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Measuring the substitution effects between High Speed Rail and air transport in Spain

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ABSTRACT

The main objective of this paper is to estimate the impact that the expansion of the HSR network has had on air transport in Spain by estimating the substitution effect between the two types of transportation. This paper considers the way that the HSR network has grown and how this growth could have affected air transport dynamically. The findings show that a dynamic vision of this substitution rate should be adopted, as opposed to assuming that the rate is constant, as has been the case in previous references. Although the rate varies significantly over the study period, only 13.9% of HSR passenger demand was found to have come from air travel during the 1999–2012 period, meaning that HSR and airlines would seem to offer more independent services than at first it might appear. This confirms the hypothesis as to the HSR's great ability to generate its own demand. The substitution rate between the two transport modes seems to be closely linked to the way that any new stations are incorporated into the HSR network. Convergence between the seasonality of HSR and air transport has also been examined. The results show that it is difficult to talk of a real HSR transport network in Spain.

1. Introduction

In these times of economic adversities (see Trachanas and Katrakilidis (2013) and Ali (2012) on this aspect) while emerging countries are preparing to start building their High Speed Rail (hereinafter HSR) networks, others, such as France, which were pioneers in this type of transport (Marti-Henneberg, 2013), have decided to postpone some schemes while continuing with others (Leheis, 2012; Bayon, 2013), or to upgrade their conventional rail increasing speeds on existing tracks up to 200 km per hour (De Rus, 2012). In this context, there are growing numbers of papers that place increased importance on the cost and economic development (Givoni, 2006), on the need for a proper prior cost assessment of the investment (De Rus and Nombela, 2007; De Rus and Roman, 2006), and the need to prevent the HSR network being developed on the basis of political, rather than economic criteria (Albalate and Bel, 2012; Bel, 2011).

A major part of this discussion about the suitability of developing HSR networks or lines focuses on the analysis of the competition or collaboration between the HSR and other means of transportation. Competition between the HSR and the car has been addressed by Gonzalez-Savignat (2004b) and Roman et al. (2007), and collaboration between the HSR and other land transport by Tapiador et al. (2009). With respect to competition between the HSR and air traffic, Kappes and Merkert (2013) indicate that the two biggest obstacles to breaking into the European air market are access to slots and competition from HSR lines. There are also studies that address collaboration between air transport and the HSR, such as those by Givoni and Banister (2006), Lythgoe and Wardman (2002), Redondi et al. (2013) and Socorro and Viecens (2013). Other paths of collaboration could emerge if secondary airports were linked to the main hub by HSR, as is the case in Spain, as this would allow international flights to be dispersed around the country (Sismanidou et al., 2013).

Specifically, the implementation of the HSR in Spain and the way that the country has become an exporter of a mode of transport is a case study of international significance (see Campos and De Rus (2009), Marti-Henneberg (2013), Redondi et al. (2013), Socorro and Viecens (2013), and Martin and Nombela (2007) on this topic). When the most recent Madrid–Barcelona–Figueres and Madrid–Valencia–Alicante lines came into service Spain quickly advanced to the position of having the second largest HSR network in the world behind China, a country that is not easily comparable to Spain due to its size and population (see Albalate

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and Bel (2011) on this topic), with, specifically, over 3100 km in service in 2013 (Adif, 2014). However, this expansion could impact negatively on regional cohesion, although the extent of any impacts varies depending on the area (see Ortega et al., 2014) or the planning level. Ortega et al. (2012) conclude that the effects are positive on the nationwide and corridor levels but that on the regional level, they might be negative.

In this context, the main objective of this paper is to estimate the effect that the expansion of the HSR network has had on air transport in Spain by estimating the substitution effect between the two types of transport. This will be done over the broad timeframe of January 1999–December 2012 that was marked by the expansion of the Low Cost Carriers (hereinafter LCCs) that included both international – for example, Ryanair and Easyjet – and domestic – especially Vueling – companies (Castillo-Manzano et al., 2012b; Bel and Fageda, 2010). This went hand-in-hand with the decline of the leading national airline, i.e., Iberia, which closed the year (2012) with losses of 351 million Euros. Obviously, this expansion of the LCCs, especially on domestic routes, is an important factor that should be taken into account as, *a priori*, the fall in the cost of air travel should increase competition with the HSR (Yang and Zhang, 2012) by reducing the appeal of the HSR compared to air transport.

The article is organized as follows: Section 2 presents a literature review of the substitution effects between the HSR and air transport. Section 3 lays out the data and presents the methodological approach. Section 4 presents the empirical results and the discussion of these findings and, finally, Section 5 presents the conclusions of the study.

2. Literature review

The analysis of the substitution rate between the HSR and air transport is especially relevant for the economy. Firstly, an estimate is required to enable the demand forecasts and/or the Social Cost/Benefit Analysis (De Rus and Roman, 2006) to be drawn up that are used to justify/not justify the viability or non viability of a new HSR line. In this line, Carrera-Gomez et al. (2006), for example, indicate that from the economic point of view the HSR between Madrid and Seville would not be socially profitable when analyzing congestion, maintenance costs, accidents and environmental costs for the car, the train, and the long distance bus along the Seville–Madrid corridor, and the elasticity of prices between them, using a function to maximize the sum of consumer and producer surpluses. From another point of view, Givoni and Banister (2006) conclude that airlines can use railway services as spokes of their own network of services. In such cases the railway infrastructure complements the air transport infrastructure, and should also be seen as part of the latter. Socorro and Viecens (2013) also use a theoretical model to conclude that plane–train integration is beneficial, or at least not detrimental, by which they are arguing that the complementary nature of the two has primacy over the substitution effect.

Martin and Nombela (2007) use an aggregate multinomial logit model to study competition according to distance. Their study concludes that the HSR will mainly attract passengers from airlines and the long distance bus on journeys of over 500 km, while for shorter journeys, the main competition will come from cars. A similar conclusion can be found in Armstrong and Preston (2011). Using logit discrete choice models González-Savignat (2004a) also concludes that the HSR may be considered as a truly competitive product to air transport over distances that can be covered in a maximum of 3 h. However, none of these studies goes so far as to offer estimations that quantify the substitution relationships between air transport and HSR.

In the case of the Madrid–Seville HSR line, DeRus and Inglada (1997) use passenger data from Iberia and RENFE (the Spanish national railway company) and demand elasticity with respect to the GDP to indicate that air passengers between the two cities fell from 694,400 (25.1%) in 1992 to 352,200 (10.1%) in 1996, the year that the HSR was brought into service, and that passengers on this new mode of transport stood at 1,438,200 (41.3%). Using an analysis based on disaggregated mode choice models with information from a mixed revealed preferences/stated preferences database, Roman et al. (2007) estimated that in the best Madrid–Barcelona scenario that they analyzed, HSR's market share would not exceed 35% of all air and train passengers. However, in reality the HSR market share of the Madrid–Barcelona route stood at around 50% in 2012, the last year for which it was analyzed.

Using a Two-Stage Least Square estimator (2SLS-IV) to estimate the equations, Jiménez and Betancor (2012) indicated that the introduction of HSR in Spain led to air operations reducing by 17% at the same time that overall demand for transport increased, which meant an even greater fall in their share.

Basing his focus on competition between the HSR and the plane, Dobruszkes (2011) finds that air companies could reduce the number of passengers per flight and increase frequency to respond to the introduction of HSR, and that this would prevent a fall in overall passenger numbers. In the same line, Fageda et al. (2011) state that air companies would also lower their prices to increase their competitiveness. For this they use a pricing equation with the two-stage least squares estimator. Yang and Zhang (2012) use a variation of the classic Hotelling model to indicate that the variables that have the greatest effect on the decision to use one mode of transport or the other in China are price and frequency. One last antecedent to this study that can be cited is Fröidh (2008), which compares generalized costs faced by plane and HSR passengers and arrives at the broad conclusion that traveling time is the most important factor for gaining market share in Sweden.

The focus of this paper offers the following advantages compared to these earlier papers. Firstly, it considers the way that the HSR network has grown and how this growth could have affected air transport dynamically. This enables the effects of new high-speed routes and of new airport terminals to be quantified. In addition, previous references have employed regression type models in order to explain the influence of new HSR stations on flight traffic by means of dummy variables and constant coefficients. Here, we report a more flexible and robust methodology that is capable of allowing parameters that vary over time. The idea behind this is to explore the substitution factor between HSR and planes on a dynamic basis. Essentially, the substitution effect between the two transportation methods can be a non-stationary stochastic variable instead of a constant coefficient. In particular, the proposed model is a Dynamic Linear Regression that belongs to the family of Time Varying Parameter (TVP) models (West and Harrison, 1989; Harvey, 1989). The advantages of our approach over the focuses of the prior literature will be analyzed in Section 3.

Finally, as the analysis extends through December, 2012, both the new lines that have been brought into service (the Cuenca–Albacete–Valencia line, for example) and the effect of the economic crisis can be included. The basis from which we start is that HSR is a high cost means of transport for the traveler, although in general terms fares will not cover the overall cost of its construction. The explosion of the LCCs onto the Spanish market as a whole also led to LCCs taking 52.5% of commercial passenger air transport in the last month of the sample.

3. Data and methods

The dataset can be divided into two groups:

(A) Air passengers on domestic flights flying to/from Madrid-Barajas, which is considered as the endogenous variable and is computed as $planepas_t$. This information is available from the Spanish Public Airport Authority (AENA, 2014).
We only used data from Madrid-Barajas airport as the vast majority of Spanish traffic had its origin or destination at the Madrid HSR stations (Madrid Puerta de Atocha and, to a much lesser extent, Madrid-Chamartín) during the period analyzed. To be specific, this was 84% in 2011 (Ferropedia, 2014) and, it can be assumed, a higher figure during the previous years, as there were fewer hubs in the HSR network. As previous studies have stated (see for example Guirao, 2013), the Spanish HSR network today has a clearly radial architecture in which Madrid clearly stands out as the central hub. This is even truer given that not only is Madrid's HSR station (Madrid Puerta de Atocha) itself located within the hinterland of the airport, but also other HSR stations, such as Toledo, Valladolid and Ciudad Real.

(B) The exogenous variables, namely:
  a The number of air operations on domestic flights with a single period delay (op_{t-1}). We assume that air passengers at time t are heavily influenced by the number of operations during the previous period. This variable strongly correlates with the evolution of LCCs in Spain,[1] and therefore corrects for their possible effect. This information is available from the Spanish Public Airport Authority (AENA, 2014).
  b High Speed Rail passengers ($hsrpas_t$). To be specific, this is the total number of passengers who traveled on the Spanish High Speed Rail network during period t. These data were obtained from the Ministry of Public Works (2014).
  c The population of the provinces connected by HSR ($popu_t$). *Source:* National Statistics Institute (INE, 2014).
  d The economic cycle measured by the unemployment rate ($unemp_t$) in the province of Madrid, according to data from the Spanish Public Employment Service (SEPE, 2014).
  e Indicator or dummy exogenous variables:
    i On 9th January, 2009 Madrid experienced a heavy snowfall that paralyzed the airport for several hours. This dummy variable ($snow_t$) is modeled as a pulse, where all the values are zero except for January, 2009, which is equal to one (ABC national newspaper, 2009).
    ii Business. The number of trading days in a month can vary considerably and this may have a substantial effect on air passengers. When considering just two types of day, for instance, weekdays and Saturdays and Sundays, this variable is calculated as the number of business or trading days in a given month minus the number of Saturdays and Sundays in said month, multiplied by 5/2. More details of this way of dealing with business day variation can be found in Harvey, 1989, p. 334. Any further holidays in the month are subtracted from the business days.
    iii Seasonal dummy variables. 11 dummy variables are employed to model the annual seasonality expected in the data.

The data were collected monthly from January, 1996, to December, 2012, resulting in a total sample of 204 observations per variable.

Fig. 1 shows passengers on domestic flights and HSR passengers. The strong annual seasonal pattern should be noted in both time series. It is interesting to note that even when both time series reveal yearly seasonality, their evolution, especially during the first years, differs notably. In fact, up to 2005, HSR seasonality was more tourism-oriented, with obvious peaks in August and December, compared to the more business-oriented seasonality of the plane, with troughs in August and December. Subsequently, from 2006 onwards, HSR seasonality increasingly approaches that of the plane.

Furthermore, by the beginning of 2008 there is a significant drop in domestic flights that matches the striking increase in HSR passengers.

Additional information to explain the substitution effect between plane and train is given in Tables 1 and 2. In particular, Table 1 shows the dates that new HSR routes came into service. Table 2 also shows the dates when new airport terminals were opened in Madrid (T4) and Barcelona.

The time series model employed in the analysis is in the class of time-varying parameters described in a State Space framework (West and Harrison, 1989). The proposed Dynamic Linear Regression model can be described as follows:

$$planepas_t = \beta_0 + \beta_1 op_{t-1} + \beta_{2t} hsrpas_t + \beta_3 unemp_t + \beta_4 snow_t + \beta_5 bus_t + \beta_6 popu_t + \sum_{i=7}^{17} \beta_i Seas_{it} + \varepsilon_t \quad (1)$$

where

1 $planepas_t$ is the number of domestic air passengers at time t at Madrid-Barajas airport.
2 op_{t-1} is the number of air operations on domestic flights at Madrid-Barajas airport during period $t-1$.
3 $hsrpas_t$ is the number of HSR passengers in the Spanish railway system at time t.
4 $unemp_t$ is the unemployment rate.
5 $snow_t$ is a dummy variable that denotes that the airport was paralyzed by a heavy snowfall in January, 2009.
6 $popu_t$ is the population of the provinces connected by HSR at time t.
7 bus_t is a dummy variable that considers the differences between business or trading days and weekends.
8 $Seas_{it}$ is a set of dummy variables for $i = 6, \ldots, 16$ and time t.

The last term in expression (1) refers to the model error, which is assumed to be normally distributed with zero mean and variance σ^2.

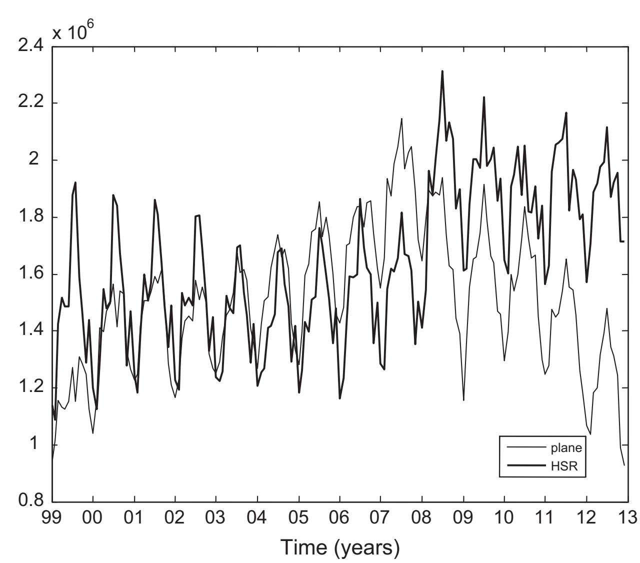

Fig. 1. Air passengers on domestic flights and HSR passengers.

[1] A scatter plot showing evidence of the significant correlation between operations and low-cost plane passengers is available from the authors upon request.

Table 1
Start dates for new HSR routes.

HSR routes	Start date
Madrid–Guadalajara–Zaragoza–Lleida	10/2003
Zaragoza–Huesca	04/2005
Madrid–Toledo	11/2005
Madrid–Tarragona	12/2006
Madrid–Malaga	12/2007
Madrid–Segovia–Valladolid	12/2007
Madrid–Barcelona	02/2008
Madrid–Cuenca–Albacete–Valencia	12/2010

Table 2
Opening dates of new airport terminals in Madrid and Barcelona.

Airport terminals	Opening date
Madrid T4	02/2006
Barcelona	07/2009

In order to associate the estimated coefficients with their respective elasticities, the variables, excluding the dummies, are log transformed. The main difference between the Dynamic Linear Regression model and the standard regression model lies in the model coefficients. Note that the Dynamic Linear Regression may be seen as an extension of the standard Linear Regression when the coefficients are not limited to remaining constant. In particular, unlike the rest of coefficients the coefficient β_{2t} in model (1) has the sub index *t*. This means that the parameter is not assumed to be constant and, thus, it may vary with time. It should be noted that most other studies assume that the coefficient is constant (De Rus and Roman, 2006; Martin and Nombela, 2007; Roman et al., 2007). β_{2t} in (1) stands for the substitution effect between plane and rail passengers. In general terms, given the number of changes that the transport industry is experiencing, such as new routes, the growth of LCCs, and aggressive price policies, it seems more sensible to assume a time-varying coefficient rather than one that is constant.

Typical least squares or maximum likelihood estimation procedures cannot be applied to estimate this parameter. Essentially, recursive estimation algorithms, such as the Kalman Filter, should be employed instead. In other applications, such as engineering, the way that the parameter evolves over time can sometimes be known *a priori*, but in economics such knowledge is not usually available. So, in this case, a Generalized Random Walk model expressed in a State Space framework (Jakeman and Young, 1981) is used to allow parameter β_{2t} to vary over time:

$$\begin{pmatrix} x_t \\ x_t^* \end{pmatrix} = \begin{pmatrix} \alpha_1 & \alpha_2 \\ 0 & \alpha_3 \end{pmatrix} \begin{pmatrix} x_{t-1} \\ x_{t-1}^* \end{pmatrix} + \begin{pmatrix} \eta_t \\ \eta_t^* \end{pmatrix} \quad (2)$$

$$\beta_{2t} = \begin{pmatrix} 1 & 0 \end{pmatrix} \begin{pmatrix} x_t \\ x_t^* \end{pmatrix} \quad (3)$$

Here (2) and (3) are the state and observation equations, respectively, where α_1, α_2 and α_3 are constant parameters; β_{2t} is a smoothed signal component consisting of the first state x_t; and x_t^* is a second state variable (generally known as the "slope"); while η_t and η_t^* are zero mean, serially uncorrelated white noise variables with a constant block diagonal covariance matrix.

Depending on the values of α_i, $i = 1, 2, 3$, the model may be particularized for special cases, such as the Random Walk; the Smoothed Random Walk; the Integrated Random Walk; the Local Linear Trend; and the Damped Trend. For instance, if $\alpha_1 = \alpha_2 = \alpha_3 = 1$; $\eta_t = 0$, the model is the Integrated Random Walk (IRW). These models are implemented in the MATLAB 'CAPTAIN' toolbox, where the state estimation is achieved by means of the Kalman Filter and Fixed Interval Smoothing algorithms. A more detailed description of the algorithms implemented in CAPTAIN can be found in Taylor et al. (2007).

In our particular case, the aforementioned IRW model has been used to estimate β_{2t}.

Finally, one positive aspect of the proposed Dynamic Linear Regression model focus over the standard regression model is that it is more parsimonious, easier to interpret and, relatively-speaking, prevents issues with omitted variables. For instance, the standard regression model would require as many dummy variables to be defined previously as potential changes are expected in the substitution effect, such as the impact of a new HSR train station or/and a new airport terminal, for example (see Tables 1 and 2). Thus, the number of dummy variables would grow substantially. Furthermore, after removing any dummy variables that are not statistically significant, the interpretation of the results would be more difficult. In other words, whereas the time-varying parameter estimation of the DLR model provides a smooth estimate of the time-varying substitution effect, the use of a constant coefficients standard regression with numerous dummies would yield an approximation of the substitution effect based on abrupt changes and potential multicollinearity issues. Regarding the robustness of the method to omitted variables, it should be noted that if there are any omitted variables in the standard regression model that affect the substitution coefficient, such as a dummy indicating a new HSR station, for example, the results might be misleading. However, the DLR captures the dynamics of the coefficient without the need for such dummy indicators, and thus, the results obtained are more robust.

4. Results and discussion

Fig. 2 shows the estimate of β_{2t}[2] versus time. It can be concluded that, as we had assumed, the parameter is not constant. In order to explore the influence of new HSR stations as well as new airport terminals, vertical lines have been added to the figure. Dashed lines represent the times when new HSR stations were opened. This information is also referred to Table 1. Dotted lines stand for the new terminal airports mentioned in Table 2.

As the variables for plane and train passengers in Eq. (1) are changed to logarithms, the β_{2t} parameter is a cross pseudo elasticity, but where the denominator is a quantity, and not a price. Basically, it provides information about the percentage fall in air passengers if HSR passengers were to increase by 1%. For example, if monthly HSR passengers have increased on average by a figure of 312,674 (20.17%) between 2007 and 2012, according to our models this correlates with a fall of 67,074 (5.78%) air passengers. Therefore only 21.4% of the increase in HSR passengers would come from air transport. This percentage would fall to 13.9% for the whole of the 1999–2012 period analyzed, as an average annual increase of 385,960 HSR passengers correlates with an average annual fall of 53,558 air passengers.

It is easy to see how the substitution rate between the two means of transport has fallen in absolute values over time, going from a figure of around 0.191 at the beginning of 1999 to a figure of 0.164 by the end of 2007. This fall process existed despite the network expanding during this period with new connections to Zaragoza and Malaga and only slowed down temporarily toward the end of 2001. This is a clear 9/11 effect and was also felt by air transport during the months after the terrorist attack. In any case, the elasticity continued to tend toward zero with the opening

[2] Note that the estimation of β_{2t} is statistically significant at the 5% level.

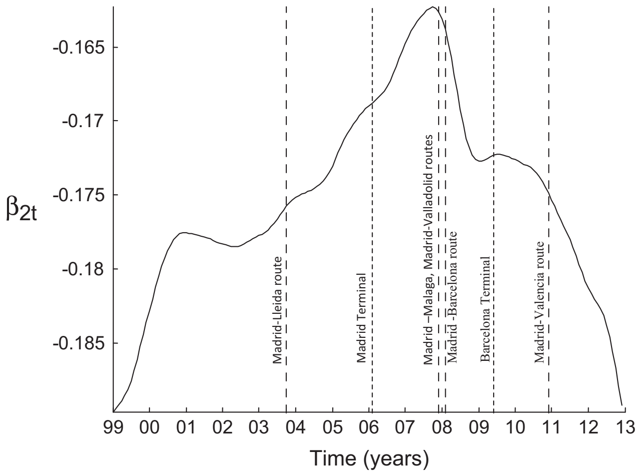

Fig. 2. Estimation of β_{2t} versus time.

of the new HSR line to Zaragoza (10/2003) and the opening of Terminal T4 in Madrid (02/2006).

Nevertheless, when the Madrid–Malaga (December, 2007) and Madrid–Barcelona (February, 2008) lines came into operation, there was a total halt in the fall in substitutability in absolute terms. This was also influenced by the fall in overall train + plane passenger numbers due to the economic crisis that affected Spain (Pagliara et al., 2012). The trend turned round and began to rise again in 2010. This effect increased when the Madrid–Valencia line came into service (December, 2010). In all these three cases we are closer to the conditions that Vickerman (1997) stated were necessary for an HSR line to be socially profitable, as the three cities involved are all large and the distances range between 354.4 km in the case of Valencia (with 2.5 million inhabitants in the province, compared to Zaragoza's 975 thousand), 530.5 km in the case of Malaga (with 1.6 million) and Barcelona's 619.9 km (with 5.5 million). This effect is further heightened as a high-value network hub is included that has traditionally been served by an air shuttle with some of the highest passenger numbers in Europe, Madrid–Barcelona.

However, it cannot be rejected that the substitution effect between the two types of transport had previously been greater, during the years following the opening of the first HSR line in 1992, which was a period marked by the high price of domestic air fares. This would help to explain why previous papers offer noticeably higher substitution rates. Unfortunately, the lack of monthly time series for the dataset used does not allow us to test this hypothesis.

Table 3
Estimation results for the Dynamic Linear Regression model proposed in (1).

Explanatory variable	Estimate
β_0	14.4*** (1.7)
op_{t-1}	0.43*** (0.11)
$unemp_t$	0.04 (0.17)
$snow_t$	−0.12*** (0.04)
bus_t	0.002* (0.0012)
$popu_t$	0.05 (0.1)
R^2	0.97
σ^2	1.8×10^{-3}
Q (12)	13.04
Q (24)	19.48
KSL	0.07 (0.21)

σ^2 stands for the innovations variance; Q (12) are the Ljung-Box Q statistics for 12; KSL is a Kolmogorov–Smirnov–Lilliefors Gaussianity test (P-values in brackets).
One, two, or three asterisks indicate coefficient significance at the 10%, 5% and 1% levels, respectively.

Table 4
Granger non-causality tests.

Null hypothesis	F-statistic	P-value
Granger: *hsrpas* does not cause *planepas*	3.7	0.01
Granger: *planepas* does not cause *hsrpas*	0.35	0.788

Note: The reference model for the Granger tests is VAR(3) identified via the Schwarz Bayesian Criterion.

The remaining parameter estimates are shown in Table 3. For the sake of clarity, the estimation of the dummy variables that model the seasonality has not been included in the table. It should be noted that, even when some seasonality dummies are not statistically significant, it is important to include them in the model in order to capture the whole seasonality pattern.

It should be noted that the model in (1) assumes that the volume of High Speed Rail passengers determines the number of air passengers. However, this assumption may give rise to an endogeneity issue. A Granger non-causality test was carried out to test this assumption (see Lütkepohl, 2005 for details). Table 4 shows that the causality direction runs from high-speed rail passengers to plane passengers, as the null hypothesis based on *avepas* not causing *planepas* is rejected with a P-value of 0.01.

5. Conclusions

Compared to earlier studies this article offers an absolutely original methodological approach that uses Dynamic Linear Regression models based on time-varying parameters developed in a State Space framework. These enable the substitution rate between the transport of HSR and air transport passengers to be analyzed in depth. Using a relevant case study, the rapid growth of the Spanish high-speed train network, provides the most precise vision to date of the degree of substitutability between these two modes of transport. Empirical evidence is also offered as to the real origin of the passengers who create the demand for HSR.

Firstly, the findings confirm that the dynamic vision of this substitution rate is the vision that should be adopted; continual changes in Spanish rail transportation with the opening of new lines mean that recursive estimation techniques have to be used to show the way that these changes impact on the substitution factor between air transport and HSR, as opposed to supposing that this rate is constant, as was assumed by previous references. The rate varies significantly over the study period. Specifically, the substitution rate can be seen to fall from its maximum absolute value during the period of study, −0.191 in January, 1999, to a minimum value of −0.164. This implies a mean average value of −0.1767 for said substitution coefficient for the period of the analysis, 1999–2012. This in turn equates to an increase of only 13.9% in HSR passenger demand coming from air travel during this period.

When this is examined alongside previous studies, De Rus and Roman (2006) can be seen to have predicted that 91% of HSR passengers that would come from other modes of transport on the Madrid–Barcelona section would come from the plane, which would mean that approximately 60% of HSR passengers would switch from air travel. Martin and Nombela (2007) predicted that air travel would lose 20% of market share nationwide by 2010, and that these passengers would transfer to the train, which logically equates to a clearly higher percentage than 20% of HSR passengers. Meanwhile, Jiménez and Betancor (2012) estimated a 17% reduction in the number of air operations due to HSR. In short, the findings of this study are more restrained than the results of the above studies, which were sometimes based on prior predictions. In other words, HSR and the airlines would seem to offer more independent services than it at first might appear.

Furthermore, there are changes in the rate between the two as time goes on; firstly, it falls in absolute value until the end of 2007, despite the fact that the supposed Spanish high-speed rail network has grown, specifically with the addition of the Madrid–Guadalajara–Zaragoza–Lerida section in October, 2003, the Zaragoza–Huesca section in April, 2005, the Madrid–Toledo section in November, 2005, and the Lerida–Tarragona section in December, 2006. The limited populations of the new cities incorporated into the network mean that these sections do not fulfill the requirements stated by Vickerman (1997) to justify an HSR connection.

There was a change in the trend with the opening of the HSR lines to Malaga and Barcelona (end of 2007 and beginning of 2008). Despite the fact that the substitution rate seems to have flat lined with the coming into operation of the new airport terminal at Barcelona, the fact of the matter is that the HSR value continued to rise, especially with the coming into service of the Madrid–Valencia line (12/2010).

These findings can also be considered indirect empirical proof that the academic debate over where HSR passenger demand comes from has been misguided, as was previously the case regarding where demand for LCCs was coming from. The latter initially focused on substitution between LCCs and Network Airlines, but an increasing number of more recent studies (see Castillo-Manzano et al., 2012a; Castillo-Manzano and Lopez-Valpuesta, 2014; Gillen and Lall, 2004; Tapiador et al., 2008) are showing that this substitution is, in many cases, negligible compared to the new demand that the LCCs generate. Subsequent analyses should therefore put more emphasis on distinguishing between the share of HSR demand that is new demand, and the share that comes from other means of transport, with the analysis of substitution rates being broadened to take in other modes of transport apart from the plane.

In addition, should the majority of passengers not come from the plane, as the findings of the present study would seem to suggest, this would have a great impact on the scenarios and results of Cost Benefit Analyses that are used to support decisions on costly new HSR lines, especially as the willingness to pay of users who switch from the conventional train and, above all, the long distance bus and the car, will presumably not cover the real costs of the HSR (see De Rus and Roman (2006) for an analysis of the willingness to pay of potential HSR users depending on the mode of transport from which they come).

To summarize, the conclusions drawn from this study allow it to be stated that even in the most geographically extensive HSR 'network' in the world compared to the surface area involved, the Iberian peninsula, there is no empirical evidence at all that the network has generated any clear network effects that will attract more passengers from air transport, since the substitution coefficient value at the end of the period of analysis is even slightly lower than the value at the beginning, when the Madrid–Seville line was the only line in service. However, the search for this possible absence of network effects would require this analysis being completed with similar analyses of HSR networks in other countries and, in the case of the Spanish network, rigorous analyses by individual line. Neither of these tasks would be easy given the very small number of HSR networks worldwide, and the lack of transparency of Spanish data.

In other words, the expansion of the network, with some lines offering less than doubtful social profitability and clearly following political criteria (Bel, 2011), has seen the substitution rate with air transport fall over many years.

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