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Moshe Givoni[ab] & Frédéric Dobruszkes[b]

[a] Department of Geography and the Human Environment, Tel-Aviv University, P.O.B 39040, Ramat Aviv, Tel Aviv 69978, Israel

[b] Transport Studies Unit, School of Geography and the Environment, University of Oxford, South Parks Road, Oxford OX1 3QY, UK

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A Review of Ex-Post Evidence for Mode Substitution and Induced Demand Following the Introduction of High-Speed Rail

MOSHE GIVONI*,**,§ AND FRÉDÉRIC DOBRUSZKES**

**Department of Geography and the Human Environment, Tel-Aviv University, P.O.B 39040, Ramat Aviv, Tel Aviv 69978, Israel; **Transport Studies Unit, School of Geography and the Environment, University of Oxford, South Parks Road, Oxford OX1 3QY, UK*

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Abstract *To date, relatively little is known about the nature of the demand for high-speed rail (HSR) soon after inauguration of the services, despite close to 50-year experience of HSR operation and 17 166 km of HSR network around the world. This is a real lacuna given the scale of HSR construction around the world, the amount of resources committed to it, the desired accessibility, economic and environmental effects associated with HSR development and the relatively poor track record of forecasting demand for HSR services. Focusing on mode substitution and induced demand effects, this review aims to fill the gap in knowledge about the ex-post demand for HSR services in order to facilitate a learning process for the planning of the future HSR network. Although there is not much evidence on the demand for HSR services and existing evidence is largely influenced by route-specific characteristics, a methodological limitation that must be acknowledged, the evidence presented allows a better characterisation of HSR as a mode of transport. The review shows that the demand for HSR a few years after inauguration is about 10–20% induced demand and the rest is attributed to mode substitution. In terms of mode substitution, in most cases the majority of HSR passengers have used the conventional rail before. Substitution from aircraft, car and coach is generally more modest.*

Introduction

In 1964, the first modern high-speed rail (HSR) service was launched in Japan on the Tokaido line connecting Tokyo and Osaka at speeds of 210 kph. The HSR has since become one of the main transport innovations, although only in 1981 the first HSR service outside Japan was launched — the TGV service in France connecting Paris and Lyons. About a decade later, HSR was operating at more than 250 kph in Spain, Germany and Italy, and the Trans-European Transport Network, in which HSR is to play an important role, was starting to take shape (Givoni, 2006). In Europe (EU-27), the HSR network in 1990 was only 1024 km long (three countries) carrying 15.23 billion passenger-km (pkm). In 2010, the European HSR network

§Corresponding author. Email: givonim@post.tau.ac.il

reached 6602 km (seven countries), carrying 104.10 billion pkm (data for 2009)[1] (European Commission [EC], 2011a). The HSR is currently in operation also in countries outside Japan and Europe and mainly in China. According to the latest data from the International Union of Railways (UIC, 2011), in 2011 there were 17 166 km of high-speed lines (HSLs) worldwide, 8838 km under construction (of which 70% in Asia and 24% in Europe) and 16 318 km of HSLs planned (53% in Europe and 35% in Asia). The world HSR network is expected to more than double in length in the future, reaching 42 322 km based on current plans.

The HSR is seen today by many policy- makers as a strategic mode of transport that is especially suitable to meet economic and environmental challenges. At times of economic recession, as currently experienced by many countries, investments in HSR are seen as important for facilitating economic growth and employment. At the same time, HSR is seen as a 'green' mode of transport that can limit the negative environmental impact of transport, although this assumption is debatable and HSR can result in significant environmental cost, especially when life-cycle analysis is considered (see Chester & Horvath, 2009, 2010; Givoni, Brand, & Watkiss, 2009; Miyoshi & Givoni, 2013). Investments in HSR fits well with the Ecological Modernisation approach in which environmental and economic objectives do not necessarily contradict each other and can be pursued in tandem (see Schwanen, Banister, & Anable, 2011 for a brief discussion). The HSR is therefore seen as central elements in transport policy, as evident in the recent EU White Paper on Transport (EC, 2011b), and in the USA in the role of HSR in the 'American Recovery and Reinvestment Act' of 2009.

Despite almost 50 years of experience in operating HSR around the world and despite the scale of current and future HSR development, there is little evidence, and little discussion, on the performance of HSR with respect to the objectives it is supposed to meet and the ex-post demand for HSR. Over the years, a substantial body of research on various aspects of HSR has been created, but the majority of it focuses mainly on expected impacts and on competition between modes (some examples include Chang & Chang, 2004; González-Savignat, 2004a, 2004b; Hensher, 1997; Ivaldi & Vibes, 2005; Mandel, Gaudry, & Rothengatter, 1997; Park & Ha, 2006; Román, Espino, & Martín, 2007; de Rus & Inglada, 1997; Mao, 2010). Even recent studies on HSR (for example reviews by Albalate & Bel, 2012; Greengauge 21, 2009; Gourvish, 2010; Nash, 2009; Preston, 2010; Rutzen & Walton, 2011; Todorovich, Schned, & Lane, 2011) do not provide much ex-post analysis of the demand for HSR services, although this is naturally critical for the purpose of planning future HSR services. One of the main reasons is the relatively dearth of such evidence.

Evidence on the ex-post demand for HSR services nevertheless does exist although it is scattered in many publications. This review collects this evidence and aims to shed light on the effect of new HSR services on demand for travel on different routes. Two effects in particular receive attention: the level and nature of mode substitution[2] and induced demand.

The importance, for planning purposes, of understanding the effect of new HSR services on demand is clear given the expectations for accessibility, economic and environmental benefits from HSR. Such benefits depend on the level of actual demand and its nature — the extent to which this demand is the result of induced demand or mode substitution, and the level of substitution from different modes (air, conventional rail and road) to HSR. It becomes even more important to understand the actual effect of HSR considering the relative poor performance of demand forecasts (Flyvbjerg, Skamris Holm, & Buhl, 2005). Analysis of traffic forecasts have shown that forecasting demand in rail projects is particularly inaccurate, more than is the case with other modes of transport. For 9 out of 10 rail projects, Flyvbjerg et al. (2005) found that passenger forecasts were overestimated, with the average overestimation at 106%. In Taiwan, a significant gap between forecast and actual HSR ridership was also evident. Original traffic forecasts (made before the 1997 Asian crisis) estimated an initial daily ridership of 200 000 passengers, but in reality daily ridership ranged between 35 000 and 50 000 in 2007 and between 84 000 and 90 000 in 2008 (Cheng, 2010). In 2011, 9.7 million passengers used the Eurostar HSR service across the English Channel. This level of demand was still lower than the 1998 forecast made by London and Continental Railways[3] for 25 million passengers in 2006 (Preston & Wall, 2008). In 2002, HSR ridership between Paris and the north of France was 6.4 m passengers, 41% lower than the 10.9 m forecast for that year and lower even than the forecast of 8.7 m for 1993 (the year the line opened) made before the line opened (Réseau ferré de France [RFF], 2005)[4].

In the remainder of the paper, we briefly discuss the elements of the demand for HSR and the review methodology before presenting the evidence collected from the literature. The paper ends with conclusions arising from the evidence presented.

Elements of Demand for HSR Services

Passengers on new HSR services can either be passengers transferred from other modes of transport — 'mode substitution' passengers — or new passengers — 'induced demand' passengers. In terms of mode substitution, HSR is treated here as a mode of transport separate from conventional rail services. Over time and thanks to technological advancement, the speed at which a rail service is considered high-speed is changing and also varies between countries. For this paper, the definition of the International Union of Railways (UIC) that categorises a rail service as high-speed if it achieves over 250 kph on some parts of the route is adopted.

The phenomenon of generated or induced demand following improvements in transport infrastructure (such improvements can relate to capacity, speed, frequency of service, change in fares, comfort, etc.) has been recognised after years of investments in adding capacity to the road network did not result in elimination of congestion. Induced demand started to get full attention largely following the work of Goodwin (1996). Estimating induced traffic or demand is important to fully understand the level of demand for HSR services and is especially important in order to assess the full environmental impact of introducing HSR services. Yet, measuring induced demand raises many methodological challenges (Bonsall, 1996). The main challenge is to determine what should be counted as induced demand. In a narrow perspective, passengers who have not shifted to HSR from other modes, i.e. have not travelled prior to the inauguration of HSR services, should be counted as contributing to induced demand. However, passengers who shifted to HSR from other modes but now travel more frequently should also be (partly) accounted for as contributing to induced demand. Furthermore, demand for travel is known to increase over time as a result of population and economic growth and also due to other non-transport changes, e.g. changes in land use in a particular destination[5] (Kitamura, 2009; Mokhtarian, Samaniego, Shumway, & Willits, 2002). The effects of population and economic growth and changes in land use represent more changes in demand over time and less generation of new demand per se and are expected to be more important as time from the start of HSR services passes. Yet, changes in land use, for example, might take place prior to the start of HSR services, in anticipation of their start (Bonsall, 1996). Overall, the creation of induced demand is a highly interactive process dependent on many factors (Mokhtarian et al., 2002). This makes it especially difficult to measure induced demand and to attribute demand that is not clearly the result of mode substitution to the improvements in the transport system (e.g. new HSR services) or to other factors. Ideally, there is a need to distinguish between short- and long- term induced demand, the former can assumed to be more directly related to the 'transport' improvements. Demand for a new transport service can also decrease over time, and this can also relate to either the 'transport — e.g. when the curiosity effect starts to wither or as a result of changes in prices, or to non-transport effects — for example, the impact on demand for the new 'Atlantic' French HSR launched in 1989 was partly lost because of an economic downturn (Klein, Claisse, & Pochet, 1997). Lastly, there is also a question if to measure induced demand at the route or network level, since new passengers on a particular corridor could have shifted from other routes on the same network (transport improvements led them to change travel destination).

Table 1 illustrates for two routes the kind of evidence and effects this review is concerned with. The table gives the effect of starting HSR services on the London–Paris and London–Brussels routes on the airlines, while also indicating the level of induced demand by calculating the difference between total demand on the route before (1993) and after (2010) the inauguration of HSR. Table 1 also illustrates the limitation of the evidence presented in this paper since it does not show any information on changes in socio-economic factors that might have led to natural growth in demand over time, regardless of the introduction of HSR.

Table 1. Comparison of air and HSR traffic on the London–Paris and London–Brussels routes for the years 1993 and 2010 (thousands of passengers)

	1993	2010	2010/1993
London–Paris			
Airlines	3665	1626	−56%
	100%	19%	−81%
HSR	0	6.728	
	0%	81%	
Sum	3665	8354	+128%
London–Brussels			
Airlines	1160	490	−58%
	100%	15%	−85%
HSR	0	2801	
	0%	85%	
Sum	1160	3291	+184%

Sources: Brussels airport, CAA, DGAC/DTA/SDE and Eurotunnel.

Methodology

As noted above, there is a substantial body of literature on various aspects of HSR. For the purpose of this review, only research that reported actual ex-post evidence on the demand for HSR was included and cited. The literature search covered scientific databases, books and book chapters as well as reports produced or commissioned by public authorities, international organisations or operating companies (when information was available). Only publications in English and French were covered. When similar information was reported in several publications, only one source is cited.

In this review, it was only possible to measure induced demand as the share of the demand that is not identified as originating from other modes. In most cases, the data reported were for a few years after the start of HSR services, thus the reported induced demand is more likely to relate to the short-term effect and as such more associated with the 'transport' changes than with the 'non-transport' changes, although this can only be assumed. Thus, there is no real consideration of the 'time' element and account of changes in socio-economic factors that can affect demand over time. It means that the estimates of induced demand reported should be seen as maximum estimates.

The level of mode substitution can be measured in various ways, as percentage of HSR passengers reporting to have used a different mode of transport prior to the start of HSR; the percentage of passengers travelling on a specific corridor using a specific mode before and after HSR; and, ideally, the number (and not the share) of passengers using each mode on a specific route before and after the launch of HSR. These categories are used below to report the evidence collected. There is also a need to examine the level of mode substitution at different points of time after the start of HSR services, but such data are rarely available.

Table 1 above illustrates the importance of knowing the actual number of passengers (not only percentage) to understand the extent of mode substitution and induced demand. While the airlines experienced a substantial fall in their market share between 1993 and 2010 — 81% and 85% on the London–Paris and London–Brussels routes, respectively — their loss of passengers was not as substantial (56% and 58% on the London–Paris and London–Brussels routes, respectively). This is largely due to the growth of the combined air–rail market over the same period, which can be considered as induced demand (28% and 84% on the London–Paris and London–Brussels routes, respectively).

Overall, the number of routes for which ex-post evidence exists is limited. For example, in Europe 21 such city-pairs were identified while an analysis of air–rail dynamics in Europe indicated there are 163 city-pairs where HSR operates and affect demand for air travel (Dobruszkes, Dehon, & Givoni, 2013). Given the different characteristics of each route and the nature of service of HSR and other modes, it is difficult to draw concrete conclusions from the review, but the patterns that do emerge from the evidence reported are important to consider and analyse. Finally, most HSLs are completed in sections or may be upgraded after several years of operation to support even higher speeds (e.g. the Tokyo–Osaka line) and this can effect actual demand, but it is usually not reflected in the data available. These limitations must be accounted for when interpreting the results and they require caution in reaching conclusions. With these limitations in mind, the next section presents the ex-post evidence on the demand for HSR services as reported in the literature.

The Evidence

Before analysing the extent to which demand for new HSR services is the result of mode substitution or induced demand, Table 2 brings evidence on the share of passengers HSR attracts on a particular route. It is clear that HSR can attract large shares, and often all, of the demand for travel on a particular route, although road passengers are often not considered in the data reported. This is mainly a factor of the route distance and the travel time (i.e. speed). On the Tokyo–Fukuoka route, for example, the distance is too large, or travel time by HSR too long, for HSR to effectively compete with the aircraft and its share was only 12% in 2009. On the other hand, on the Frankfort–Cologne, Paris–Lyons and Paris–Avignon routes HSR have captured almost of all the market. Since the average speed of HSR services varies across routes, depending on the maximum speed design of the train and the line, the proportion of the route travelled on HSLs[6], the number of stops and other restrictions, it is better to examine the share of HSR on a particular route by travel time, if data can be obtained. Figure 1 illustrates how sensitive passengers are to variations in travel time in comparison to the alternative modes of travel. When HSR share is examined only against that of the aircraft it appears that the share generally decreases with travel time and that up to about 3.5 hours of travel by HSR, the HSR can capture more than 50% of the market. On the other hand, when considering all modes of transport and including road and conventional rail transport, it appears that the market share of HSR increases with travel time and it becomes substantial (over 30%) when HSR travel time gets to one hour. Figure 1 demonstrates well the competition of HSR with road transport (car but also inter-city coach services, especially on the Taiwanese routes — see below) and it shows that other factors than travel time effect the mode share, since the share of HSR for a group of routes remains the same when travel time increases.

Induced Demand

The evidence on short-term induced demand following the introduction of HSR services is relatively scarce and is only reported as a share of the demand for HSR several years after the service started. Table 3 reports the share of passengers which were not transferred from other modes to the HSR according to the route served, the year in which the HSR service was launched and the year (when available) when induced demand was measured.

While it is difficult to draw a clear conclusion on the extent to which HSR services lead to induced demand, it is clear that there is always (in the cases reported) such an effect. The induced demand effect ranges from 6% to as high as 37% up to four years from the launch of HSR services and higher on the two Chinese routes but there the data include to some extent also mode substitution effect. It is not possible to identify a pattern in the level of induced demand across the routes, for example, with respect to distance. As expected, it seems the level of induced demand rises with time from the inauguration of the service, although the different observations over time from the Madrid–Seville route do not support this and

Table 2. Share of passengers using HSR on different routes (%)

Region/country	Modes considered	Route (distance)	Years HSL sections completed	Year of data	HSR share	Source
Japan	Air and HSR	Tokyo–Nagoya (366 km)	1964[a]/1992	2009	100%	Clever and Hansen (2008)
		Tokyo–Osaka (553 km)	1964[a]/1992	2009	86%	
		Tokyo–Okayama (733 km)	1975[a]/1993	2009	82%	
		Tokyo–Hiroshima (894 km)	1975[a]/1993	2009	56%	
		Tokyo–Fukuoka (1180 km)	1975[a]/1993	2009	12%	
Europe	Air and HSR	Paris– London[b] (489 km)	1994/2003/2007	2005	66%	Campos and Gagnepain (2009)
		Paris–Amsterdam (547 km)	1997/2009	2004	45%	
		Brussels– London[b] (370 km)	1994/1996/1997/2003 /2007	2004	60%	
		Paris–Brussels (312 km)	1996/1997	2006	100%	
France	Air, Road and HSR	Paris–Lyons (427 km)	1981/1983	2008	97%	Zembri (2010)
		Paris–Avignon (657 km)	1981/1983/1992/1994/2001	2008	95%	
		Paris–Marseilles (750 km)	1981/1983/1992/1994/2001	2007	83%	
		Paris–Strasbourg (450 km)	2007	2008	70%	
		Paris–Bordeaux (570 km)	1989/1990	2008	68%	
		Paris–Montpellier (736 km)	1981/1983/1992/1994/2001	2006	65%	
Europe	Air and HSR	London– Paris[b] (492 km)	1994/2003/2007	2010	80.5%	Groupe Eurotunnel (2011)
		London– Brussels[b] (373 km)	1994/1996/1997/2003/2007	2010	84.4%	
Europe	Air and HSR	Paris–Nantes (387 km)	1989	N.A.	89%	Steer Davies Gleave (2004)
		Lille–Lyons (645 km)	1984/1994	N.A.	60%	
Europe	Air and HSR	London– Brussels[b] (376 km)	1994/1996/1997/2003/2007	2002	44%	Steer Davies Gleave (2006)[c]
		London– Brussels[b] (370 km)	1994/1996/1997/2003/2007	2005	62%	
		London– Paris[b] (494 km)	1994/2003/2007	2002	62%	
		London– Paris[b] (489 km)	1994/2003/2007	2005	68%	
		Paris–Marseilles (782 km)	1981/1983/1992/1994/2001	2000	45%	
		Paris–Marseilles (750 km)	1981/1983/1992/1994/2001	2004	67%	
		Frankfort–Cologne (180 km)	2002	2005	97%	
		Madrid–Barcelona (637 km)	2003/2006/2008	2005	11%	

[a]First year is at 210 kph only, before subsequent improvements.
[b]The HSR line from London to Paris and Brussels on the UK side opened in stages and hence the different route distances for different years.
[c]Some values were deduced from a graph.

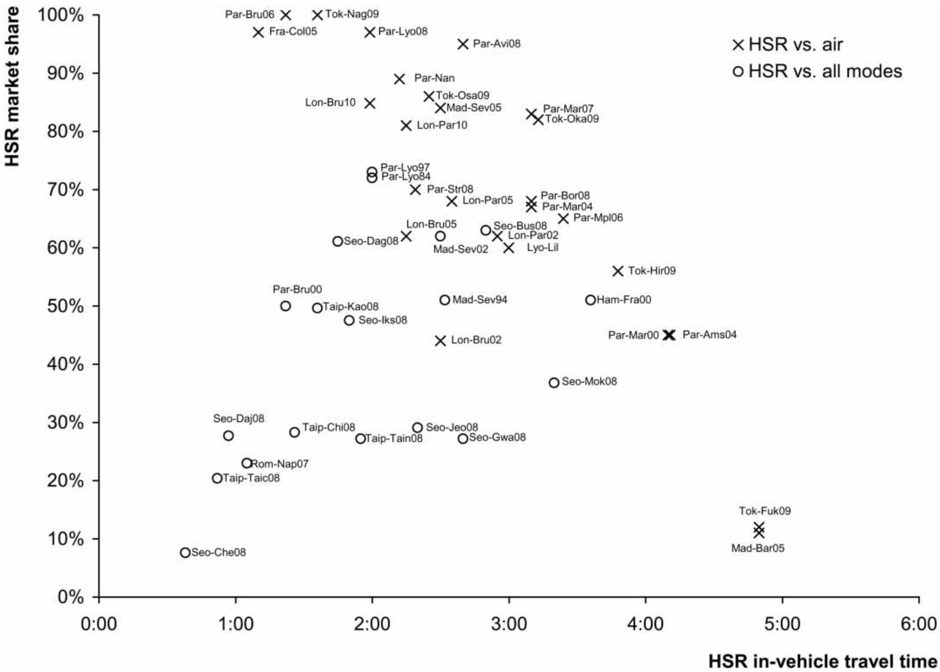

Figure 1. HSR market share as a factor of journey time.
Source: Based on various sources, all cited in the paper.

indicate more variations over time, or just inconsistency in measurement method. Furthermore, it seems that the generation of new demand begins immediately with the introduction of HSR services. Within the same year of its launch, 8% induced demand was measured on the Taiwanese HSR service. In all cases given in Table 3, it can be assumed that induced demand is the result of the 'transport' improvements and not other changes, given that the data are for up to four years after HSR operation started. Still, the figures reported are naturally influenced by changes in the economic situation of the region in question, although the extent of this over all the routes is probably small. Furthermore, the 27–37% of induced demand on the Paris– Lyons route is net of the effect of economic growth over time. On the Paris–Rhone-Alps HSR corridor, the 36% of induced demand is amongst business passengers only.

Mode Substitution

There is more evidence on mode substitution, but also in this case the nature of the available data and the unique circumstances and characteristics of each case do not allow reaching concrete conclusions. The evidence, however, does allow portraying a general picture of mode substitution. For ease of interpretation, the results are presented in a series of tables, each based on a different element or unit of comparison across different routes (Tables 4–6).

The demand for HSR services several years after the service started shows that most of it (75–90%) is demand shifted from other modes of transport (Table 4). Large variations exist across the routes analysed when examining the origin of passengers who shifted to HSR. In most cases, conventional rail (denoted as

Table 3. Observed induced demand on various HSR routes

Route (distance[a])	HSR launch[b]	Measurement year	Induced traffic as a share of HSR ridership	Source[c]
Osaka–Hakata[d] (554 km)	1972/1975	N.A.	6% (pax)	Sands (1993) after Okabe (1979)
Taiwan	2007	2007	8% (pax)	Cheng (2010)
Thalys (Paris–Brussels–Amsterdam/Cologne)[e]	1995/1997	N.A	11% (pax)	Segal (2006)
Madrid–Seville (470 km)	1992	Five different months between March 1993 and October 1995	11.7–18.7% depending on the months surveyed (pax)	Menéndez (1998)
Madrid–Ciudad Real (171 km)/ Puertollano (210 km)	1992	Five different months between March 1993 and October 1995	13.9–28.7% depending on the months surveyed (pax)	Menéndez (1998)
Madrid–Seville (470 km)	1992	1996	15%	EC (1998)
Eurostar (London–Paris/ Brussels)[e]	1994/1997	N.A.	20% (pax)	Segal (2006)
Rome–Naples (222 km)	Late 2005	2007	22% (pax)	Cascetta et al. (2011)
France	Many lines since 1984	2000	24% (pkm)	Authors from Commissariat Général au Développement Durable (CGDD, 2009)
Madrid–Seville (470 km)	1992	1994	26% (pax)	Vickerman (1997)
Paris–Rhone-Alps	1981/1983	1985	36% among business travellers (pax)	Plassard (1998)
Paris–Lyons (427 km)	1981/1983	N.A.	37% or 27% without trend in growth (pax)	EC (1998)
Wuhan–Guangzhou (968 km)	Late 2009	2010	45%[f]	Bullock, Salzberg, and Jin (2012)
Beijing–Tianjin (131 km)	2011	N.A.	80%[f]	Bullock et al. (2012)

[a]Distances are rail distances. Not reported in the case of regional/national network.
[b]A second year corresponds to additional HSLs (only lines completed before the estimate of induced demand are reported).
[c]The figures for induced demand reported may be observed directly by the authors cited or by others, including railways operators or public authorities.
[d]More than 250 kph only from 1993.
[e]Segal (2006) only makes reference to Thalys and Eurostar and it is not clear if their entire network is covered but this is the assumption.
[f]Bullock et al. (2012) state for the Wuhan–Guangzhou route: "45% have been either generated or transferred from bus and car, with the overwhelming majority of these being generated" (p. 5) and for the Beijing–Tianjin route: "either transferred from private vehicles (including minibus) or has been generated" (p. 5).

Table 4. Demand for HSR services as a percentage of passengers' mode of origin

Route	Year	Induced[a]	Rail	Planes	Cars	Coaches	Source
Paris–Bruxelles–Cologne/Amsterdam[b]	N.A.	11%	47%	8%	31%	3%	Segal (2006)
London–Paris/Lille/Brussels[c]	N.A.	20%	12%	49%	7%	12%	Segal (2006)
Paris–South-east	1984	49%		33%	18%		Bonnafous (1987)
Madrid–Seville	1994	26%	14%	32%	25%	3%	Vickerman (1997)
	1996	15%	18%	42%	20%	5%	EC (1998)
Rome–Naples	2007	22%	69%	1%[d]	8%	1%[d]	Cascetta et al. (2011)
Osaka–Hakata	1970s	6%	55%	23%	16%		Okabe (1979)[e]
Korea (first stage)	April 2004	N.A.	56%	17%	12%	15%	Suh, Yang, Lee, and Ahn (2005)
Wuhan–Guangzhou	2010	45%[f]	50%	5%	N.A.	N.A.	Bullock et al. (2012)

[a]Induced demand – same data as in Table 3.
[b]Thalys (see comment 5 in Table 3).
[c]Eurostar (see comment 5 in Table 3).
[d]1% for planes and coaches together.
[e]Quoted by Sands (1993) and less than 250 kph at the time.
[f]See Table 4.

rail) is the main mode of origin for HSR passengers. Although this form of mode substitution does not usually get much attention (essentially there is no real change of mode), it has important implications (see Conclusion section). In contrast, most attention in the literature is usually given to substitution from air to HSR, also due to the problem of airport congestion and the environmental impact of air transport (Givoni, 2007). Table 4 gives that air to rail substitution can be large, close to 50% of HSR passengers on the London to Paris, Lille and Brussels routes. On the London–Paris and London–Brussels routes, the HSR, about 20 years from its inauguration, captures over 80% of the combined air–rail market (Table 2). But there is also evidence that such substitution can be limited. This notably depends on the characteristics of the air and conventional rail services (fares, for example) and the differences between them prior to the start of HSR services. A similar picture arises when considering substitution to HSR from road transport, there is large variability in the level of substitution across the seven markets examined. In sum, road transport is the third most important source of HSR passengers after conventional rail and air transport. With the exception of the Korean and Eurostar cases, mode substitution to HSR from coach services appears modest.

Table 5 reports the share of the market each mode captured before and after the introduction of HSR services. Conventional rail and HSR services are in many cases considered together as 'rail' mode and the 'after' observed market shares include induced demand. It is clear that in the routes examined, air transport loses the most market share from the introduction of HSR services and most of the effect (at least it was on the Madrid–Seville and Paris–Lyons routes) is relatively soon after the start of HSR services (as suggested by EC, 1998 and López-Pita & Robusté, 2005). The HSR is clearly affecting also the share of road transport

Table 5. Mode share on a route before and after the introduction of HSR services (%)

Route (distance)	Period (before/ after)	Mode	Passengers (before)	Passengers (after)	Source
Madrid–Seville (470 km)	1991/1994	Rail	16%	51%	Cited in EC (1996)
		Air	40%	13%	
		Coach	10%	5%	
		Car	34%	31%	
Madrid–Seville (470 km)	1991/2002	Rail	16%	62%	Cited in Campos and Gagnepain (2009)
		Air	40%	8%	
		Coach	44%	30%	
		Car			
Paris–Lyons (427 km)	1981/1984	Rail	40%	72%	Cited in Givoni (2006)
		Air	31%	7%	
		Coach	29%	21%	
		Car			
Paris–Lyons (427 km)	1981/1997	Rail	40%	73%	Cited in Campos and Gagnepain (2009)
		Air	31%	6%	
		Coach	29%	21%	
		Car			
Paris–South-east	1991/1994	Rail	28%	52%	Cited in EC (1996)
		Air	N.A.	N.A.	
		Coach	N.A.	N.A.	
		Car	N.A.	N.A.	
Paris–Brussels (312 km)	1994/2000	Rail	24%	50%	
		Air	7%	2%	
		Coach	9%	5%	
		Car	61%	43%	
Hamburg–Frankfort (524 km)	1985/2000	Rail	23%	51%	
		Air	10%	4%	
		Coach	57%	45%	
		Car			
Taipei–Kaohsiung (345 km)	April 2005 / April 2008	HSR	0.0%	49.6%	Cheng (2010)
		Conv. rail	7.8%	2.5%	
		Air	28.7%	5.0%	
		Coach	35.3%	22.3%	
		Car	28.2%	20.6%	
Taipei–Tainan (308 km)[a]	April 2005 / April 2008	HSR	0.0%	27.2%	
		Conv. rail	6.7%	3.8%	
		Air	13.6%	2.2%	
		Coach	55.3%	46.1%	
		Car	24.3%	20.7%	
Taipei–Chiayi (246 km)	April 2005 / April 2008	HSR	0.0%	28.3%	
		Conv. rail	8.5%	6.6%	
		Air	4.2%	0.0%	
		Coach	45.8%	31.0%	
		Car	41.6%	34.2%	
Taipei–Taichung (160 km)	April 2005 / April 2008	HSR	0.0%	20.4%	
		Conv. rail	9.1%	6.9%	
		Air	0.4%	0.0%	
		Coach	32.7%	26.5%	
		Car	57.8%	46.3%	

(*Continued*)

Table 5. Continued

Route (distance)	Period (before/after)	Mode	Passengers (before)	Passengers (after)	Source
Seoul–Cheonan (97 km)	2004/2008	HSR	0.0%	7.6%	Cho and Chung (2008) and Rail Safety Information System (RSIS, 2009)[b]
		Conv. rail	21.1%	14.2%	
		Air	0.%	0.0%	
		Express coach	8.6%	7.6%	
		Car	70.3%	70.6%	
Seoul–Daejeon (166 km)	2004/2008	HSR	0.0%	27.7%	
		Conv. rail	27.5%	12.4%	
		Air	0.0%	0.0%	
		Express coach	22.9%	17.0%	
		Car	49.6%	43.0%	
Seoul–Daegu (326 km)	2004/2008	HSR	0.0%	61.1%	
		Conv. rail	40.5%	5.3%	
		Air	14.7%	0.0%	
		Express coach	14.7%	8.0%	
		Car	30.2%	25.6%	
Seoul–Busan (442 km)	2004/2008	HSR	0.0%	63.0%	
		Conv. rail	37.9%	4.6%	
		Air	42.2%	17.0%	
		Express coach	7.8%	7.3%	
		Car	12.1%	8.1%	

[a]Travel time on this route is longer than on the Taipei–Kaohsiung route, although it is shorter in distance, since the service from Taipei stops more often than the service from Taipei to Kaohsiung.
[b]Only the Gyeongbu corridor (Seoul–Busan) is included because on the Seoul–Mokpo route most of the journey is not on HSL.

travel, but less. In Korea and Taiwan, road transport retains high market share not only on the shortest routes where car use is usually more convenient (see below), but also after the start of HSR services.

Table 6, unlike Table 5, allows to appreciate the actual level of mode substitution taking place by providing data on the number of passengers using a particular mode and the level of service before and after the HSR. The extent to which conventional rail services lose passengers to the HSR varies a lot, for example, 94% reduction in the number of conventional rail passengers on the Madrid–Seville route, but only 18% reduction on the Taipei–Taichung route. It is reasonable to assume that most, even if not all, of the reduction in the number of passengers is due to a shift to the HSR. Thus, there is clear evidence that HSR services can 'cannibalise' the conventional rail services, in some cases to the extent that conventional rail becomes insignificant on the route, although it can still, like on the Taipei–Taichung route, maintain a sizeable market (in absolute demand).

Table 5 suggested that conventional rail to HSR substitution is the largest mode substitution effect. Yet on four out of five routes where comparable data for air and rail exist in Table 6, the reduction in the number of passengers is substantially larger for air transport (the exception being the Taipei–Taichung route). It is clear that HSR can eliminate the demand for airline services (or close to it, e.g.

Seoul–Daegu route). On some routes, however, the effect of HSR on demand for air transport is not so detrimental. The Cologne–Munich route is a notable example with only 20% reduction in the number of passengers flying after the opening of the HSR, even though the route distance is favourable for air to HSR substitution. The explanation for this is the long (more than 4.5 hours) journey time, as most of the route is not high-speed.

The effect of HSR on car travel seems more modest than on other modes. The reduction in the number of passengers on the routes examined is in the order of 10 –20%. On one (short) route (Rome–Naples) demand for car travel remain stable and in one case (Madrid–Seville) it actually increased by 23% after HSR services begun. Given the general trend in most countries of increase in demand for car travel over time[7], it is difficult to discern the actual effect of HSR. The HSR might attract car passengers, perhaps the more likely outcome, but the effect of HSR on conventional rail services (the reduction in demand noted above) might result also in mode substitution from conventional rail to car if conventional rail service is deteriorated as a result[8], and thus indirectly HSR can increase car use. Reduction in the number of passengers travelling by coach is recorded on all the routes for which data are available. The level of reduction, either as percentage change or absolute number of passengers, appears to be similar to that of car transport.

The level of substitution across all modes together similarly varies substantially across routes. On the four routes in Taiwan and one in Spain for which data are available for all modes, the reduction in the number of passengers ranges from 14% (on the Taipei–Taichung route, from 2.1million passengers before HSR to 1.82 million passengers after) to 43% (on the Taipei–Kaohsiung route, from 0.83 million passengers to 0.48 million passengers). The evidence given in Table 6 and the discussion resulting from it is distorted by the larger representations of routes in Taiwan. Coach services seem to be a more important inter-city, long distance travel mode than in other places, e.g. in Europe. Yet, the evidence on the four routes in Taiwan allows to appreciate the effect of the route distance on the level of mode substitution, even more so considering that all routes involve traffic from/to Taipei. The 14% reduction in the number of passengers noted above is on a 150-km route and the 43% on a 345-km route. Reduction in the number of passengers across the conventional rail, air, car and coach modes on the Taipei–Tainan route (308 km) was 29% and on the Taipei–Chiayi route (248 km) was 27%. Assuming that most of the changes reported are directly related to the introduction of HSR, the picture emerging from Table 6 is that mode substitution to HSR varies a lot across routes and between modes. Thus, although it can be expected that the development of HSR will result in mode substitution, it is not possible to assume its nature based on evidence from other countries, unless there is evidence for several routes on the same network. The evidence from Taiwan points that HSR does not always become the main mode of transport on the route.

Table 6 also highlights that there can be an important difference in the extent of mode substitution when recording changes in the number of passengers or the number of services. On four Spanish routes and on the Seoul–Busan route, the reduction in the number of air passengers was more substantial than the reduction in the number of flights and it is the latter that affect the environment and congestion levels. In a recent research, Kappes and Merkert (2013) found that the presence of HSR services is for airlines, a major entry barrier to the market (route)

Table 6. Changes in the level of ridership on different modes of transport before and after the introduction of HSR services

Route (distance)	Period (before/after)	Unit	Mode	Before	After	Change (%)	Source
Paris–Lyons (427 km)	1980/1984	Pax	Air	N.A.	N.A.	Halved	Vickerman (1997)
Paris–Geneva (555 km)	1980/1984	Pax	Air	N.A.	N.A.	Around −20%	
Rome–Naples (222 km)	2005/2007	Pax	Conv. rail	2 672 000	1 874 000	−30%	Cascetta et al. (2011)
			Car	2 758 036	2 738 112	−1%	
Taipei–Kaohsiung (345 km)	April 2005 / April 2008	Pax	Conv. rail	65 020	23 852	−63%	Cheng (2010)
			Air	240 890	47 397	−80%	
			Car	236 560	196 626	−17%	
			Coach	295 880	212 473	−28%	
Taipei–Tainan[a] (308 km)	April 2005 / April 2008	Pax	Conv. rail	47 410	26 193	−45%	
			Air	96 270	15 100	−84%	
			Car	172 310	142 119	−18%	
			Coach	391 940	317 319	−19%	
Taipei–Chiayi (246 km)	April 2005 / April 2008	Pax	Conv. rail	41 110	32 599	−21%	
			Air	20 630	0	−100%	
			Car	202 190	168 780	−17%	
			Coach	222 710	153 015	−31%	
Taipei–Taichung (160 km)	April 2005 / April 2008	Pax	Conv. rail	192 270	157 680	−18%	
			Air	7600	0	−100%	
			Car	1 219 290	1 059 966	−13%	
Madrid–Seville (470 km)	1990/1994	Pax	Conv. rail	145 554	8671	−94%	EC (1998)
			Air	367 186	157 204	−57%	
			Car	308 815	380 698	23%	
			Coach	92 912	69 262	−25%	
	1991/1994	Flights	Air	3692	2080	−44%	
Madrid–Barcelona (621 km)	Monthly data around February 2008	Pax	Air	345 228	269 217	−22%	Jiménez and Betancor (2012)
		Flights	Air	3255	2806	−14%	
Madrid–Málaga (513 km)	Monthly data around December 2007	Pax	Air	105 971	79 771	−25%	
		Flights	Air	971	708	−27%	
Madrid–Zaragoza (307 km)	Monthly data around December 2003	Pax	Air	7935	1986	−75%	
		Flights	Air	232	85	−63%	

(*Continued*)

Table 6. Continued

Route (distance)	Period (before/after)	Unit	Mode	Before	After	Change (%)	Source
Seoul–Daegu	2003/2011	Pax	Air	706 773	379	−100%	Lee, Yoo, and Jung (2012)
		Flights	Air	6505	3	−100%	
Seoul–Busan	2003/2011	Pax	Air	2 588 595	1 180 950	−54%	
		Flights	Air	15 996	9790	−39%	
		Pax	Coach	690 040	606 552	−12%	
Guangzhou– Wuhan (968 km)	2009/2011 (rough, monthly figures)	Pax	Air	120 000	60 000	−50%	Bullock et al. (2012)
		Flights	Air	900	600	−33%	
Guangzhou– Changsha (621 km)		Pax	Air	90 000	30 000	−67%	
		Flights	Air	750	250	−67%	
Guangzhou– Wuhan (968 km)	October 2009/October 2010	Seats	Air	146 061	75 966	−48%	Fu, Zhang, and Lei, (2012)
		Daily flights	Air	32	17	−47%	
Guangzhou– Changsha (621 km)		Seats	Air	111 382	41 178	−63%	
		Daily flights	Air	25	10	−60%	
Paris–Metz (315 km)	From the maximum volume before HSR to 2010 (monthly figures)	Seats	Air	7528	0	−100%	Dobruszkes (2011)
		Flights	Air	172	0	−100%	
Paris–Brussels (312 km)		Seats	Air	36 652	4216	−88%	
		Flights	Air	390	31	−92%	
Brussels–London (373 km)		Seats	Air	112 950	50 658	−55%	
		Flights	Air	935	443	−53%	
Paris–Marseilles (750 km)		Seats	Air	166 689	96 912	−42%	
		Flights	Air	1194	640	−46%	
Cologne–Munich (621 km)		Seats	Air	75 920	61 092	−20%	
		Flights	Air	557	445	−20%	

[a]See note 1 in Table 5.

suggesting that there is 'enforced' mode substitution simply since airline services would not be available.

Factors Explaining the Demand for HSR

Given the variance in the level of induced demand and that of mode substitution (in total and for specific modes) across different routes, it is difficult to articulate the factors explaining these levels. Nevertheless, it is clear from reviewing studies that attempted to provide explanation (by means of a statistical analysis) that there are several factors which are most critical. The evidence is naturally biased by the data available which in turn is influenced by the ease of measuring a factor (like travel time) that might influence mode substitution and associating it to the observed level of demand.

It is reasonable to assume that travel time, which directly relates to operating speed, is the main factor explaining the demand for HSR and the level of mode substitution. A study by Steer Davies Gleave (2006) found that travel time explains 84% of the difference in market share of rail (including HSR) vs. air on eight different routes. Cascetta, Papola, Pagliara, and Marzano (2011) found in a revealed preference survey on the 222-km Rome–Naples route that travel time is the main reason for choosing the HSR. Likewise, a survey done by RENFE (Spanish Railways) on the Madrid–Seville line in 1993 (Coto-Millán, Inglada, & Rey, 2007) found that the main reasons for choosing HSR, and not the alternatives, were: speed/time (57%), comfort (17%), novelty (9%), service schedule (8%), with fare only stated as a reason by 2%. At the same time, those continuing to fly on the route stated comfort (31%) as their main reason to choose the aircraft, while car users stated speed/time (42%) followed by comfort (35%) as the main reason to travel by car (ibid.). A survey made on the same route in 1996 (EC, 1998) reveals that the main reasons for still flying are connections (53%) and speed (18%).

In the competition between modes, travel time to get to/from the HSR station or airport is also important and so is the quality of the travel time (e.g. the number of transfers required). In other words, it is the door-to-door travel time and its quality and not that of station-to-station or airport-to-airport travel time that are important in mode choice decision. Chang and Lee (2008) find that poor HSR station accessibility is the second reason for not using the Korean HSR (32%), after its price (38%) when users of HSR, conventional rail, car, express bus, and aircraft were surveyed on the Seoul–Busan and Seoul–Mokpo corridors. Likewise in Taiwan, Chou, Kim, Kuo, and Ou (2011) find that HSR station location, mostly away from the city centre, and (partly as a result) the access to stations are perceived as the least appreciated attributes of the service by HSR users. In the Taiwanese HSR case, disconnection between the HSR and conventional rail networks appears to have a large effect on the (poor) accessibility of the HSR stations (Chou et al., 2011). Clever and Hansen (2008) highlight in this respect that for a given line-haul travel time (i.e. station to station or airport to airport), the competition between HSR and aircraft services depends on the access and egress times to the railway station.

Travel time clearly emerges as the main factor determining the level of mode substitution, but it is also clear that considering only the in-vehicle (e.g. the HSR or the aircraft) travel time is not enough, even if it does provide a good indication for the ability of the HSR to attract passengers from other modes. Estimates of the value of time for access/agrees journey suggest that saving (or shortening) one minute travel time on the access journey is perceived by inter-city passengers to be the same as saving two minutes of the in-vehicle journey (see, for example,I-seki & Taylor, 2009, reporting Wardman (1998 and 2001)). Other factors are also important in determining the demand for HSR vs. other modes and their importance increase when the advantage of HSR with respect to travel time over other modes diminishes. Thus, when HSR travel time increases, it is found that HSR passengers are less sensitive to time than airlines passengers (suggesting other factors determine their choice to use HSR) (Cascetta et al., 2011). According to Figure 1, these factors gain importance when HSR travel time is less than 1 hour or more than 3.5 hours.

Travel time by HSR, conventional rail, aircraft and coach (less so by car) is the most readily available and accurate data that can be used to investigate mode choice and is the first factor used in any analysis, with often only a few other factors included. There is therefore a risk that the analysis of travel time masks the influence of other attributes that are not included in the analysis.

Information on fares is probably the most important factor that explains the demand for HSR that is not readily available and often not included. The Korean HSR case indicates that expensive HSR services allow express buses and conventional rail services to maintain relatively large significant market shares (Chang & Lee, 2008). In this respect, the emergence of low-cost airlines (LCAs) might change the balance of air to rail mode substitution (Dobruszkes, 2011; Rothengatter, 2011) and can potentially result in rail to air substitution if HSR services are more expensive. Friederiszick, Gantumur, Jayaraman, Röller, and Weinmann (2009) find that LCAs entry into the German market resulted in a decrease in rail passengers, at least 7% in second class passengers and 18% in first class passengers when considering 84 domestic routes. The effect of LCAs on demand for rail was stronger on longer routes. A survey on four German routes, reported by Friebel and Niffka (2009), indicates that 2.8% (when rail travel time is more than 10 hours) to 33.25% (when rail travel time is less than four hours) of LCAs' passengers would have chosen rail if LCA had not been available, depending on rail travel time. Yet, Behrens and Pels (2009) did not find a LCA effect on the London–Paris route in 2003/2004. They found that HSR passengers are less sensitive to frequencies, fares and total travel time than airline passengers more generally. The difference between the cases might be attributed to the difference in travel time. In Germany, many HSR journeys are above three hours while the London –Paris route was less than three hours, which is more difficult for airlines (low cost or not) to match given access/ egress time to the airport.

Although it is reasonable to expect fares to influence mode choice, and some evidence for this was found, the few studies that report price elasticises suggest that it might not be as important in determining mode choice. For example, Campos and Gagnepain (2009) computed cross-price demand elasticities on the Paris–Amsterdam route in 2005. They find that HSR would not attract air passengers from traditional airlines or LCAs with lower fares. In contrast, HSR would gain air passenger if traditional airlines would increase their fares. Like with travel time, in most cases, the costs of the access/egress journey are not accounted for while they could be significant.

The attractiveness of travelling by car, from a cost perspective, is greatly influenced by the size of the group travelling, i.e. how many passengers share the cost of one car journey. Cascetta et al. (2011) found that the cross-price elasticity of demand show low potential for modal shift from car to rail with regard to travel time and cost. The car also seems to have advantage over the HSR with respect to the 'other' factors that influence mode choice. The car offers flexibility with respect to time of travel (schedule) and is likely to offer the most direct journey or a flexible route choice. Using the car can also be considered more attractive when travelling with luggage, especially large or heavy items. In contrast, road congestion, and thus travel time reliability, might play in favour of choosing HSR as well as the opportunity to use travel time more effectively when travelling by HSR (e.g. better opportunities to work). However, ex-post empirical evidence for these effects with respect to demand for HSR was not found.

Finally, a factor that might explain the choice of HSR services over airline services is passengers' attitudes. 'Green' attitudes are likely to have important effect on the choice of HSR services for some groups, but also here there is no empirical evidence.

Conclusions and Discussion

Although there is not much ex-post evidence on the demand for HSR services and existing evidence is largely influenced by route-specific characteristics, several conclusions can be drawn from the above review of the literature.

The evidence presented above allows a better characterisation of HSR as a mode of transport. Acknowledging the limitation of the measurement of induced demand, it can be concluded with caution that a few years after the introduction of HSR, on average, about 20% of the demand is new, induced demand (with large standard deviation). Given this, it is reasonable to assume, for planning purposes, and especially when modelling/forecasting is not possible, that induced demand will be in the order of 10 −20% 2 −4 years after the introduction of HSR.

Given the level of induced demand, it can be assumed that on average about 80% of the passengers using HSR a few years after its inauguration will be passengers that previously used other modes to travel on the route, including conventional rail. The level of mode substitution varies between routes and so is the composition of the passengers shifting to HSR. The picture emerges from the routes examined is that mode substitution, when considering the demand for HSR, is mainly from the conventional rail to HSR. The effect of mode substitution, however, can be larger on some routes for air to HSR substitution.

It is clear that the level of substitution from conventional rail to HSR is likely to be high, yet the implications this will have on conventional rail services and use at the network level, and on rail use overall (combined high-speed and conventional rail) is not clear. In a policy context of promoting rail use at the expense of car and air modes, this is an important matter for further research and a subject that does not get enough attention in the context of HSR research. Investments in HSR can have adverse impacts on the conventional rail network due to both reduction in demand and reduction in investments in the conventional network and deteriorating service as a result. The two are closely linked, for example, in a monopolistic system like in France or in Spain, the national rail operator may have the freedom to reduce or cut conventional rail services since demand is low, while reduction in demand can also be associated with lack of funds to maintain and invest in conventional rail. Investments in HSR might lead to overall reduction in rail use at the national level, and an unintended increase in the dependence on car since the spatial coverage of the HSR network (e.g. number of stations) cannot match that of the conventional network. Martínez Sánchez-Mateos and Givoni (2012) largely support this view. On the other hand, increase use of HSR might facilitate the use of conventional rail on lines that are well integrated with the HSR network. Conventional rail to HSR substitution might also free up capacity for freight services or regional passenger ones on the conventional network, which is considered to be a desirable effect. In France, the main conventional rail lines have remained in use for regional services and for freight and HSR is believed to boost the use of rail overall. Furthermore, when the HSR can also operate on the conventional rail network, like in France, HSR facilitated the upgrade and electrification of conventional rail lines thus contributing to the conventional rail network. An important question is whether the substitution from conventional rail to HSR results in rail becoming more expensive to use.

The airlines seem to be most affected by mode substitution in terms of passengers shifting to HSR and the introduction of HSR services can result in closing air services. In some cases, the airlines might as a result decide to cooperate with the HSR operator and offer their service by HSR instead of aircraft. It is more difficult to conclude on the effect of mode substitution on demand for car travel. It is likely that this effect depends largely on the ease to access the HSR station. This in turn depends on the size of the city (or metropolitan area) and the location of the station. It seems that in the Taiwanese case, where the stations are largely located at the city outskirts, the share of passengers transferring to HSR is larger than in the case where stations are located at the city centre (see Table 5 vs. 6). In general, and all other things being equal, as route distance increases HSR gains market share from road transport until at some point it starts to lose market share to air transport.

Mode substitution is important for estimation of the environmental effect of developing the HSR network. While in most cases, HSR's environmental performance is better than that of the aircraft and can be better than that of the car (especially in single occupancy car journey), an issue that is often overlooked is induced demand at the airport and roads. When demand for runway capacity exceed supply, as in most of the world's large cities especially those with HSR services, or planned HSR services, it is likely that any capacity released as a result of air to rail substitution will be quickly taken up by other aircraft services. These are likely to be aircraft services to more distant cities, leading to net impact of increase in pkm flying out of an airport. As a result, mode substitution is likely to increase air transport impact on the environment. Similarly, any road capacity freed as a result of road to rail substitution is unlikely to result in reduction in traffic congestion on the route. It is also clear that more attention needs to be given to the effect of mode substitution on the level of service supplied by conventional rail, aircraft and coach services, since in terms of freeing up capacity this is the effect that matters.

The levels of mode substitution and induced demand together are crucial to understand in order to assess the need for HSR as well as the justification for the high investments required to build the HSR, the costs and the benefits from investments in HSR (de Rus & Nombela, 2007; de Rus, 2011). There is certainly a need for more extensive and rigorous ex-post analysis of the demand for HSR, and especially of mode substitution and the phenomenon of induced demand. Such an analysis is crucial to undertake now, before all the planned HSR lines across the world are realised. Furthermore, there is also a need for those involved in developing and planning the current and future HSR network to take the time and devote more resources to learn from past experiences rather than to invest in yet another demand forecasting exercise.

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Notes

1. Includes lines or sections of lines on which trains can go faster than 250 kph at some point during the journey (EC, 2011a).
2. Mode substitution is used since it is the term commonly used in the literature to refer to passengers changing from using one mode to another. Since in most cases, the new (HSR) and previous (aircraft, car, etc.) modes continue to operate there is no actual substitution of modes, but transfer between modes. Furthermore, in changing from conventional train to HSR, there is certainly no change of mode, but change of service, yet for simplicity also in this case we refer to mode substitution.
3. London and Continental Railways is the private company that won in 1996 the contract to finance build and operate the Channel Tunnel Rail Link (CTRL — nowadays called High Speed 1).
4. Excluding international traffic since HSR lines in the UK, Belgium and the Netherlands were opened later than expected.
5. Such changes in most cases cannot be fully separated from changes in accessibility following improvement in the transport network, making the matter more complicated.
6. Considering, for example, the Paris–Amsterdam route in 2004 (Table 2), a HSL was then only available between (north of) Paris and (south of) Brussels (52% of the distance).
7. Reduction in demand for car travel has been recorded in some cases, but not in the periods and/or countries examined here (but see Goodwin and Van Dender (2013) for a special issue on 'Peak Car').
8. The extent to which the development of HSR is positively or negatively affecting the conventional rail network is difficult to determine and requires further analysis, which is outside the scope of this paper. This issue is revisited in the conclusion section.

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