

# Modal Shift and High-Speed Rail: A Review of the Current Literature



MTI Report 12-35



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REPORT 12-35

# **MODAL SHIFT AND HIGH-SPEED RAIL: A REVIEW OF THE CURRENT LITERATURE**

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## EXECUTIVE SUMMARY

This report provides a review of scholarly literature with direct relevance to the topic of modal shift and high-speed rail (HSR). HSR systems are usually planned on the expectation that they will attract riders who would have chosen other modes (such as air, automobile, bus, etc.) had the HSR not been created. Identifying and measuring the actual ability of HSR to effect modal shift is therefore critical. To establish the most current systematic research on the topic, this report examines the evidence concerning HSR and modal shift in both secondary analyses of previous studies and in newer studies that use primarily original data. The studies that were reviewed comprise a large variety of HSR systems, time periods, data sources, and means of analysis.

Although this literature is still in a formative stage, with key pieces of data and analysis still unavailable, the existing research is quite clear that HSR is extremely competitive with other modes. This finding emerges from essentially every study examined for this report and is reflected in outcomes from the HSR systems of Europe and Asia, with limited information from the US. The convergence of these multiple sources and analytic frameworks on similar results provides a reasonably secure basis for inferring that new HSR systems placed in appropriate travel corridors and managed well are likely to result in significant amounts of modal shift. Essentially, the literature affirms that HSR has resulted in significant-to-dramatic mode shifts where it has been systematically evaluated.

The most extensive and convincing information concerns HSR versus airline service. In both Europe and Asia, air service for specific routes was reduced, or even curtailed altogether, following coverage of the same routes by HSR. The most dramatic demonstrations of HSR's ability to attract market share tend to occur under specific circumstances. When HSR is faster from beginning to end of city pairs, for example, HSR gains market share rapidly and decisively. Other possible mediating factors of HSR market share include time to access and egress the system; fare cost versus that of other modes; service frequency; service quality; and number of transfers required.

The research concerning direct competition with automobiles is much less definitive. The completed research does generally confirm that adding HSR results in substantially less automobile travel, with a few exceptions that seem linked to extraneous factors and not the competitiveness of HSR per se. As well, there is evidence of modal shift to HSR in some markets served by express buses (e.g., Taiwan), but the evidence is relatively scant. When it competes directly with conventional rail, HSR has been shown to emerge as the dominant force in the market, although conventional rail also serves as a complement in many HSR systems.

The studies compiled here document, with a variety of data and research approaches, that HSR systems have proven competitive in a great variety of settings in industrialized countries. Although this study does not include analysis of new data that would address the California HSR system, the findings from the research reviewed here are highly consistent with the expectation that the planned HSR system is well positioned to achieve comparable modal shift.



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## I. INTRODUCTION

Ground will be broken soon on a new high-speed rail (HSR) system in California. Common in many other industrialized nations, the first HSR route was created in Japan in 1964, featuring trains that ran at approximately 130 mph.<sup>1</sup> Since that time, HSR service has been added and, in many instances, rapidly expanded in many other countries. It is particularly well established in Japan, China, Taiwan, Germany, Spain, and France. Although there is no globally accepted standard for what constitutes HSR,<sup>2</sup> in the US the Federal Railroad Administration (FRA) has defined various categories of HSR, including “HSR express”:

***HSR – Express.** Frequent, express service between major population centers 200–600 miles apart, with few intermediate stops. Top speeds of at least 150 mph on completely grade-separated, dedicated rights-of-way (with the possible exception of some shared track in terminal areas). Intended to relieve air and highway capacity constraints.<sup>3</sup>*

The California system is planned to meet the “express” standard for HSR over its newly constructed route. Of particular significance here is the last part of the FRA definition, which specifies at least part of the purpose of creating HSR systems: relieving capacity constraints posed by air and highway systems. Depending on the context, HSR systems may be intended to achieve several other key objectives. Among these are enhancing economic development and job creation, reducing environmental impacts of transportation, and generating a positive return on investment.<sup>4</sup> However, the goal nearly always associated with new HSR projects is to provide some form of relief as a viable alternative to congested air and roadways, and this certainly is among the primary motivations for developing the California system.<sup>5</sup>

If HSR systems are to provide such relief, as well as the many other benefits ascribed to them, they must succeed in attracting passengers from other modes of transportation. Moving passengers from existing (and perhaps future) air, bus, and automobile options to HSR is generically referred to as “mode shifting,” “mode substitution,” or “diverted demand.”<sup>6</sup> This paper provides a review of existing research concerning effectiveness of the HSR system in effecting modal shift, particularly from airplanes, automobiles, and buses.

To help ensure use of objective and scientifically reliable findings obtained with rigorous methods, the focus for this review is almost exclusively on scholarly and/or peer-reviewed research that documents either the potential or the record of HSR systems to attract riders from other modes. Additionally, although older research was consulted, the emphasis here will be on more recent research that reflects the latest data and analytic techniques available. Extensive search on relevant terms was conducted in a variety of environments, including the Transport Research International Documentation (TRID), Google Scholar, various Transportation Research Board resources (including ACRP, TCRP, and TRB conference websites), domestic and international rail agency websites, and various electronic library databases, including the Social Science Citation Index, and Academic Search Premier (which encompasses multiple databases). The sources examined emerge from a panoply of journals reflecting the variety of academic disciplines comprising transportation policy. This paper will address the following questions that are directly related to HSR and modal shift:

- How do researchers identify and measure mode shift?
- How much modal shift among air, auto, and other modes is believed to be caused by the availability of new HSR systems and routes?
- How much modal shift has been documented by HSR systems in specific countries that have more mature HSR systems?
- Which factors have been shown to affect size and quality of mode shift?
- How much modal shift has been forecast with direct reference to the California system?
- What implications does the existing research generally have for the California system?



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## II. FORMS OF DEMAND FOR HSR

Relatively little of the existing literature addresses modal shift directly (for exceptions, see, e.g., Janic 2003; Tsamboulas et al. 2007; and Moeckel et al. 2013).<sup>7</sup> Most studies that invoke the concept (either explicitly or implicitly) use it in the course of addressing the demand for HSR more generally. Mode shift is one of the major constituents of overall demand for HSR: Many passengers are expected to be persons who would otherwise have flown, driven, or used some other mode of transportation.<sup>8</sup>

As a rule, researchers are addressing modal shift when they explore “competition” between HSR and other modes. Most of the literature explored in this analysis explicitly uses the concept of competition to explore modal shift, although competition in the sense of economic battle is not the ultimate objective for HSR systems. HSR systems are intended to advance a number of policy aims, including environmental objectives, more rational allocation of public infrastructure, and other goals. However, to achieve these goals, significant modal shift to HSR is paramount, hence the literature’s emphasis on competition. In these studies, competition assumes a wide variety of forms, but it tends to focus on point-to-point travel times, costs, and the quality of the travel experience.

Before addressing the existing research on intermodal competition, it bears mentioning that scholars note two other potentially significant sources of demand for HSR services: (1) complementary demand and (2) induced demand. Complementary demand is created when passengers choose to use HSR service in concert with the use of another mode, such as when a person travels via HSR to connect to an airline flight. In this case, HSR does not subtract ridership from the air mode but helps enable the use and, perhaps growth in the use, of both modes. An expanding body of research addresses the nature and scope of this phenomenon, generally finding complementary demand to be a significant and growing component of HSR demand in many rail systems (see, e.g., Bory 1999; Givoni 2007; ACRP (Coogan et al.) 2010; Adler et al. 2010; Coogan 2011; Chiambaretto and Decker 2012; Clewlow et al. 2012; Albalade et al. 2013).<sup>9</sup>

Induced (also referred to as “generated”) demand refers to the capacity of HSR—by virtue of its location, speed, the novelty of its technology, and a variety of other qualities—to generate ridership among those who otherwise would not have traveled. Just as new highways can create more automobile traffic, new HSR train services can attract more use of a given train route.<sup>10</sup> Although recognized as a potentially significant source of HSR ridership, forecasting or measuring the amount of induced demand created by HSR is extremely problematic.<sup>11</sup> Givoni and Dobruszkes state that “the main challenge is to determine what should be counted as induced demand.”<sup>12</sup> A further complication is that complementary and induced demand are not, presumably, mutually exclusive, meaning that—as one example—HSR could attract new riders for airlines by making access to airports easier or more attractive.

Thus, demand for HSR service is known to extend significantly beyond that associated with riders substituting rail for other modes. However, this review will exclude explicit consideration of either complementary or induced demand, as neither (by definition) is directly associated with modal shift to HSR from other modes.



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### III. MODAL SHIFT

Mode shift to HSR results when passengers select HSR over modes, such as airplanes or cars because the competitive advantages of HSR, in sum, offer greater perceived value. Although researchers have frequently included measures of modal shift in their studies of HSR, identifying and measuring it is not always the direct objective. Typically, research includes measurement of modal shift as one component of demand. Researchers may attempt to measure or estimate modal shift in two generic ways: (1) forecasting (also known as “ex ante”) changes in future demand for HSR service that incorporate modal shift and (2) documenting changes in demand, including the changes attributable to modal shift, that already have occurred (also known as “ex post” evidence). Givoni and Dobruszkes note that forecasts of modal shift outnumber ex post evaluations, and they attribute the gap to the general lack of appropriate data. However, increasing amounts of ex post data are available.<sup>13</sup>

Neither of the two strategies is particularly straightforward because it is difficult to predict how people will make travel decisions in the future and perhaps equally difficult to determine with certainty whether riders in the past considered other modes before choosing HSR. As the earlier discussion concerning induced and complementary demand suggests, high ridership levels do not necessarily connote modal shift. *Nevertheless, the bulk of available evidence points to the conclusion that, under most circumstances, HSR presents a significant competitive challenge to other modes and often provides noteworthy advantages in terms of travel time from point of origin to final destination, quality of travel time, environmental benefits, and costs to the traveler, among others.*

Forecasts of mode shift are based on a variety of techniques but primarily rely on theoretical models that use existing data to predict how a particular proposed or newly created HSR route will attract passengers from other modes. Generally, these theoretical models are predicated on assumptions about how modal choices are affected by the characteristics of HSR travel vis-à-vis other modes. For example, in a relatively early effort, Gonzalez-Savignat (2004) modeled demand for HSR versus private vehicles as a function of travel time, travel costs, and service frequency for the two modes.<sup>14</sup> To estimate ridership on specific routes in Spain, she assembled data from an existing line (Madrid–Seville) and from surveys of potential passengers, and these were combined to estimate how a (then-) future line (Madrid–Barcelona) would compete with automobiles. (Gonzalez-Savignat concluded that the proposed route would more successfully attract business travel than leisure travel.)<sup>15</sup>

More recently, Moeckel et al. (2013) developed a model to forecast mode choice for long-distance travel. The model posits mode choice as a function of the relative cost to the rider, along with distance, transit system accessibility, frequency of service, number of transfers, and parking costs. However, the model does not explicitly incorporate HSR, although the characteristics of HSR could conceivably be applied and used to generate forecasts of the modal share of a particular HSR route.<sup>16</sup> A variety of other theoretical models that involve predicting mode choice have been developed in prior years, but only relatively few have invoked HSR explicitly as a mode choice (see Chang and Chang 2004; Tsamboulas et al. 2006; e.g., Adler et al. 2010; de Lapparent et al. 2009).<sup>17</sup>

Forecasts of demand for specific HSR routes or systems—with and without estimates of mode shift to HSR—have been criticized for being generally inaccurate and systematically higher than subsequent ex post data would indicate. Many forecasts are generated by scholars operating outside of a peer-reviewed context, and few are subjected to subsequent validation by analysis of actual demand.<sup>18</sup> Additionally, few of these forecasts appear in searches for scholarly research, making them generally poor sources of information about HSR modal shift.

Analyses of ex post demand generally are based, at least in part, on actual ridership data and are more likely to be valid than forecasts.<sup>19</sup> Each study uses a slightly different approach, but generally ex post demand is identified by comparing pre- and post-HSR ridership within a particular route, market, or country. Specific measures of mode shifts may include percentage or number of passengers traveling in various modes before and after HSR, although survey reports of similar information may also be used.<sup>20</sup> Other studies imply modal shift by reporting “after-only” market share of HSR, the presumption being that if HSR dominates in a given corridor, it must have displaced possible users of other modes.

Another kind of measure related to modal shift is travel elasticity, which refers to the rate at which passengers substitute one mode for another, given a change in the relative price, time of travel, or other characteristic of two modes. For example, if a 1% decrease in the price of an HSR trip results in a 1% increase in trips compared to the same trip by air, the elasticity of price for HSR versus air travel is calculated at -1%.<sup>21</sup> Elasticity estimates may potentially be more useful than demand data from a policy or management standpoint, as they can help to predict how transportation markets react to a given change, such as an increase or decrease in price or service level.

One general weakness of all forecasts and ex post measurements of modal shift is that they reflect imperfect experimental designs; as a rule, they do not account in any way for the possible influence of other variables that may affect modal shift. More specifically, the influence of economic forces that might increase or decrease use of HSR and other modes cannot be incorporated into the research designs.<sup>22</sup> The global economic downturn may have affected ridership of HSR in some countries and possibly at a level that is disproportionate to its effect on other, more established modes.

Another common design weakness among these studies is that they typically examine only one time period for the pre- and post-HSR analysis. Ideally, multiple post-HSR assessments would enable a more detailed and valid measurement of modal shift. For example, the Taiwanese HSR system initially reported very disappointing daily ridership figures of approximately 35,000.<sup>23</sup> However, more recent figures indicate a daily ridership of approximately 130,000, with attendant gains in modal share for the HSR system.<sup>24</sup> The reasons behind this increase will be explored later in this paper, but the case illustrates that modal shift may increase—or possibly decrease—over a relatively short period of time, and a one-point measure of mode share may be misleading.

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## IV. EVIDENCE OF MODAL SHIFT USING SECONDARY ANALYSIS OF AGGREGATED EXISTING DATA

This section provides a review of sources that provide modal shift information about an aggregate of HSR routes or systems as well as those that aggregate data from existing research. This subset of research is useful because it helps summarize what is generally known about the ability of HSR to attract mode share over relatively longer periods of time, and the larger scope may provide a better, more rounded perspective on HSR competitiveness.

**Multinational (2007), Givoni.** Givoni presented a review of the “development and impact of the modern high-speed train.”<sup>25</sup> As it is a more qualitatively oriented and historical review of HSR to approximately 2006, the study offers relatively little in the way of systematic data analysis. Moreover, the article is focused primarily on economic costs and benefits of HSR, although it does emphasize the attraction HSR holds for passengers from other modes, particularly air travel. Givoni concludes that “shorter travel times and an increased level of service (a higher frequency and also improved travelling conditions) following the introduction of HST lead to changes in the modal share on the route and to the generation of new demand.”<sup>26</sup> The modal share data that this conclusion is based on is both somewhat sketchy and dated: It consists of before-and-after comparisons from the French Paris–Lyon TVG line from 1981–1984 and the Spanish Madrid–Seville line from 1991–1994.

The data presented by Givoni indicate that creation of the French Train a Grande Vitesse (TGV) line resulted in a 24% loss of market share for aircraft and an 8% reduction in car and bus travel. In Spain, a 27% loss of market share was observed for aircraft and an 8% loss for cars and buses.<sup>27</sup>

Givoni also states (with relatively little data to support the conclusion) that the modal share captured by HSR depends “mainly on the travel time it offers compared with other modes, but also on the cost of travel and travel conditions.”<sup>28</sup> This theme—of the relationship between travel time, cost, and conditions—is explored in greater detail in subsequent research summarized in this review. In sum, although it contains relatively little data, Givoni’s review documents early successes—linked to attractive travel times, cost, and overall convenience—of HSR lines in France and Spain.<sup>29</sup>

**Multinational (2009), Campos and De Rus.** In a “review of HSR experiences around the world,” Campos and De Rus analyzed information from 166 HSR projects globally.<sup>30</sup> Their primary purpose was to analyze the economic costs and demand patterns for HSR, although the emphasis is on the former. The projects include completed rail routes in operation (24%) as well as those under construction and those pending approval and/or funding.<sup>31</sup> Lines that at least loosely fit the FRA definition of either express or regional HSR were included. (HSR regional rail entails “Top speeds of 110–150 mph, grade-separated, with some dedicated and some shared track.”)<sup>32</sup>

Campos and De Rus note that “the demand figures of HSR are indisputable.”<sup>33</sup> According to their analysis, the Japanese Shinkansen lines recorded over 150 billion passenger-kilometers<sup>34</sup> between its introduction in 1964 and 2005. The Korean lines that began service in 2004 recorded more than 40 million passengers per year in their first two years

of operation. European systems (combined) recorded 76 billion passenger-kilometers in 2005 alone.<sup>35</sup>

With respect to modal share in these systems, Campos and De Rus indicate that HSR accounts for 40% of the total passenger market over medium distances in Europe.<sup>36</sup> The Korean system bested total domestic air travel just two years after its introduction (through 2006). They note that as HSR systems get older (i.e., 20 years of operation or more), the rate of increase in passenger loads slows somewhat, indicating the existence of a possible “maturity effect” for HSR lines. This observation, presented as a hypothesis by Campos and De Rus, is based entirely on the fact that the rate of increase in the Japanese Shinkansen lines was 50% lower during its second 20-year period of operation.<sup>37</sup> However, Campos and de Rus do not provide more detailed information about modal shift. Their research provides an overview of the stunning growth of HSR demand in a variety of countries and regions, but only a few specifics about market share and modal shift.

**Europe (2009), De Rus and Nash.** De Rus and Nash note that despite 30 years of worldwide experience with HSR, relatively few ex post analyses of the intermodal effects have been offered.<sup>38</sup> Operators and governments tend to have relatively more interest in forecasts of demand than they do in evaluating projects after they have been completed, in their view. This article provides both a summary of the empirical research that preceded it and a theoretical model that could be used to evaluate future projects.

De Rus and Nash state that HSR is generally known to be most attractive to travelers at distances of up to about 800 kilometers. After that approximate point, air travel is faster, bearing in mind that total travel time is the key to the competitive edge of either mode.<sup>39</sup> In that respect, total travel times of three hours or less are known to favor HSR, and that edge decreases rapidly when HSR travel time exceeds that amount. Both of these generalizations have exceptions; for example, business travelers are known to prefer whichever alternative can complete their trips in a single day—regardless of travel time.<sup>40</sup>

Generally, European air service faces severe cutbacks immediately after competing HSR service is introduced and for the following two to five years. By 1997, the airlines’ share of domestic travel had decreased by nearly half, from 30% to 16% (74). Airlines, however, do not necessarily simply exit the market, as they sometimes need existing routes to feed traffic to more profitable routes (75).<sup>41</sup>

The article states that, primarily due to insufficient data, much less is known about the competition between HSR and cars. However, the authors present data demonstrating that in specific corridors where data were available, the automobile share of travel decreased drastically, by an average of approximately 12% before and after HSR in France (Paris–Lyon), Spain (Madrid–Seville), and Germany (Hamburg–Frankfurt). Additionally, analysis of Japan and Korea traffic has revealed significant decreases in express bus service (75).

De Rus, et al. also present a forecasting model; however, the model is designed to predict how operators of both airlines and HSR lines will adjust costs and prices in response to direct competition, and doesn’t directly bear on mode choice.

In summary, the De Rus, et al. article provides a concise summary of what was known about intermodal competition and modal shift, particularly in Europe at the time. Consistent with the other studies reviewed in this paper, the authors found a significant mode shift away from airlines and automobiles in Europe following introduction of HSR services.

**Multinational (2011), Albalate and Bel.** This article is a review of “the most important HSR projects carried out around the world,” with the goal of providing lessons for policy makers and managers who are implementing HSR systems.<sup>42</sup> Most of the review focuses on experiences from the following systems: Shinkansen in Japan, TGV in France, ICE (specifically, “*Neubaustrecken*,” or newly constructed HSR lines) in Germany, AVE (Velocidad Española) in Spain, and AV/AC (Rete Alta Velocità/Alta Capacita). It therefore omits detailed consideration of other significant HSR systems, such as those in China, Korea, and Taiwan. The review focuses much more on construction and operation costs than it does on modal share, but it does provide some relevant information.

Although they present relatively little specific data to support their conclusion, Albalate and Bel state that the modal distribution of travel created by the introduction of HSR in the cases they analyzed “has been affected.”<sup>43</sup> They note that the biggest impact has been on the airline industries of Spain and France: “the share by held by air transport fell significantly in both countries immediately after the introduction of HSR service.”<sup>44</sup> They also note that air traffic on the Barcelona–Madrid corridor shifted by one third to the HSR service, although no time frame is provided for this shift. Finally, Albalate and Bel state that the bus service between Barcelona and Madrid was not affected by the new HSR service.<sup>45</sup>

**Multinational (2012), Coogan.** Coogan provides a more quantitative analysis that focuses specifically on competition (as well as complementarity) between air and rail in Europe and the US, although the analysis is somewhat narrowly focused on airport-related transportation.<sup>46</sup> It is one of the few articles reviewed for this paper that provides analysis of mode shift in the US, although the American experience is limited to the Northeast Corridor. The purpose of Coogan’s paper was to “examine the scale of markets for both intercity rail as a feeder to airports, and for intercity rail as a source of diversion from air to rail.” Although “intercity rail” could also mean conventional rail service, Coogan provides a special emphasis on HSR.<sup>47</sup>

Coogan states that in the US, “long-distance rail plays a more important role in its competitive function in the diversion of passengers away from airports than it does in the complementary role of carrying people to airports” (3). His analysis indicates that in the Northeast (Boston to New York) corridor, “nearly 600,000 annual air passengers have been diverted since 1999 with the introduction of the high speed rail program, a loss of nearly half the...market.” Coogan finds that although similar diversions have occurred between Washington, DC, and New York, they are difficult to document because the train service has been upgraded incrementally over a period of decades. However, he concludes that it is safe to assume that more than one million rail passengers “would have been on the air system if the rail travel time improvement had not been made over the past few decades.”<sup>48</sup>

Coogan, assembling older data from Wardman, et al. (2002), states that in three specific major corridors connecting Paris to other countries and the rest of France (Paris–London,

Paris–Lyon–Marseilles, and Paris–Strasbourg), HSR has diverted approximately three million passengers (3). Coogan reports that the Madrid–Barcelona line has captured 46% of the 5 million-passenger market, with smaller but significant diversions of passengers between Madrid–Seville and Madrid–Malaga, and more anticipated from an upcoming Madrid–Valencia line.

These diversions demonstrate a significant competitive edge to HSR in these corridors. However, Coogan's larger point is that they are dwarfed by the 23 million European riders who use long-distance rail to access a major airport—a significant “complementary” role. Additionally, Coogan (4) finds that the rail share of passengers is demonstrably linked to travel time: As rail travel time decreases, HSR mode share increases significantly.

Coogan also finds significant modal shift has occurred in the UK, although it is associated with incremental speed upgrades and not an “express” HSR system. The UK rail system has strategically focused on providing a higher frequency of faster service instead of the French and Spanish reliance on train speed, per se. Significant numbers of passengers have been diverted to rail, but Coogan reports that, due to the incrementally developing nature of the improved service, a precise number cannot be calculated (9). He estimates the total number of diversions to be over 1 million, however (10).

In sum, Coogan's review of data over multiple rail systems in the US and Europe provides a great deal of evidence to support a general advantage for HSR (versus air travel options) in its ability to attract passengers. The same holds true for incrementally faster rail. The review further validates the general link between length of service and mode share captured by rail service: The shorter the trip, the higher the proportion of a given market likely to opt for rail service.

**Multinational (2013), Givoni and Dobruszkes.** In terms of breadth and scientific rigor, Givoni and Dobruszkes provide the most extensive existing review of modal shift.<sup>49</sup> They assembled data from a variety of existing studies and sought to “facilitate the learning process and the planning of the future HSR network.”<sup>50</sup> Their study is prefaced with the observation that there is generally little (“a dearth”) existing ex post data about demand for HSR services. They identified such data for 21 city pairs in Europe, although up to 163 pairs have existing services that might compete with air service. Although their findings were published in 2013, the data they accessed came from sources that date from 2006 to 2012, with most of the sources from before 2010. Their latest observations tend to occur during the economic slowdown, which potentially affects the results they identified. Nonetheless, this article provides perhaps the most extensive and rigorous compilation of analyses of existing ex post mode share data yet available.

The most generalized finding from this review is that HSR is extremely attractive to potential airline passengers when travel times are also competitive: Givoni and Dobruszkes note that on European routes with attractive travel times (e.g., Frankfurt–Cologne, Paris–Lyon, and Paris–Avignon), HSR has “captured almost all of the market.”<sup>51</sup> When automobile mode share is considered, however, market share of HSR increases with longer travel times and generally exceeds 30% of the entire market when HSR travel time reaches one hour. The latter conclusion appears to be based on much less available data than the first.



Moving from market share to actual mode shift, Givoni and Dobruszkes note that the existing data do not allow “concrete conclusions,” but “a general picture of mode substitution” is allowed.<sup>52</sup> Two kinds of data for modal shift are included: (1) mode share before and after the introduction of HSR service and (2) changes in the number of passengers served by each mode before and after HSR service.

With respect to modal share before and after HSR, the data are culled from eleven routes in five countries (Spain, France, Germany, Korea, and Taiwan). However, only one route is in Germany (Hamburg–Frankfurt), and four are from Taiwan. The Taiwanese data—although it does exhibit considerable evidence of modal shift—seems potentially misleading in the present, given the large increases in ridership since the 2005–2008 period reported. Korea also has experienced large increases in ridership since the study period of 2003–2011.<sup>53</sup>

In any event, Givoni and Dobruszkes find that (1) air transport loses the most market share after introduction of HSR, (2) road share is also affected, and (3) in countries with significant amounts of pre-HSR conventional rail service share, a portion of the shift is from conventional rail (731–732).

With respect to changes in actual ridership before and after HSR, Givoni and Dobruszkes present information from 22 routes located in six countries as well as from international routes (730–731). Again, the data came from different time periods, with only a few instances from the current decade. The data again support the conclusion that significant amounts of modal shift from air to HSR occur following the introduction of HSR: “It is clear that HSR can eliminate the demand for airline services...” (731). Consistent with studies mentioned earlier, longer routes tend to displace fewer airline passengers (732).

Givoni and Dobruszkes (732) find that HSR impacts automobile use less than it does air travel, but actual figures vary significantly from route to route. This finding is based on data from just four routes, including an actual *increase* in automobile trips of 23% in Madrid Seville between 1990 and 1994, but modest decreases in the other three routes (733). Givoni and Dobruszkes report that mode shift from bus service appears to be about the same as that from automobiles. Adequate data are sorely lacking for both modes.

Givoni and Dobruszkes also offer an analysis of factors behind the observed variation in modal shift in the studies that they reviewed, with the following general conclusions:

1. Travel time is the prime determinant of both demand for HSR and modal shift to HSR.
2. Travel time to get to and from the station and/or airport, as well as the quality of the travel time (e.g., number of transfers required), are also important.
3. Other factors, such as fares and the number of passengers considering an automobile trip, may also be important, but data are unavailable to investigate such hypotheses.<sup>54</sup>

On the whole, this article provides an extremely useful distillation of the available ex post data on HSR mode shift and its determinants. The authors make a strong case for the capacity of HSR service to substitute for other modes, particularly air travel. Yet, they were also able to identify instances where modal shift has been less modest and offer some useful insights into the causes and nature of this shift. Unfortunately, as the authors state forcefully, the available data are insufficient in various ways to make compelling generalizations. Those contained in this review are among the best available at this time.

## V. SUMMARY OF EVIDENCE OF MODAL SHIFT USING SECONDARY ANALYSIS OF EXISTING DATA

The summary characteristics of the secondary analysis articles are collected in Table 1. These articles that revisit and compile existing research collectively represent the most current systematic analysis in the academic community of modal shift and HSR through approximately 2010. Without exception, in each country that has introduced an HSR, research has documented that transportation markets have reacted with modal shift from other modes to HSR. That is particularly well documented with respect to airlines upon which most of the research has been focused. Airline service on routes where HSR has been introduced has shed significant amounts of the transportation market share. The existing research also indicates that automobiles and buses lose market share, but there is simply little data upon which to base this conclusion. Finally, to this point, most of the existing research attends to the European experience, whereas some of the fastest recent growth in access to HSR service has been in Asia (Korea, Taiwan, Japan and, especially, China).

**Table 1. Summary of Studies Using Primarily Secondary Data**

Study Author(s)	Published Year	Span of Data* (Years)	Countries	Modes	Primary Methodology
Givoni	2006	1981–1998; 1991–1994	France, Spain	Air, car, bus	Share comparison
Campos and de Rus	2009	1994–2004	Global	HSR only	Share comparison
Rus and Nash	2009	1981–2006	Global	Air, car, bus	Share comparison
Albalade and Bel	2011	1981–2007	Spain, Italy, Germany, France, Japan	Air, bus	Share comparison
Coogan	2012	1993–2010	Spain, England, France, UK, US	Air	Ridership and share comparison
Givoni and Dobruszkes	2013	1993–2010	Global	Air, car, bus, rail	Share comparison

\* Denotes earliest and most recent data used in analysis.

A second major theme of these secondary analyses is that the extent of modal shift—particularly from airlines to HSR—co-varies with several key characteristics of the various modes on specific routes, generally: length of route, travel time, and access to the transport. Coogan’s analysis suggests a curvilinear, nearly bimodal relationship between HSR market share and HSR in-vehicle travel time: Routes with trips under 3 hours perform noticeably better, versus air, than those above 5 hours (10).

Finally, as Givoni and Dobruszkes emphasize, not enough systematic data has been collected and analyzed to make specific statements about the precise and scientifically rigorous impact of HSR on modal shares.



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## VI. RECENT EVIDENCE OF MODAL SHIFT USING ORIGINAL DATA

This section contains a review of recent studies that use original data (or previously unused data from existing sources) to explore the relationship between HSR service and shift to other modes published from 2010 to the present. The data used in these studies, however, was not necessarily drawn from that same time period. Additionally, not every article in this section was originally intended by its authors to specifically address the issue of modal shift, but each offers results relevant to the attraction HSR holds for potential riders. The strength of this kind of research is that it is potentially more likely to be internally valid than aggregated secondary analyses because the researchers have more control over the creation and analysis of each study. However, as these articles are primarily focused on a single route, country, or market, their external validity—the extent to which their findings can be applied to other settings—may be limited.

**London–Paris (2010), Behrens and Pels.** Behrens and Pels focus on modal share, and modal shifting between, HSR and air travel in the London–Paris passenger market from 2003–2009. They seek to explain how “introducing HSR affects passenger preferences and market shares of travel alternatives...”<sup>55</sup> The data used in this study are quite different from that described in the studies in the previous section; the primary source is survey data from the International Passenger Survey (IPS), a survey of a random sample of passengers entering or leaving the UK through all applicable modes (270). Approximately 20,000 survey responses—divided by purpose of travel: business, or leisure—from 2003 through 2009 were analyzed with respect to the travel alternatives available to each respondent, along with a number of control variables. This enabled the researchers to model what determined the mode each respondent chose.

The results suggest that the following variables are the “main determinants” of the mode chosen by travelers from the survey sample: frequency of service, total travel time, and distance to the (UK) port. As these variables have changed in the study area over time, they do not connote that a specific mode is more likely to be chosen in every conceivable circumstance. As the HSR service between London and Paris has improved over the study period, so has the competitive performance of HSR vis-à-vis air service (278). Additionally, the frequency of air service decreased over time, further enhancing the attractiveness of HSR to potential passengers. In substantive terms, this means that “the competitive position of London Heathrow–British Airways has become worse” (286).

Behrens and Pels also found that the market for leisure travel differs significantly from that of business travel, with competition for the former being stronger between HSR and low-cost airways than among airlines, and vice versa for business travel. The general finding is that the Eurostar HSR is in a “dominant position” and that airlines are leaving this specific market due to their inability to maximize profits in the competitive environment created by HSR (287).

This study is of particular interest because it uses a different kind of data and research (thousands of travel survey responses juxtaposed with actual travel conditions) that seems to be consistent with other approaches. Additionally, the study is relatively recent and uses

more data points, especially compared to most of the results presented in the reviews summarized in the previous section.

The authors claim that these results can possibly be applied to the San Francisco–Los Angeles market (283) and that they are in line with official forecasts published by the CHSRA. This assertion will be explored further in a subsequent section.

**Taiwan (2010), Cheng.** Cheng presents an ex post cost-benefit analysis of the Taiwanese HSR system and also examines possible ways to increase ridership in that system.<sup>56</sup> In doing so, he addresses some issues that are relevant to modal shift, although that is not the focus of the study. In providing background for the development of the Taiwanese system, Cheng notes that most of the HSR stations were built outside of downtown areas, leaving them without convenient transit access. Cheng reports that ridership for the system averaged up to 90,000 passengers a day in 2008 (56). As noted earlier, ridership has since increased to around 130,000 per day, making the findings here somewhat dated, if not suspect. By contrast, more recent study states that the system is ‘booming,’ with an average annual growth ratio of 19.45% since 2007.<sup>57</sup>

Nevertheless, Cheng finds that HSR performed very well vis-à-vis domestic airlines over the period of the study. One year after the HSR system began service, domestic air flights dropped dramatically, although the total impact of the shift in terms of mode share and ridership is not particularly clear in the article. For example, between April 2007 (shortly after introduction of the HSR system) and April 2008, the number of air trips from the northern terminus in Taipei to and from the southern terminus in Kaohsiung decreased from 124,100 to 77,577 (37.4%). The total share of the market represented by air trips decreased from 13.0% to 8.6%. Similar and greater (by percentage) decreases occurred in most of the other cities served by HSR (63).

During the same period, automobile trips from end to end of the HSR declined from 304,532 to 196,626 (35.4%) as the modal share of the automobile dropped from 31.9% to 21.2%. Intercity bus ridership and share were essentially unaffected during the period of study, a fact that the author attributes to the market for low-cost bus service that undercut the HSR pricing system. However, intercity buses represented just around 5.3% of the end-to-end ridership in Taiwan.

The focus of the article is on strategic and managerial problems that resulted in lower-than-expected ridership during the first few years of service for the HSR system, including lack of connectivity for the HSR stations and questionable pricing and reservation policies. Even in that context, the HSR system made significant inroads into the modal share for the island nation.

**China (2011), Fu et al.** Relatively little scholarly research reviewed for this study has addressed the Chinese HSR, which is the most ambitious in the world. Fu et al. focus on the effect of the growth of HSR services on Chinese airlines.<sup>58</sup> Both the airline and HSR markets are expanding rapidly in China; from 1978 to 2007, air traffic grew at an average annual rate of 17%. HSR has rapidly expanded to serve nearly every major city in the country (13). In China, the relatively underdeveloped airline industry is seriously

challenged by the aggressive expansion of HSR service. This article is devoted primarily to analyzing how the developmentally “unbalanced” (24) Chinese airline industry can address the competitive environment, but it provides insight into how HSR has captured much of the domestic travel market. (The article does not address how HSR has affected automobile and bus shares of the Chinese transportation market.)

Fu, et al. report that HSR and air service are now directly competing for passenger market share. During the period from 2005 to 2008, all domestic flights between Shanghai and Ningbo and between Qindao and Jinan were canceled because of the introduction of HSR service. Enormous cuts in the amount of air service on a variety of other domestic routes occurred. In addition to cutting services, domestic airlines (including low-cost airlines) were forced to make significant cuts in their airfares and still lost passenger share to the HSR system (19). Fu et al. summarize the situation by stating, “Chinese airlines have been unable to compete with [HSR] on the short-/medium-haul routes even with cost-based pricing” (20).

The Chinese transportation system and Western systems have fundamental differences that make interpretation of these findings problematic. Lower per capita income in China translates into a lower valuation of time, which can make rail more attractive under some conditions (18), and the HSR system uses electricity fueled by low-cost coal. The Chinese government has significant influence in determining costs for both HSR and the domestic airlines (20). That being said, the findings reported in this article confirm the ability of HSR to attract passengers from air service.

**Europe. (2011), Dobruszkes.** Dobruszkes offers an analysis of the European transportation network using data from routes where airlines face competition from HSR.<sup>59</sup> For this article, airline transportation is measured in numbers of seats and number of flights available, and it is analyzed with respect to the volume of scheduled HSR service. Dobruszkes notes that air service in Europe has increased much more quickly than HSR service, which has evolved relatively slowly over a 30-year period. Stated another way: In 2010, 264 city pairs were served by HSR routes of 3 hours or less, but 3,262 were connected by air links. Therefore, states Dobruszkes, “European air transport has been developing considerably within a market segment where there are no high-speed trains or those that exist fail to compete with planes” (873).

However, five city pairs where both HRT and airline service exist are the focus of the study’s empirical analysis. The pairs were selected as a non-random, purposive sample that is suggestive of the range of environments in which the competition between HSR and airlines exists. The five city pairs selected were: Paris–Metz/Nancy, Paris–Brussels, Brussels–London, Paris–Marseilles, and Cologne–Munich. The results of the analysis indicate that competition between these five city pairs has transpired in five different ways, ranging from total elimination of air services (Paris–Metz/Nancy) to an actual increase in air services (Cologne–Munich). The intermediate cases all gave evidence of competitive dominance by HSR, but at different levels and in different ways. The author posits that the increase in air service between Cologne and Munich is due to the fact that the “high-speed” link requires more than four hours of travel due to stops and the density of the German rail net work (875–878).

This study provides an interesting perspective on the market relationship between HSR and airlines in Europe. The air system is growing more quickly than the HSR system, but where HSR exists it is attracting a significant market share. The author notes that a significant increase in the number of major European cities served by HSR is in the offing and that perhaps even more will be necessary to maintain the overall position of HSR in the European market (879).

**Rome–Naples, Italy (2011), Cascetta et al.** Cascetta et al. provide an analysis of a single Italian route, Rome–Naples, using survey data.<sup>60</sup> In that respect, it is similar to the Behrens and Pels (2010) study. The Rome–Naples line was completed in 2005. It does not compete directly with airlines at this time but does compete with several conventional rail lines (Eurostar and intercity) and automobiles; creation of the HSR route reduced travel time from 105 minutes on conventional rail to 65 minutes (636).

The article is unclear about how many survey respondents from each mode were part of the survey sample. Unlike the UK-based survey by Behrens and Pels (2010), the data for this survey were not linked to specific travel conditions at the time. Mode choice at the time of the survey was measured directly by the survey. Cascetta et al. use existing data from the Italian train operator, Trenitalia, to indicate that, whereas use of cars and conventional rail did not increase between 2005 and 2007, the use of HSR has increased significantly. This pattern resulted in a market share shift from 49% to 55% for trains and a reduction of the automobile share from 51% to 45% (637). However, this connotes that some of the increase in HSR was from conventional rail.

The survey responses were analyzed to help explain why travelers chose from the various alternatives. The analysis indicates that cost, travel times, number of travelers, time accessing and egressing the train system, and other variables, all affect modal choice in a statistically significant manner. The results generally comport with the ridership figures that show the HSR route did not seem to reduce the number of individuals likely to use their cars for this particular trip. Unfortunately, the authors do not elaborate on why the HSR system has apparently not greatly reduced automobile use on this route, but, based on the results, it seems likely that the travel time and expense associated with driving does not exceed that associated with the HSR. Another source (Beria and Grimaldi 2011, 19), that cites the Cascetta et al. (2011) study reports that this result may be due to the fact that the speed for the route was not at current levels until 2009 (a year after the current study).<sup>61</sup>

**Spain (2012), Jimenez and Beanco.** This study examines the market shares of HSR and airlines in Spain over the period of 1999–2009, which excludes consideration of some of the more recently opened lines in that country.<sup>62</sup> However, the focus of this study is more on the airlines' reaction to the introduction of HSR competition than on the modal shift that occurred during the period of study. The study mentions in passing, however, that HSR market share of the Madrid–Barcelona increased threefold over the ten years, doubled for Madrid–Malaga, and captured nearly the entire Madrid–Zaragoza market (36). The authors conclude: “the advent of HSR has increased...transport demand substantially; [yet,] in spite of...the increase, the share of air transport in the total market has declined” (40).



**Spain (2012), Pita et al.** This brief study examines how airline service was affected by the introduction of HSR (and other events, including the opening of Spanish domestic air markets to international competition) in various route/markets in Spain during various time periods.<sup>63</sup> Of particular relevance to the topic of modal shift is the authors' analysis of mode shares before and after HSR on the Madrid–Barcelona and the Madrid–Seville routes. In both instances, the authors identify a significant shift to HSR service. The Barcelona route captured 47% of the airlines' share in just one year; the Seville route captured 82% in the same amount of time.

However, the authors contend that the Barcelona market share, while impressive, is somewhat lower than comparable routes in Western Europe. They attribute this ostensible shortfall to the fact that the Barcelona air route was more firmly established than many European counterparts—Madrid to Barcelona was the busiest air route in Europe in 2007, with nearly 5 million passengers. There is no additional data or methodology supplied in the study to support this hypothesis.

The lower market share of the Barcelona route may well have something to do with the consolidation of the air service there. However, the authors make no mention of the possible impact of the world economic slowdown and the near-collapse the Spanish economy adjacent to that period. More recent data might shed additional light on this explanation. In any event, this study provides ample evidence that the Spanish HSR system gained significant amounts of modal shift shortly after being introduced on the two routes in the analysis.

**Italy (2013), Cascetta et al.** A second and more recent study regarding the Italian system by Cascetta et al. (with one of the same researchers from the previous study of the Rome–Naples HSR line) provides a system-level ex post analysis of the entire HSR system.<sup>64</sup> The study uses a combination of pre- and post-data sources, including on-board counts, a “retrospective” survey of Rome–Naples travelers (apparently the same one analyzed in the previous study: Cascetta 2011) and a more recent survey of a stratified sample from various city pairs.<sup>65</sup>

The most immediate finding was that between 2009 and 2011, HSR ridership in Italy increased by 40% in the areas studied (58), primarily due to the completion of the HSR network between the cities of Salerno, Milan, and Turin. With respect to modal shift, Cascetta et al. stated that in the same areas, domestic air traffic was essentially flat and automobile traffic decreased 3%. The authors concluded that “the introduction of the new HSR services had a direct impact on the modal split of long-distance travel demand” (55).

Focusing on the Rome–Naples route, served by the newest HSR link, the share of automobile trips declined from 45% to 37%, HSR increased from 37% to 49%, air transportation remained flat, and intercity rail decreased from 9% to 6% (55). Cascetta et al. noted that the share and number of air trips did not decline due to the fact that the Italian HSR network primarily serves shorter routes “where air demand is negligible” (56).

In sum, this article provides considerable evidence that the Italian market share of HSR grew considerably in response to new HSR service. It may also support the notion that

modal share may fluctuate relatively quickly and that a longer-term perspective may be necessary to judge it in a given context.

**Taiwan (2013), Jen and Su.** Jen and Su focus on the situation for airlines in Taiwan after the “HSR revolution led to a redistribution of market share in the long-distance travel market.”<sup>66</sup> The article presents essentially the same market share information as that of the Cheng (2010) article reviewed earlier in this paper, and follows the development of HSR modal shift in Taiwan only between 2006 and 2007. Because HSR service was both cheaper and faster than domestic airline service, drastic reductions in air service occurred, even in the longest route (Taipei–Kaohsiung), the number of passengers decreased by nearly 50% (141). On the whole, this study confirms the quantum shift from air to HSR in Taiwan after introduction of HSR, but offers little new insight and does not provide modal shift information concerning automobiles and buses. Given that ridership has increased dramatically since collection of the data presented in this study, it would be helpful to see how modal shift has transpired in Taiwan.

**Korea (2014), Jung and Yoo.** This article addresses airline passenger service in Korea in the wake of the introduction of HSR service between Seoul and Busan in 2010.<sup>67</sup> It is based on a survey of 3,834 passengers conducted over a three-week period at the Incheon International Airport near Seoul in 2012. The survey was used to identify passenger preferences for mode of transportation. Similar to other mode preference survey studies reviewed in this paper, Jung and Yoo modeled passenger preference as a function of time, cost, access to stations or airport, terminal waiting time, and other factors. Similar to previous studies, the authors were interested in examining the differences between business and leisure travelers in mode preference. They informally hypothesized that business travelers would be more sensitive to travel time and leisure travelers would be more sensitive to price.

As predicted, the variables of fare, travel time and access time were found to be associated with mode choice in a statistically significant manner. Also consistent with expectations, business passengers were found to be more responsive to access time (i.e., frequency of service) than were leisure travelers, and less responsive to fares and access costs (46–47). The authors conclude from these findings that improving access time is an important consideration for transportation managers seeking to gain market share of business travelers (43).

Thus, the article tends to confirm what previous research had already concluded about the factors likely to affect the choice between HSR and air travel. The authors do not extend the application of their findings to determine precisely how well HSR performs compared with air travel in Korea. Nor do they attempt to identify whether and how HSR competes with driving.

**Milan–Rome, Italy (2014), Mancuso.** In this extremely technical piece, Mancuso analyzes mode choice with respect to the Milan–Rome service corridor.<sup>68</sup> However, the precise nature of the data—including whether it was obtained by survey or from archives—is not evident from the article. Mancuso states that this route is unique in that it exemplifies both intermodal (air vs. HSR) and intramodal competition (HSR provider Trenitalia vs. a

new, private company, Nuovo Trasporto Viaggiatori (NTV), as well as between multiple air carriers). Curiously, however, the data for the analysis dates from 2008, before the new transportation market situation reportedly began in 2012.

Mancuso's model suggests that under the terms of the new competitive environment, both the existing airline and the existing (national) HSR service will lose significant amounts of their shares of both the business and leisure travel market, whereas both the new, private HSR service and a new, low-cost air carrier (EasyJet) will gain market share. The automobile also loses some market share in Mancuso's model. However, the article does not make it clear whether HSR as a whole will gain or lose market share under the new competitive environment.

As this article does not really use ex post data, what it provides is actually more of a forecast based on older data. Given the situation it posits—more than one HSR service provider and the introduction of a new, low-cost air carrier—its implications for other markets seem limited. It will be interesting to see how accurate Mancuso's model proves to be once ex post data are available.

**China (2014), Xu, et al.** This article contains a very brief analysis of the market shares of air service and HSR in China.<sup>69</sup> However, it is based on travel time and fares and is not directly linked to actual passenger behavior. Xu, et al. state that the number of HSR passengers in China increased from about one billion in 2004 to 1.89 billion in 2012, whereas air served just 0.32 billion passengers in 2012 (the article provides no air passenger data for 2004). HSR dominates markets where routes are within 1000 kilometers, and air service tends to be more attractive to passengers at routes longer than 1300 km. The two modes are most competitive at trip lengths between 1000 and 1300 km. However, newer, faster trains with speeds of up to 350 km/hour will tend to increase the attractiveness of HSR, even on longer routes. Transportation via automobile tends to be more expensive than HSR service in China, limiting its competitiveness. Overall, the article touches only briefly on the relationship between HSR and other modes in China, and on what drives respective modal shares. It does, however, illustrate the vast role that HSR plays in the world's most populous country.

**Taiwan (2014) Li et al.** Li, et al. use monthly ridership data to provide an analysis of "demand adaptation" to HSR in Taiwan.<sup>70</sup> They also compare ridership with air travel demand for the same period. This research represents the only study reviewed for this paper that uses multiple data points in a time series analysis, rather than simple before-and-after or after-only survey data. In theory, this sort of time series analysis may have fewer potential problems with internal validity, as the multiple data points allow for use of control variables. The study is able to introduce factors that other studies reviewed in this paper have not been able to provide, such as macroeconomic trends (unemployment rate, for example) and fluctuations in the price of gasoline, etc.

The analysis covers the period from the opening of the Taiwanese HSR service in January 2007 through December 2012—a longer period than the other ex post study reviewed in this paper (Chen 2012)—thus spanning a period of economic decline as well as one of economic improvement. During that period, Li, et al. (6) report that total HSR ridership

increased from 169.6 million to 220 million (+30%), whereas the number of domestic air travelers decreased from 19.29 million to 10.68 passengers (-44%). (The article notes that in 2012, flights to Taiwan's west coast were suspended.)

During the same period, the number of express bus riders declined by 22% to 197 million, but the number of private vehicles stayed approximately constant (7) at around 480 million. The authors do not offer any explanation for the apparent failure of HSR to decrease use of automobiles along the HSR route, although it is possible that most automobile trips are relatively shorter than most of the HSR trips; the study does not describe the source or nature of the automobile data.

The primary purpose of the paper is to predict changes in HSR ridership over time using a SARIMA (seasonal autoregressive integrated moving average) model with a number of explanatory variables, which include total population, unemployment rate, the ratio of gross domestic product to fuel prices, car ownership, the month of the Chinese New Year, the month of summer vacation, and what the authors call "adaptation effects" (14).

Although most of the variables in the analysis have little direct bearing on modal shift, the fact that car ownership is significantly and negatively associated with HSR ridership implies that the more Taiwanese car owners, the fewer the number of HSR riders. In other words, increasing car ownership in Taiwan appears to be a drag on HSR ridership (13).

The "adaptation effects" are apparently a surrogate for a variety of social reactions to the availability of HSR, such as people learning about the speed, reliability, and service frequency of HSR. The authors mention that, increasingly, business trips are conducted in a single day that involves trips between major HSR stations. From the standpoint of understanding modal shift, these effects are intriguing, although not fully explored in the article. It seems possible that some of the "effects" might be induced demand for HSR, and that the Taiwanese are choosing to travel more as the mode's utility becomes increasingly clear. However, some of this variable probably also represents modal shift: The Taiwanese increasingly chose HSR as they realized how attractive it is vis-à-vis air travel. The article does not provide enough explanation or statistical detail about the "adaptation effects" to fully explain what they comprise or imply for HSR mode shift.

As a whole, this article provides a useful and relatively recent overview of modal shift in Taiwan. HSR has clearly supplanted air travel as a means of traversing the island of Taiwan. However, the extent to which it has replaced use of automobiles is less clear, since automobiles appear to be making the same number of trips. The time series data and model used in the study stand out as providing more scientific rigor than most of the research designs embodied in the articles reviewed in this paper. The key finding that so-called "adaptation effects" are one of major drivers of HSR demand certainly bears further investigation; the extent to which it involves modal shift is unknown. As the article states, "one might conclude that the [HSR system] is slowly changing the 'mobility culture' of private as well as business people of the country" (13).

**Multiple systems (2014), Albalade et al.** Albalade et al. seek to specify the amount and quality of competition between HSR and air transportation in Europe.<sup>71</sup> They review some

of the same data regarding modal shift that appears in other articles covered in this paper. They also offer an analysis of the number of airline seats available due to the presence of absence of HSR stations in four countries: France, Germany, Italy, and Spain. These countries were selected because of they contain a number of cities with and without HSR train service.

The analysis models the number of airline seats available on a given route as a function of (1) whether or not HSR service is available; (2) whether or not the route includes an airport that serves as the hub of a network airlines; (3) the distance served by the route; (4) population of origin and destination; and (5) average GDP of the countries served.

In terms of vying for modal share, the authors note that France is the country with the highest proportion of air routes with comparable HSR service—40% of the air routes that serve France are subject to intermodal competition. The corresponding figure for Spain, Germany, and Italy is lower than 10%. This result suggests that although HSR is quite commonplace in Europe, it has not permeated many cities that have airports.

The results confirm that “airlines subject to competition from HSR do decrease the number of seats offered in the route” (13). However, with the exception of Spain, they apparently do not reduce the number of flights, which the authors interpret to mean that airlines seek to maintain competition by keeping frequency of service high, so as not to further lose competitiveness (13). Moreover, the attractiveness of HSR is more pronounced in cities with airports that are airline hubs: “...reduction of air service in hub airports is generally higher than in no-hub airports.” (13). The authors reason that airlines at hub airports could benefit by using HSR connections as complements to their more profitable long-haul flights.

Using a different form of data than the other cities in this review, this study serves to validate the notion that HSR reduces airline service, and does so more dramatically in route-pairs of cities that include a hub airport.



## VII. SUMMARY OF RECENT EVIDENCE OF MODAL SHIFT USING ORIGINAL DATA

Recent empirical research using original data is extremely consistent with the earlier research addressed in the previous section: Each study reviewed here contains evidence of significant amounts of modal shift to HSR from other modes. However, given the breadth of contexts, data, and methods used, these studies add considerable fineness to the general conclusion that HSR successfully competes with other modes. Essentially, using different research designs and metrics, these studies, too, affirm significant or dramatic mode shifts wherever mode shift has been systematically evaluated.

Additionally, the more recent studies provide more insight into Asian markets than do most of the secondary analyses. The ability of HSR to draw significant market share—and frequently dominate markets—in Taiwan, Korea, and China are documented. The research suggests that these systems are not yet as mature as their European counterparts and might be expected to add ridership and market share as they expand and become more a part of the fabric of their respective nations and cities. The summary characteristics of original data analysis articles reviewed here are collected in Table 2.

**Table 2. Summary of Studies Using Primarily Original Data**

Study Author(s)	Published Year	Span of Data (years)*	Countries	Modes	Primary Methodology
Behrens and Pels	2010	2003–2009	UK–France (London–Paris)	Air	Logistic regression of survey responses
Cheng	2010	2006–2008	Taiwan	Air, bus, car, train	Ridership
Fu, et al.	2011	2005–2010	China	Air	Ridership
Dobruszkes	2011	1991–2009	France, Germany, UK,	Air	Ridership
Cascetta et al.	2011	2008	Italy	Air	Logistic regression of survey responses
Jimenez and Beanco	2012	1999–2009	Spain	Air	Market share
Pita, et al.	2012	1974–2009	Spain	Air	Market share
Cascetta et al.	2013	2009–2011	Italy	Air, bus, car, train	Market share
Jen and Su	2013	2006–2007	Taiwan	Air, bus, car, train	Market share
Jung and Yoo	2014	2012	Korea	Air	Regression of survey responses
Mancuso	2014	2008	Italy (Milan–Rome)	Air, car, train, HSR	Discrete choice modeling
Li, et al.	2014	2007–2012	Taiwan	Air, bus, car, train	Time series analysis
Albalate, et al.	2014	2002–2010	Spain, Italy, France, Germany	Air	Regression of ridership

\* Denotes earliest and most recent data used in analysis.

Collectively, these studies help validate the older, frequently anecdotal forms of research on the study of modal shift by increasing the number of data points, incorporating new and sometimes improved research designs, and extending their geographic scope. Taken as a whole, the empirical and secondary research comprises a form of “multiplism” that enhances the validity of general findings. Multiplism refers to using a diversity of data sources, research designs, theoretical perspectives, and other components to address a policy question.<sup>72</sup>

Despite the advances in market share created by modal shift from air service to HSR, the literature documents relatively little about HSR’s ability to draw modal share from automobiles. Most of what is summarized in this paper suggests that HSR service does reduce use of automobiles, although the magnitude of the shift appears to be relatively lower than that garnered by air service in those few markets studied.

Although each study adds to the general canon of what is known about the competitiveness of HSR, several add to our understanding how, why, and under which circumstances it is most competitive. Some of these details were broached by the studies of secondary analysis and are affirmed here, such as the importance of total travel time, frequency of service, and route length. Some of the recent empirical studies also seem to point to the following factors:

- HSR tends to attract more potential airline passengers in cities with airports that serve as airline hubs (Albalate, 2014)
- HSR is much more competitive where it exists; many European airports do not have to compete directly with HSR (Albalate 2014)
- HSR market share can continue to increase over time, and reflect “adaptation effects” of increased market share as people learn how to exploit its benefits (Li et al.)
- Business travelers tend to value time, whereas leisure travelers are more sensitive to fares, which may affect the attractiveness of HSR to passengers in different travel markets (Behrens and Pels; Jung and Yoo)



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## VIII. BROAD IMPLICATIONS OF RESEARCH FOR CALIFORNIA HSR

Although the vast bulk of the ex post findings suggest that HSR is generally competitive and attracts many riders from existing modes, relatively little of the research reviewed for this study was designed to offer specific or direct insight into how the California system might fare.

Coogan's findings documented significant gains in rail market share from airline service and cars by the (non-express speed) Acela line in the Northeast Corridor of the US. More specifically, Behrens and Pels suggest that their research might be applicable to the planned San Francisco–Los Angeles HSR route. They suggest that many airlines will have trouble competing with HSR in this market because they will not be able to increase their service frequency by very much and will have difficulty lowering their prices to match HSR. However, this is assuming that the London–Paris market surveyed this study is substantially similar to the California market, among other things. Behrens and Pels do not use their model to calculate specific market shares or modal shift. Albalade and Bel (2012) note that “the HSR in California is the only site likely to obtain volumes of demand close to those on the most successful routes elsewhere, such as the Paris–Lyon route, which served 25 million passengers in 2008” (p. 337).

In many ways, the general findings from both the secondary analyses and the more recent empirical studies place the California system in a very favorable position with respect to achieving comparable amounts of modal shift. It is beyond the scope of this study to determine exactly how the California HSR system aligns with respect to the many specific variables identified by the research as having the potential to influence mode choice. However, with respect to a handful of key characteristics, the geography and demography of the planned system place it within a “sweet spot” of factors known to enhance HSR competitiveness. Among these, the California system may potentially encompass the following:

- Middle-range route distance (approximately 800 km)
- Density of cities served
- Planned travel times under three hours
- Planned accessibility of stations in major urban centers
- Planned high frequency of service
- Planned connectivity to other modes
- Projected congestion and delays associated with other modes

The vast majority of existing research is tied to the HSR systems of other countries and transportation systems. The underlying assumption of such research is that it is acceptably safe to infer from the results obtained in these systems to other systems, such as the

planned California route. However, the research designs used in these studies do not specifically guarantee with any certainty that the conditions in California (or anywhere else) are or will be similar enough to produce the same results. However, the findings from the research are highly consistent with the expectation that the California system is well positioned to achieve comparable modal shift. The fact that HSR systems have proven competitive in such a variety of settings in industrialized countries, as documented, with a variety of data and research approaches, in the studies compiled here, gives reason to believe that this assumption is reasonably well grounded.

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## IX. CONCLUSION

This paper represents a compilation and distillation of more recent existing academic research concerning modal shift to HSR from other modes. Some of the research entails secondary use or analysis of previous studies; the rest was based on original research. The overwhelming pattern of findings that emerged from this review was that existing research indicates that HSR is extremely competitive with other modes and that introduction of HSR nearly always results in significant decreases in the modal shares of other modes.

The research tends to be focused on modal shift to HSR systems from airline transport. That is not to say that automobile and bus use are not responsive to competition from HSR; it is a reflection of the fact that more data are available or have been developed for air travel. The research that has been conducted does point to modal share being gained by HSR at the expense of those other modes, but much less is known about the travel conditions under which HSR is more or less effective in doing so.

The international experience provides evidence of a varying amount of modal shift when new HSR service comes on line. Although some evidence reviewed here suggests that the largest amount of shift occurs almost immediately after introduction of HSR service, other sources provide evidence of a slower growth process. This seems to be true in Taiwan, where initially disappointing ridership figures were tripled within a few years of the initial introduction of HSR service. The difference is reflected in the findings from two studies reported here, Cheng (2010) and Li et al (2014). Several themes emerge from the research regarding what factors explain the amount of market share captured by HSR from other modes, including: length of route in terms of time and distance, frequency of service, access and egress time, and number of transfers, among others.

Although HSR introduction often has immediate, profound impact, there is evidence that in some markets the public “learns” how competitive it can be. Growth of HSR routes in a network may also delay the overall impact of the mode. In Taiwan, Jen and Sue attribute the more recent growth in HSR ridership and market share to “adaptation effects,” reflecting the public’s ability to learn how to exploit HSR service.

How well will these findings translate to the intermodal competitiveness of the planned California system? The planned California HSR seems to encompass many of the key variables with respect to capturing market share, such as travel distance and time. The underlying assumption of HSR modal shift research is that results can be readily applied to other countries, but there are known differences in travel and travelers across different countries. The value of time, cost of driving, and macroeconomic conditions in the US and California may positively (or negatively) impact the modal share of HSR service.



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## ABBREVIATIONS AND ACRONYMS

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ACRP	Airport Cooperative Research Program
AV/AC	Rete Alta Velocità
AVE	Velocidad Española
FRA	Federal Railroad Administration
HSR	High-Speed Rail
ICE	Intercity-Express
TCRP	Transit Cooperative Research Program
TGV	Train à Grande Vitesse
TRB	Transportation Research Board
TRID	Transport Research International Documentation

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