDP on Employment and Employment on Accessibility. In the different trials of the model, the lagged effects of the endogenous variables on themselves were initially included. However, the results were unsatisfactory, therefore, we removed those paths.

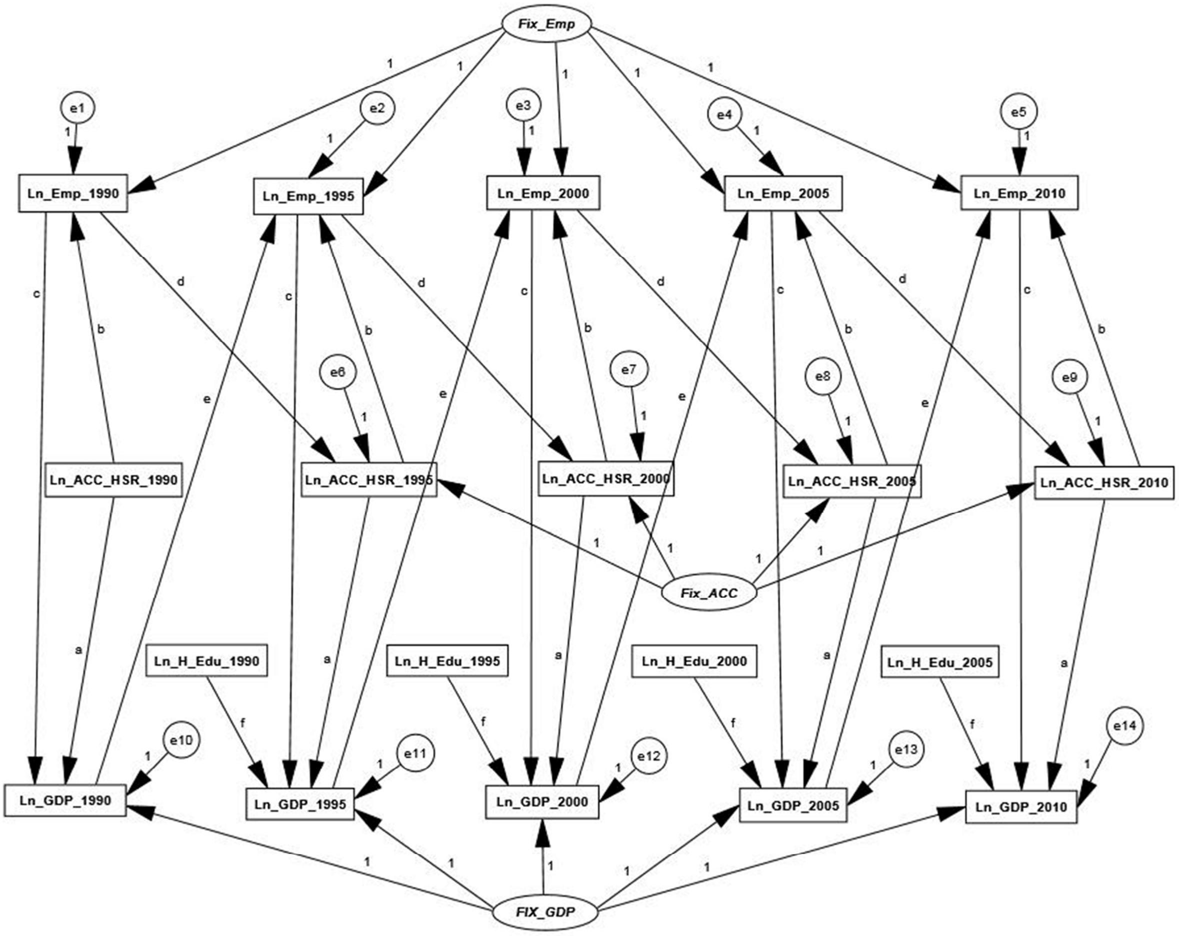

Fig. 1. Path Diagram of SEM Panel Model

3.3. Result Discussions

Analytical procedures were conducted using the statistics packages SPSS and AMOS. The maximum likelihood estimation (MLE) approach was chosen to estimate the SEM. The model estimation is performed in AMOS 20 (Arbuckle, 2011). Unfortunately, the estimated models does not show a good fit (see Table 2), in terms of the ratio between chi-square and the degree of freedom. The closer the Chi-square value is to the degrees of freedom for a model, the better the fit of the model (Thacker et al., 1989). Jackson et al. (1993) suggested that a ratio of 5 to 1 was considered to be acceptable. There are a few reasons to justify the relatively poor fit of the model. Firstly, the number of observations in this case is 47 provinces. SEM is a large sample technique, usually with sample size greater than 200 (Kline, 2011). Secondly, the Chi-square statistic is strongly sensitive to sample size. The Chi-Square statistic nearly always rejects the model when large samples are used (Bentler and Bonett, 1980;Jöreskog and Sörbom, 1993), and when the small samples are used, the Chi-Square statistic lacks power and because of this may not discriminate between good fitting models and poor fitting models (Kenny and McCoach, 2003). Thirdly, the accessibility is measured at provincial level, which might be too aggregated to reflect the variations in the improvements brought by the HSR operation, and thus introducing the risk of collinearity with other economic factors. However, despite that fact that our model has the Chi-square to degree of freedom ratio around 7.6, the variances of the fixed effects terms and the errors terms and the covariance among the exogenous variables and the fixed effects term of GDP are all statistically significant at 95% level. Since this work is a preliminary investigation on the applicability of SEM to model the economic impacts of HSR and aims to provide insights for further research, we consider that these objectives have been met.

Table 2 presents the direct effects of the model. The t-values of all the regression weights are greater than 1.96, which means that there is only less than 5% of chance that the null hypothesis is true. In other word, all the estimated regression weights are statistically significant. All the coefficients possess the hypothesized signs. Due to the logarithm nature of the formulation, the estimated coefficients actually reflect the elasticity between the variables, meaning that 1% increase in accessibility contributes to the growth in GDP and employment 0.26% and 0.96% respectively. And 1% increase in the employment induces about 0.3% growth in GDP. In the meantime, education level, employment and GDP also have effects on the economy in following period. The lagged five-year effects show that, education level in year t positively contributes to the GDP in year t+5. And the accessibility of year t+5 is endogenously related with the employment level of year t and also indirectly on GDP with a lag of 10 years. Higher employment level induces more transport demand, thus stimulates the improvement of the transport supply. GDP level of five years ago also possess the power of increasing the employment level in the next five years.

Table 2. Model Estimation Results – Direct Effects

Regression Weights			Estimate	T-value
Ln_GDP_*t*	<---	Ln_ACC_HSR_*t*	0,264	6,12
Ln_Emp_*t*	<---	Ln_ACC_HSR_*t*	0,963	77,27
Ln_GDP_*t*	<---	Ln_Emp_*t*	0,307	6,99
Ln_GDP_*t+5*	<---	Ln_H_Edu_*t*	0,019	2,52
Ln_ACC_HSR_*t+5*	<---	Ln_Emp_*t*	0,755	63,96
Ln_Emp_*t+5*	<---	Ln_GDP_*t*	0,045	3,06
Minimum was achieved; Chi-square: 1244; Degrees of freedom: 164				

Here we also compare the SEM model results with the estimates obtained from the single equation formulations, using fixed effects model with the same panel data and the same specification as in the path diagram in Figure 1. The results of the single equation models are presented in Table 3.

Table 3. Estimation Results of Single Equation Panel Model

Single Equation Panel Model					
Parameter	Estimate	t-value	Parameter	Estimate	t-value
Intercept	-2,742	-21,11	Intercept	1,219	7,96
[Time=1,0]	-0,306	-10,76	[Time=1,0]	0,253	8,03
[Time=2,0]	-0,243	-9,89	[Time=2,0]	0,247	9,94
[Time=3,0]	-0,132	-5,67	[Time=3,0]	0,238	11,48
[Time=4,0]	0^b	-	[Time=4,0]	0^b	-
Ln_H_Edu_lag	0,275	8,79	Ln_GDP_Lag	0,543	18,61
Ln_HSR_ACC	-0,357	-6,70	Ln_HSR_ACC	0,458	15,29
Ln_Emp	1,098	19,99			
Dependent Variable: Ln_GDP			*Dependent Variable: Ln_Emp*		

b. This parameter is set to zero because it is redundant

Comparing the estimated coefficients in Table 3 with the results in Table 2, one can see that the impacts of accessibility "*Ln_HSR_ACC*" on GDP and Employment are contradictive, positively related with employment but contributes negatively to GDP. The effects of HSR reflected in this type of formulation are rather unstable. It is easy to see that a model that permits only one set of relationships to be estimated, while ignoring other potentially important relationships, could be a distortion of reality. Hence, the SEM model estimated in the current study, albeit without an adequate fit, represents a fairly significant improvement over single-equation models. Another advantage of the SEM formulation is that the potential endogeneity considering that additional investments in transport infrastructure could as well be triggered by the need to reinforce the economic development is explicitly expressed in the SEM model. Understanding the reverse causal links is as important as evaluating how the economy reacts to the improved transport services.

4. Conclusions

The empirical results aim to verify our hypothesis if the investment in HSR together with higher education level have positive impacts on stimulating the GDP, increasing the employment level at provincial level. The findings are also to reinforce the concern that the transport investment of one province is endogenously related with its economic development. The proposed model has innovative features when compared with single equation models. First, it has a systematic perspective, the relationships between HSR service and the various aspects of the provincial development are represented in a way that they interact with each other in a more realistic manner. Secondly, the panel feature of the model allows us to examine the lagged year effects, the endogeneity of the transport infrastructure and as well as the temporal effects of the 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 growth in provincial economy, stimulating GDP, increasing the employment level. The findings also reinforce the concern that the provincial employment level also plays an important role in the transport infrastructure improvement. Overall, the results presented in this model are fairly strong evidence in favor of concluding that HSR investment has wider economic impacts on the provincial development. However, there are a few issues needed to be solved in the future research. One issue is that we need to use more accurate and disaggregate measure of accessibility, because the accessibility indicator used in this paper ignores the distribution of the population within the province and simply treat them as concentrated in the centroid only (this approach was mainly a result of time constraints). Another issue is that the sample size has to be bigger, which in other words, the methodology has to be tested on analyzing the impacts of HSR both at municipal and regional levels, using a multilevel SEM formulation. Bigger sample increases the variations within the variables and reduces the collinearity among them, and thus helps to improve the model goodness-of-fit.

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