INVESTING IN HIGH-SPEED PASSENGER RAIL NETWORKS: INSIGHTS FROM COMPLEX INTERNATIONAL SUPPLY CHAIN, TECHNOLOGIES AND MULTIPRODUCT FIRMS

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SUMMARY

The growth of population and business during the rapid urbanization process in the twentieth century has generated significant demand for transportation. As the demands have grown, road and air transportation are suffering from significant congestion and delays. Continuing expansion of highways and airports has become both expensive and difficult, along with not being able to provide adequate solutions to the growing congestion. One alternative, which is being pursued by many countries, is to invest in efficient high-speed rail networks to meet the pressing demand for mass passenger transportation. This alternative is also one that may have beneficial impacts by reducing energy consumption and alleviating some of the environmental concerns. But to make these infrastructure investments, governments need to make difficult decisions due to the complexity of the industry and technologies involved.

This thesis examines decision making by government for such investments. In order to carefully study the industry, we use a two part approach. First, we examine the HSR industry supply-chain. We create a detailed taxonomy of the industry supply-chain and highlight various aspects of the advanced technologies being used, the sophisticated multiproduct nature of the firms, and the diverse international location of the companies. Second, we gather information on all the international HSR contracts between 2001-2011. These contracts enable us to examine business strategies pursued by the major HSR trainset suppliers and component manufacturers, insights into the size of the orders and type of trainsets being delivered, and the formation of partnerships and collaborations to meet the complex demands imposed by Governments when they invite bids for these expensive projects.

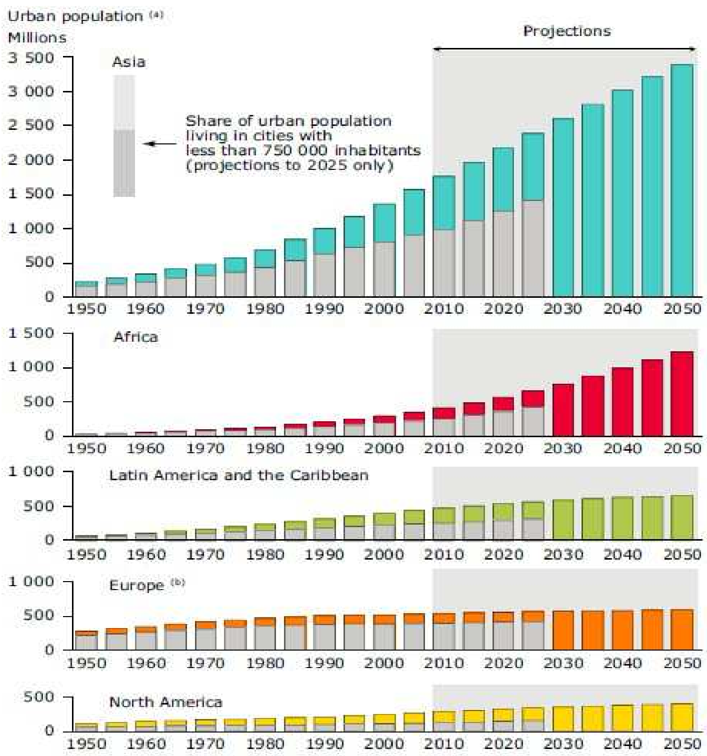
A detailed examination of the supply-chain shows that the core technologies and competencies are highly concentrated in those countries which historically have had high demand for high-speed rail. Germany, Japan, France, for example, have the highest number of trainset and component suppliers. In more recent years, South Korea and China have emerged as the new frontiers of trainset and components suppliers. This implies that countries who are outside of this group are highly dependent on either importing these technologies and investments or make a concerted effort to develop them via partnerships and technology transfer agreements.

Our examination of contracts shows that the size of HSR investment order is important for both business and government strategy. The order size determines the extent of domestic content and production. While many components will inevitably be imported, a larger order size may allow for various components to be manufactured domestically. Order size also appears to influence the nature of partnerships among the firms in the industry. We observe a growing number of HSR investment partnerships among trainset suppliers over time, possibly due to the need to pool risk in these highly complex and uncertain investments, as well as the changing competitive dynamic of HSR markets.

CHAPTER 1

INTRODUCTION

Urban areas worldwide are becoming increasingly larger and highly congested. The twentieth century witnessed the rapid urbanization of the world's population. As displayed in Figure 1, the urban population increased dramatically from 1950 to 2010. The global proportion of urban population increased from a mere 13 per cent in 1900 to 29 per cent in 1950 and, according to the 2007 Revision of World Urbanization Prospects, reached 49 per cent in 2007. Based on the projections, the proportion will reach 69.6 per cent by 2050. At the same time, cities are reaching unprecedented sizes and the number of megacities is rising across the globe.

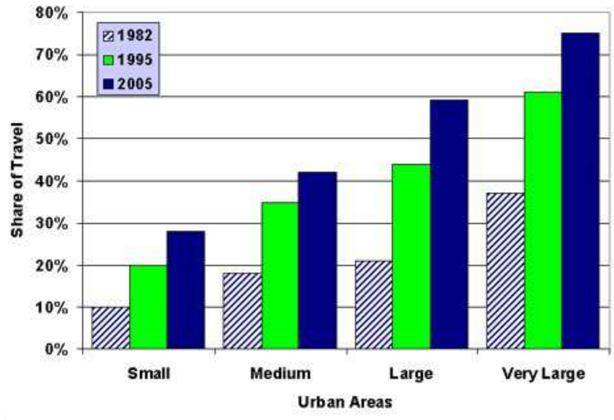


Source: UN population division (2010).

Figure 1: Urban population trend

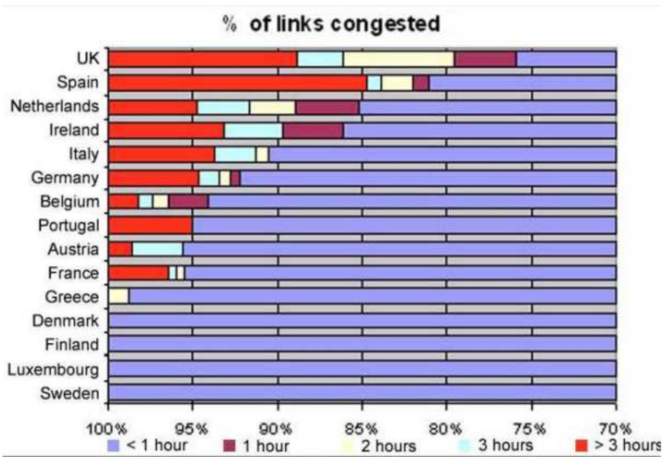
The growth of population and businesses during the urbanization process generate significant demand for transportation. Depending on the locations, passenger transit between urban areas depends on road, air and rail travel. Within a country, for cities which are relatively far apart from each other, such as Atlanta and New York or Beijing and Shanghai, air transportation is generally the more efficient and preferred mode of travel. For metropolitan areas that are not too far away, such as Washington D.C. and NYC, road, rail and air travel are all viable. Therefore, depending on proximity, we can get greater demand for all three modes of transportation or specific ones such as road or air. Due to growing urban populations and high demand for transportation, transportation by air and auto is increasingly suffering from severe congestion and delays.

Road traffic congestion is a worldwide problem due to road traffic growing at a faster rate than the road capacity. Road congestion results in significant costs due to wasted time and fuel costs. According to TTI (1999), more than 31 percent of urban freeways in the US are congested and is becoming worse every year. Traffic congestion costs motorists more than $72 billion a year. Americans waste more than 4.3 million hours per stuck in traffic (approximately 34 hours per driver) annually. Figure 2 shows 63% of travel during peak hours is congested. As expected, traffic congestion is worse in very large urban areas – 75% of travel in very large urban areas experienced congestion in 2005, compared to 28% in small urban areas. Many European and Asian countries are also experiencing severe traffic congestion (see figure 3). Besides congestion, air pollution and fuel prices all prevent the further car use and make it necessary to develop alternative modes for transportation increase.



Source: Texas Transportation Institute (1999).

Figure 2: Share of travel in congested area[1]



Source: UN population division (2010).

Figure 3: Road congestion worldwide

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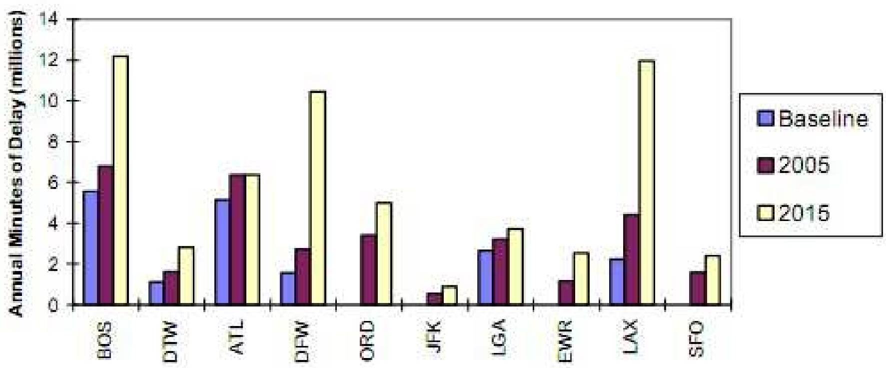
[1]Small Urban Areas – Less than 500,000 population.
Medium Urban Areas – Over 500,000 but less than 1 million population.
Large Urban Areas – Over 1 million and less than 3 million population.
Very Large Urban Areas – Over 3 million population.

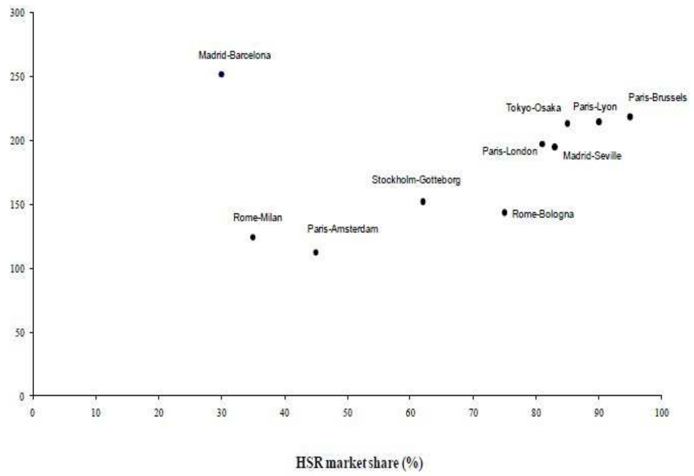
Air traffic has become popular today because of the maturation of the air travel industry, better hub-and-spoke networks, and the decline in prices in real terms from the 1970s to today (US Department of Transportation, 1997). As with roads, the expansion of air traffic has far outpaced the growth in airport capacity and this imbalance between demand and capacity has led to significant air traffic congestion and flight delays, with delays starting at congested airport. As demonstrated in Figure 4, there are significant delays caused by the congestion in many U.S. airports. LMI (1997) predicts an increase of 78 million minutes of delay for U.S. air travel between 1996 and 2005, and another 33 million minutes by 2010. The air-traffic capacity is limited due to the constraints on runway (spacing between the planes for safety), gate availability and air-traffic control. For most cities, like London, which is already highly congested with very little scope for airport expanding, continuing expanding the airport is expensive and sometimes impossible.



Source: Kostiuk, Gaier and Long (1998).

Figure 4: Airport delay forecast for several of the busiest US airports

As for the rail transportation, traditional rail is often too slow to compete with the automobile and air transportation options. We need to increase the maximum speed to above 186 mph for trip distance above 500 km or at least 125 mph for shorter distance trip to maintain competitive times relative to air transport. Figure 5 shows the rail lines speed and the corresponding market shares. As the train speeds increase, the rail market share is likely to increase with that as some passengers who earlier used road or air now travel using the higher-speed trains.



Source: De Rus (2010).

Figure 5: Rail market share and railway speed

The above considerations related to significant congestion, along with rising fuel prices and concerns about environmental degradation, are resulting in many governments and regions to seriously rethink strategies for enabling more efficient passenger mass transit systems.

One of the solutions increasingly considered by national governments and regions is high-speed rail (HSR) connections to facilitate rapid passenger transit across important urban areas. This realization is partly based on the necessity to alleviate congestion and become more fuel-efficient, but also on observing success stories of such networks that have existed for a long time in Europe and Japan. Japan introduced the world’s first New HSR—the Shinkansen (or “bullet train”)—in 1964; Japan's Shinkansen success in mass transit, together with rising oil prices, a growing environmental interest, and rising traffic congestion on the roads, contributed to a revival for the idea high-speed rail in Europe. In Continental Europe, several countries started to build new high-speed lines during the 1970s: Italy's Direttissima between Rome and Florence; Western Germany’s Hannover–Würzburg and Stuttgart–Mannheim lines; and France’s Paris–Lyon TGV line. Countries continue to expand or start the HSR networks due to these successes. By 2004, Japan had been expanded its HSR network to 2,387.5km. Between 1996 and 2004, there was a sharp increase of 62.5% in the HSR industry in the number of passengers in France. Germany demonstrated a massive increase of 132.8% in the same period. In addition, China inaugurated her first (HSR) in 2008 between Beijing and Tianjing. Today, China has the world largest HSR networks with about 6,012 mile of routes in service as of June 2011 including 2,184 miles of rail lines with top speeds of 186 mph

While HSR offers a potential solution, the scale of investments needed to firmly establish such infrastructure has proved to be a daunting task. This is made even more challenging due to the fact that the components supply-chain for this industry is highly complex, and populated by sophisticated multiproduct firms on a global scale. The investment costs, in conjunction with the complex technologies involved, imply difficult investment decisions faced by Governments.

Our primary objective in this paper is to analyze the complex international supply-chain, the advanced technologies involved and the sophisticated multiproduct nature of the firms to provide an analysis of optimal decision-making by Governments for such infrastructure investments.

This thesis is organized as follows. First, we establish the background against which HSR investments are being considered in many countries with established mature HSR networks. In this discussion we examine factors related to emerging urban mega-regions, congestion, over-utilized existing modes of transit such as roads and air travel, and examine the need for rethinking optimal solutions to mass transportation systems. Second, we briefly describe the HSR industry, and the characteristics and magnitude of investments needed, to establish reliable service and a meaningful network. Third, we detail the HSR final product, and provide taxonomy of the complex international supply-chain. This allows us to examine in detail the characteristics of the components, technologies and firms, and their diverse global locations.

Fourth, we analyze the cost and R&D portfolios of the multiproduct firms in depth. Fifth, following up on the above analysis, we briefly examine some strategies employed by the major HSR trainset related to partnerships in bidding for contracts in international jurisdictions, and technology transfer agreements. Sixth, based on the details of the supply-chain, technologies and firms, we provide an analysis of the extent to which new HSR investments by countries can take place primarily based on domestic content and production versus imported content.

CHAPTER 2

NEED FOR HSR INVESTMENT

We examine the background against which HSR investments are being considered in many countries. In this discussion we examine factors related to emerging urban mega-regions, congestion, over-utilized existing modes of transit such as roads and air travel, and examine the need for rethinking optimal solutions for mass transportation systems.

The bulk of New HSR research and development has taken place after World War II in Japan, France, and Germany. Japan introduced the world's first New HSR—the Shinkansen (or "bullet train")—in 1964; France followed with its train à grande vitesse (TGV), and Germany with its Intercity Express (ICE). Other countries have followed suit. Sourth Korea boasts a new HSR system and opened in 2004. China inaugurated the first HSR in 2007. Although adhering to sometimes divergent design principles, new HSR systems have uniformly succeeded in reducing journey times and capturing increased traffic among the major cities served (Table 1).

Table 1: Transportation impact of HSR

HSR system	Impacts after HSR operation	Referred literature
Japan Shinkansen	The traffic of Japan's Sanyo Shinkansen was diverted by (1) 23% from air (2) 16% from cars and buses (3) 6% induced demand	Givoni (2006)
France TGV	After the line of TGV Sud-Est, air traffic between Paris and Lyon decreased 50%. After the line of TGV Atlantique, air carrier traffic decreased 17%.	Vickerman (1997)
	The traffic of TGV Sud-Est from Paris to Lyon is derived from as follows: (1) 24% from air (2) 37% from cars and buses	Givoni (2006)
Germany ICE	About 12% of traffic transferred from air and roads.	Vickerman (1997)
Spain AVE	The demand (Madrid–Sevilla) for air carriers decreased 60%, and the demand diverted from the other modes is as follows: (1) transferred from air 32%, (2) transferred from buses 25%, (3) transferred from conventional railway 14%.	Vickerman (1997)
	The market share of domestic air carriers decreased from 89% to 36–47% (Madrid to Barcelona).	Lopez-Pita and Robuste (2005)
South Korea KTX	(1) 28% of air passengers preferred to travel by air after the opening of KTX. (2) Air traffic dropped by 20–30% after KTX operation and the traffic of the short-distance route (less than 100 km) increased about 20%.	Park and Ha (2006)

Source: Cheng (2010).

In this part we briefly examine HSR implementations in countries such as Japan, France, Germany, Spain, and China. All these countries have built extensive HSR network to reduce rail travel time between the main cities.

2.1 Japan

Japan is the pioneer in HSR industry. Japan initiated the Tōkaidō Shinkansen project to promote mobility demand in the corridor between Tokyo to Osaka due to the rapid economic growth experienced after World War II. In this densely populated country, especially the 45-million-people area between Tokyo and Osaka, both the roads and narrow-gauge rail traffic was highly congested even during the 1950s. The route between Tokyo to Osaka was already so densely populated and rail- oriented that highway development would be extremely costly and a single additional line between Tokyo and Osaka could bring service to over half the nation's population. The construction of the new line could expand the capacity of the existing overcrowded rail corridor. Since 1987 Japan continued to expand its HSR networks to stimulate the economy with infrastructure spending during the economic slowdown of 1990s, which was supported by the government.

Japan has several large metropolitan centers located a few hundred kilometers apart from each other with a high demand for travel between them, which has favored HSR. For example, the Tokaido line connects Tokyo, Osaka and Nagoya, Japan’s biggest cities (approximately 30, 16 and 8.5 million inhabitants, respectively), which are a few hundred kilometers apart from each other (Tokyo–Osaka 560 km with Nagoya located on the route 342 km from Tokyo) and generate high demand for travel between them (132 million passengers on the Tokaido Shinkansen in 2002; Central Japan Railway Company, 2003).

After the world first HSR, Tōkaidō-Shinkansen, started service in 1964, the travel time from Tokyo to Osaka was reduced to only four hours or less from the previous six hours and 40 minutes. The increasing speed enabled passengers to make day trips and significantly changed the lifestyle of Japanese business and leisure travelers. The Tōkaidō-Shinkansen line is the most heavily traveled high speed line in the world, carrying 138 million people in 2009, and the entire Shinkansen network, carrying 322 million. This line transports more passengers than all other high speed rail lines in the world combined.

2.2 France

France is the second country, following Japan, to create the mature HSR network. The main line between Paris and Lyon was projected to run out of capacity by 1970. The level of congestion on the rail link joining Paris and Lyon – the gateway to south-east France - led to the introduction of first HSR service in France with the building of a new, separate network in 1981.

France has relative low population density and the Paris plays a central role in business and politics. The French HSR network has been developed as spokes radiating outward from the central Paris hub. The subsequent expansion of the HSR network was carried out mainly to serve corridors with sufficient traffic, connecting cities of significant size.

The TGVs brought the cities within three hours of one another. The dramatically reduced travel time caused explosion in ridership. It was the commercial success that inspired other countries to expand or start high speed rail networks. The French rail operating company, SNCF, reports that its TGVs have taken the dominant share of the air-rail travel market in several of the high speed corridors, taking over 90% in the Paris-Lyon market. The total number of rail passengers increased following its inauguration, rising from 12.5 million in 1980 to 22.9 million in 1992 – 18.9 million of whom were TGV passengers (Vickerman, 1997).

2.3 Germany

Germany is the third country to develop the HSR networks. Germany opened its first high speed rail line in 1991. Its high speed trains are called InterCity Express (ICE). The rationale underpinning the HSR network was somewhat different in Germany. Given the west-east orientation of the rail network constructed before WWII and the then current north-south patterns of industrial cooperation, Germany sought to reform the network so as to facilitate freight transportation from the northern ports to the southern industrial territories. For this reason, the first two neubaustrecken – new lines - were those linking Hannover and Würzburg and Mannheim and Stuttgart, respectively. The main goal was to solve congestion problems in certain corridors and to improve north-south freight traffic.

The German InterCity Express (ICE) arrived a decade after the French. There are several reasons for this delay. Germany has a mountainous terrain, which increases the complexity of building the networks. Besides that, it proved considerably more complicated to obtain the necessary legal and political approval for building to start. Since Germany has denser and more evenly distributed population, its network has been developed to connect many hubs, which varies significantly from France's hub-and-spoke network. Also, Germany's high speed trains have more stops than those in France, whose system emphasizes connecting distant city-pairs with few intermediate stops. These considerations have led German strategy to be significantly different from the models adopted by Japan and France. Germany choose to put more emphasis on upgrading existing rail lines to accommodate higher speed service, and less emphasis on building new high speed lines. Thus, the network is shared by high-speed and more conventional passenger trains together with freight trains. One result is that Germany's high speed trains have longer average trip times than do those of France and Japan over comparable distances, though the HSR networks still offers commercial speed gains of around 60% (Albalate and Bel, 2010).

Germany's multi-purpose HSR networks achieved significant success. The average increase in the market share achieved by the introduction of the HSR was 11%, while the average net revenue per train-mile of the ICE service was 1.7 times higher than the average for its other long distance services (Ellwanger and Wilckens, 1993). However, from a financial perspective, building delays and Germany's topography resulted in higher-than expected construction cost overruns, as well as operating deficits and increasing debt burdens, which increased the financial pressures to reform the system.

2.4 Spain

The first Spanish HSR link, the AVE, was inaugurated in 1992 between the capital Madrid and Seville. Like France, its population density is relatively low by European standards, and, except for Madrid, the capital and largest city, which is located in the center of the country, the population is largely concentrated near the coasts. In Spain, government spending on rail infrastructure surpassed spending on road in 2003. The high speed rail network is seen as a way of improving mobility with less environmental impact than automobile or air travel, and as a way of promoting the development of Spain's regions, as well as creating transportation-related employment.

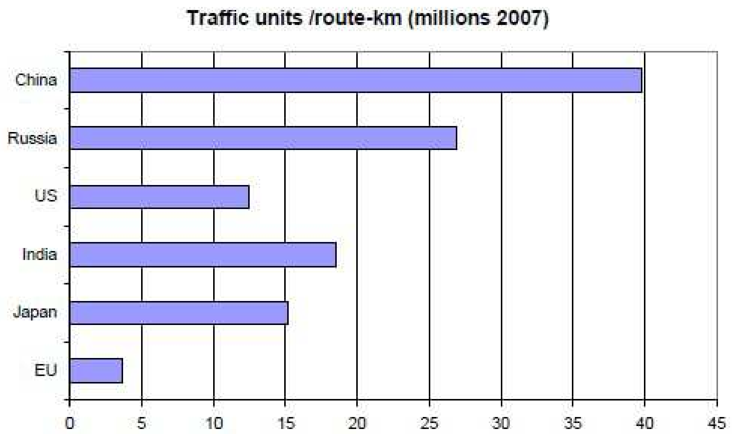
Spain decided to construct a separate HSR network, as had been done earlier in Japan and France. Moreover, Spain opted to buy in rail technology rather than developing its own (Vickerman, 1997), which is another distinguishing feature from the projects implemented in the other countries studied.

The service's punctuality, speed and accessibility to city centers are its main attractions. Indeed, commercial speed gains in Spain are over 100% with the AVE capable of a maximum speed of 217.5 mph. Also, the HSR network construction in Spain had a marked impact on mobility patterns. Before the introduction of the AVE in 1992, the combined number of rail and air passengers traveling between Madrid and Seville stood at around 800,000 each year. Just three years after the introduction of AVE, in 1995, HSR recorded 1.4 million passenger journeys, while the numbers of those flying fell to 300,000 (Menendez, 1998). No effects have been reported for the interurban bus service, which has continued to carry around 200,000 annual passengers in that period. However, the inauguration of the first AVE had a marked impact on conventional rail services, with the latter losing a large part of their traffic in the corridor.

2.5 China

China has been undergoing an HSR building booming. High-speed rail service in China was introduced on April 18, 2007. China is developing an extensive high speed rail system in part to relieve the pressure of both passenger and freight demand on its overcrowded existing rail system, in part to improve transportation connections between its different regions, and in part to promote the economy of less developed regions.

According to figure 6, Chinese traffic densities per route-km are nearly twice the next highest (Russia) and far higher than India and the US Class 1 system. Even the expanded network size in recent years is not sufficient to meet the demand.



Source: Transport Coordinator, China Country Office (2009).

Figure 6: Traffic density: international comparisons

With generous funding from the Chinese government's economic stimulus program, 17,000 km (11,000 miles) of high-speed lines are now under construction. In early 2011, the HSR network was expected to reach 13,073 km (8,123 miles) by the end of the year, and 25,000 km (16,000 miles) by the end of 2015. China currently has the largest network in the world[2].

2.6 Summary

Several factors can motivate constructing or upgrading rail network to high-speed system. Congestion is the leading factor that can justify capital investments which provide travel time savings and boost productivity. The motives that led various countries to implement high speed rail lines are varied. ; some, like Japan and China, did so originally in part to meet the demand on already overcrowded conventional rail lines, while others did so in part to try to preserve rail's declining mode share in the face of the growing role of automobile and air travel. In most cases we examined above, the regions served were more densely populated than most areas in the United States.
Historically, HSR system emerged for three basic reasons.

First, to overcome the limited capacity of conventional lines, where some new investment was needed and more effective solutions like HSR were required. This is the essential reason for the Tokaido Shinkansen and TGV Sud-Est. Korea, China and Taiwan had similar reasons. Second, HSRs increased the speeds on particularly slow sections of conventional lines, where huge costs and low rail technology could not increase speeds. This was the case for Germany. Third, HSRs were suggested as ways of improving accessibility to more remote regions, most notably the Sanyo Shinkansen between Osaka and Fukuoka and the first Spanish AVE line, Madrid-Sevilla.

The relative efficiency of HSR as a transportation investment varies among countries, as its level of usage is likely to depend on the interplay of many factors, including geography, economics, and government policies. For example, compared to the

[2] See http://en.wikipedia.org/wiki/High-speed_rail_in_China#cite_note-26

United States, countries with HSR have higher population densities, smaller land areas, lower per capita levels of car ownership, higher gas prices, lower levels of car use (measured both by number of trips per day and average distance per trip), and higher levels of public transportation availability and use. Also, there is a significant difference in the structure of the rail industry in these countries compared to the United States. In virtually all of those countries, high speed rail was implemented and is operated by state-owned rail companies that operate over a state-owned rail network, a network on which passenger rail service was far more prominent than freight service even before the introduction of high speed rail. By contrast, in the United States, the rail network is almost entirely privately owned, and freight service is far more prominent than is passenger service. Yet even with the introduction of HSR, and with other factors that are more conducive to intercity passenger rail use than in the United States, in most of these countries intercity rail travel (including both conventional and high speed rail) represents less than 10% of all passenger miles traveled on land (Peterman, Frittelli and Mallett (2009).

CHAPTER 3

THE HSR INDUSTRY

In this chapter, we describe the HSR industry, and the characteristics and magnitude of investments needed to establish reliable service and a meaningful network.

3.1 HSR definition

There is no single definition for high speed in the context of rail services. Usually, HSR can be subdivided into the following categories in terms of overall speed:

1. High Speed Rail (HSR) whose maximum speed is around 125-155mph, on upgraded track.
2. Very High Speed Rail (VHSR), whose maximum speed is 155-220mph, on dedicated track.
3. Maglev, whose speed is 200-300+ mph either in German or Japanese versions.

Both the HSR and VHSR use steel wheel on steel rail technology and Maglev use the magnetic levitation technology. In this paper, we only study the first two types and don't discuss the Maglevs.

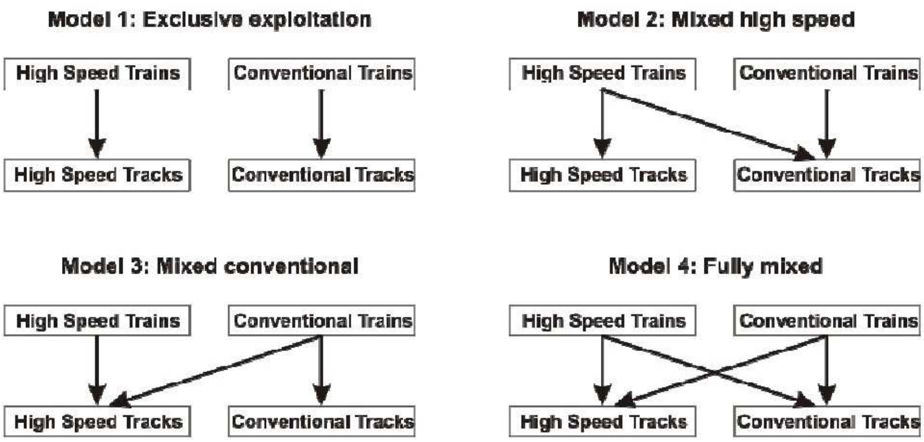
The increase speed will on the one hand make the HSR more competitive, while on the other hand, need more construction cost. As a result, the speed of HSR is set based on the distance of the trip. For example, for trip distances above 500 km, maximum speed above 300kmph may be needed to maintain competitive times relative to air transport. However, for shorter distances a maximum speed in the range of 200 to 250kmph may be adequate to win sufficient market share without the additional costs of attaining very high speeds.

HSR is designed for different purpose. HSR with top speed of at least 150 mph on completely grade-separated, dedicated rights-of-ways (with the possible exception of some shared track in terminal areas) is called HSR-Express. It is designed for the frequent, express, service between major population centers 200-600 miles apart with few intermediate stops. It is designed to relieve air and highway capacity constraints.

HSR with top speeds of 110-150 mph, grade separated, with some dedicated and some shared track (using positive train control technology) is called HSR-Regional. It is designed for relatively frequent service between major and moderate population centers 100-500 miles apart, with some intermediate stops. It is intended to relieve highway and, to some extent, air capacity constraints.

3.2 HSR models

Based on the relationship between HSR service and conventional rail service, HSR models can be divided into four types. Figure 7 shows the four types of HSR models. In this section, we introduce the types of HSR models and analyze the advantage and disadvantage of each model.



Source: Campos, De Rus and Barrons (2006).

Figure 7: HSR models

In the exclusive exploitation model, the high speed trains and conventional trains use completely separate tracks and each one uses its own infrastructure. Japan used this model when building Shinkensan in 1964. Such a HSR model makes the market organization of both HSR and conventional services fully independent, which proved to be a valuable asset. However, since we need to build new infrastructure for HSR, which is not compatible for the conventional rail, the cost will substantially higher compared with other models.

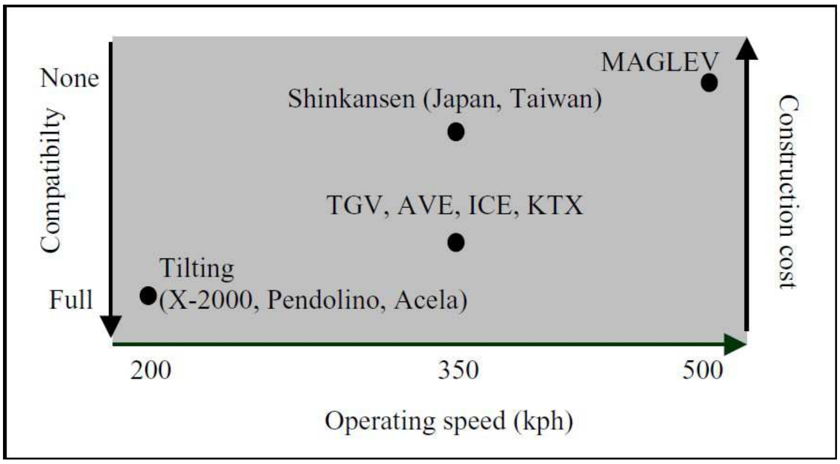
In the mixed high speed model, high speed trains can use both the conventional tracks and the dedicated high speed tracks, while conventional trains can only use the conventional tracks. This model corresponds with the French TGV. In this way, TGV can reach secondary destinations or city centers without building new tracks all the way to the station, which significantly reduces the building cost.

In the mixed conventional model, conventional trains can run on both high speed tracks and the conventional tracks, while high speed trains can only run at the dedicated tracks. This model is adopted by Span's AVE. On the one hand, since the high speed trains can only operated on the standard gauge, it is difficult for Span's AVE to run on the conventional tracks, which are narrow gauge such as the Japanese lines. On the other hand, adaptive technologies are used in their conventional trains, which make it possible to run on the dedicated high speed tracks. The main advantage of this model is the saving of rolling stock acquisition and maintenance costs and the flexibility for providing 'intermediate high speed services' on certain routes.

In the fully mixed model, the rail system is completely flexible. This is the case of German ICE and the Rome-Florence line in Italy, where high speed trains occasionally use upgraded conventional lines (as in France), and freight services use the spare capacity of high speed lines during the night.

3.3 Investment cost

Figure 8 shows the compatibility with the conventional rails, maximum operating speed and construction cost of difference groups of HSR networks.



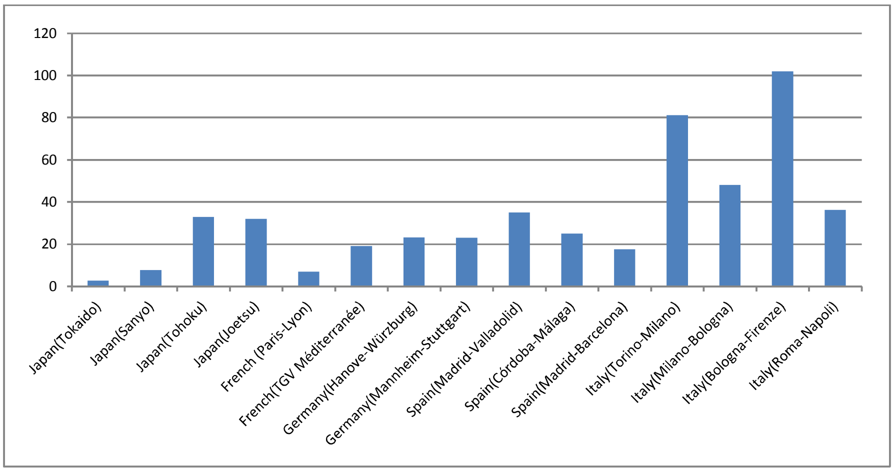
Source: Givoni (2006).

Figure 8: Characteristics of HSR networks

To better analyze the costs of different HSR networks, we divide the cost of HSR project into costs associated with the infrastructure and costs associated with the rolling stock. Infrastructure costs include investments in construction and maintenance of the guideways (tracks)3, energy supplying and line signaling systems, train controlling and traffic management systems and equipment, among others. Construction costs are incurred prior to starting commercial operations (except in the case of line extensions or upgrades of the existing network). Maintenance costs include those related to the overhauling of infrastructure, including labor costs, materials, spare parts, and among

[3] This part includes the sidings along the line, terminals and stations at the ends of the line and along the line, respectively

others. It occurs periodically, according to planned schedules calculated according to the assets depreciation (Compos, de Rus and Barron, 2007). Figure 9 shows the infrastructure costs of HSR lines in several countries. Based on that, we can see the infrastructure costs are slightly lower in French and higher in Italy. The difference can be explained by characteristics of the territories and the construction procedures. Spain and French are similar in terms of geographical characteristics. They both built the HSR lines in less populated areas outside the major centers, which significantly reduced the average infrastructure costs (Compos, De Rus and Barron, 2006). The HSR lines per kilometers are expensive in Italy than any other countries because they have been built over more densely populated areas, without those economies of space, densely urbanization and urban structure, mountainous terrain and high seismic risk areas (Daniel and Germa, 2010). From construction procedures, Spain and Japan adopted HSR models which need new rail infrastructure construction as mentioned in section 3.2. This will obviously increase the average infrastructure costs.



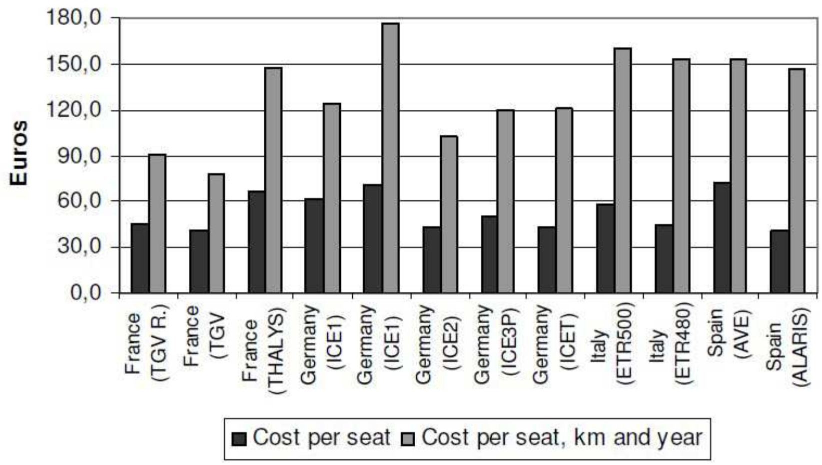
Source: Daniel and Germa (2010). (Data reorganized by Author.)

Figure 9: Infrastructure costs per kilometer of HSR lines by country[4]

Rolling stock costs include three main subcategories: acquisition, operation and maintenance. With regard to the first one, the price of a HSR trainset is determined by its technical specifications, such as capacity (number of seats), the contractual relationship between the manufacturer and the rail operator, the delivery and payment conditions and the specific internal configuration demanded by the operator. The operation costs mainly include the costs of the labor, energy consumed for the running of the trains, train formation (if it is necessary) and in-train passenger services (food, drinks, etc). These costs usually depend on the number of trains (fleet) operated on a particular line, which in turn, is indirectly determined by the demand. The maintenance costs of the rolling stock include again labor, materials and spare parts and are mainly affected by the train usage and indirectly affected by the demand (through the fleet size) (Campos, de Rus and Barron, 2007). Figure 10 and Figure 11 show the operating and maintenance costs of

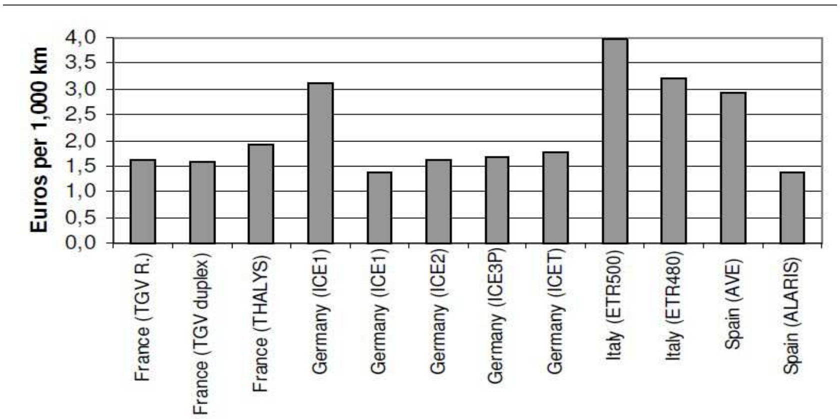
[4] The value is expressed in US dollar millions. The exchange rates are used as 1Eruo=1.5 $US

different types of HSR rolling stocks. On average, the cost per seat exhibit little dispersion for all types of HSR rolling stocks, which means the cost of rolling stocks are related to the capacity positively. When considering the operation of the train, the cost per seat, kilometers and year shows that French HSR technology is between 10-20% cheaper compared with others (Compos, Rus and Barron, 2007).In terms of maintenance costs, the lowest is German ICE, whereas the highest is Italy's ETR500.



Source: Compos, Rus and Barron (2006).

Figure 10: Rolling stock operating costs by train type and country



Source: Compos, De Rus and Barron (2006).

Figure 11: Rolling stock maintenance cost by train type and country

3.4 HSR technologies

3.4.1 Locomotive and multiple units

Locomotive and individual motors in self-propelled multiple units (MU) provide propulsion for the train. Locomotive has several advantages including easy replacing, flexible and safe, while MU is largely used in HSR since it offers high acceleration and deceleration and reduces the damage to the track when the speed is very high due to the lighter vehicles. From the 1910s onwards, the steam locomotives began to be replaced by less labor intensive and cleaner (but more complex and expensive) diesel locomotives and electric locomotives, while at about the same time self-propelled MU vehicles of either power system became much more common in passenger service. Locomotive-hauled passenger trains are used for speeds up to 160 kmph, while Electric Multiple Units (EMU) are used for higher-speed services[5].

[5] See http://en.wikipedia.org/wiki/Locomotive

A locomotive is a railway vehicle that provides the motive power for a train. Considering several advantage of locomotives, many earlier trains are still locomotive-hauled. Locomotive can be classified as, by their source of energy, steam locomotive, gasoline locomotive, diesel locomotive, electric locomotive, hybrid locomotive, steam-diesel hybrid locomotive, gas turbine-electric locomotive, fuel cell-electric locomotive, slug or drone locomotive. Earlier high speed trains use the gas-turbine electric locomotive. For example, the earliest French high-speed train TGV 001, which is also the world's second high speed train followed by the Japanese Shinkansen, is a gas-turbine-electric locomotive-hauled train and keeps the speed record of gas-turbine powered train. In 1972, the Advanced Passenger Train, an experimental tilting train developed by British Rail, is also gas-turbine powered. Due to the steep oil price, later models are gradually replaced by electric locomotives after the 1973 oil crisis and the subsequent rise in fuel costs.

The electric locomotive is supplied externally with electric power, either through an overhead pickup or through a third rail. Electric locomotives may easily be constructed with greater power output than most diesel locomotives. For passenger operation it is possible to provide enough power with diesel engines (see e.g. 'ICE TD') but, at higher speeds, this proves costly and impractical. Therefore, almost all high speed trains are electric. Electric locomotives, because they tend to be less technically complex than diesel-electric locomotives, are both easier and cheaper to maintain and have extremely long working lives, usually 40 to 50 years. Although the capital cost of electrifying track is high, electric locomotives are capable of higher performance and lower operational costs than steam or diesel power[6]. Electric locomotives are used on

[6] See http://en.wikipedia.org/wiki/Electric_locomotive

high-speed lines, such as ICE in Germany, Acela in the US, CRH in China and TGV in France.

The advent of modern power electronics and AC asynchronous traction motors has considerably reduced the volume of traction equipment. This, along with other technological developments, has facilitated the development of trains with decentralized traction, which is so-called multiple units (MUs)[7].

MUs is used to describe a self-propelled carriage capable of coupling with other units of the same or similar type and still being controlled from one driving cab. MUs don't need the separate locomotives to provide the motive power. MUs are used for higher-speed services for its higher acceleration rate. According to their power source, MUs can be classified to two main types: electric multiple units (EMUs) and diesel multiple units (DMUs). Most high speed trains, such as most recent CRH, German ICE 3 and Japanese Shinkansen, use the electric power because it is much quieter and energy efficiency[8].

In most countries, the locomotive-hauled high-speed trains are gradually replaced by the MUs. For example, all the CRH trains in China, which previously locomotive-hauled, become EMUs after the 6th speed-up campaign of China in 2007. In Japan, most long-distance trains had been operated by locomotives until the 1950s, but by utilizing and enhancing the technology of short-distance urban MU trains, long-distance MU vehicles were developed and widely introduced in the mid-1950s. This work resulted in the original Bullet Train development in EMU type vehicle and the Tokaido Shinkansen operated in 1964 is just EMUs. By the 1970s, locomotive type trains were regarded as slow and inefficient, and their use is now mostly limited to freight. Japan's high

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[7] See http://www.railway-energy.org/tfee/index.php?ID=220&TECHNOLOGYID=23&SEL=100&EXPANDALL=3
[8] See http://en.wikipedia.org/wiki/Electric_multiple_unit

population density with a large number of railway passengers in relatively small urban areas, requires frequent operation of short-distance trains. Therefore, the high acceleration ability and quick turnaround times of MU have advantages in Japan. Additionally, the mountainous terrain in Japan gives the MU's advantage on grade more importance than in most countries, particularly in driving adoption on small private lines many of which run from coastal cities to small towns in the mountains.

The construction costs for EMUs are lower than those of locomotive-hauled trains since EMUs don't need to build separate locomotive to provide the motive power. However, compared with a locomotive-hauled passenger trains, EMUs are much more expensive in maintenance.

3.4.2 Railway electrification system

Since most HSR networks use electric to provide the motive power, the electrification system is necessary. A railway electrification system supplies electrical energy to railway locomotives or multiple units as well as trams so that they can operate without having an on-board prime mover. Railway electrification has many advantages but requires significant capital expenditure for installation.

Electrification Systems are classified by three main parameters: voltage, current and contact system. Now, more and more countries that used the low-voltage (3KV/1.5KV) direct current (DC) are beginning to change their electrification system to 25KV alternating current (AC) to achieve higher speed.[9] The 25KV AC electrification system is ideal for railways that cover long distances and generates higher speed. For example, the first generation of ETR, a series of Italy's HSR which uses the 3KV DC,

[9] Most recent high speed trains use the overhead lines, 25 kV Alternating current (25KV, AC) and 50HZ railway electrification system, except countries like Austria, Germany, Sweden, Switzerland and Norway use 15kv AC, 16.7 HZ system, and some old lines in Southern France and Italy use the direct current (DC) systems.

only has a maximum speed of 155mph. When Ferrovie dello Stato chose to electrify the lines at 25KV AC for the second generation ETR, the trains can achieve a top speed of 186 mph[10].

Though achieving higher speed, the high voltage requires higher investment. The initial costs are higher because high voltage leads to a requirement for a slightly higher clearance in tunnels and under overbridges. The ongoing maintenance costs are also higher. For example, to avoid short circuits, the high voltage must be protected from moisture. Various weather events, such as the wrong type of snow, have caused moisture accumulation and resulted in failures in the past. This increases the maintenance cost[11].

3.4.3 Track

The history of high-speed train operation follows two primary paths:

1. Trains getting higher speed on dedicated new high-specification track. For example, Shinkansen routes are completely separate from conventional rail lines (except Mini-shinkansen which goes through to conventional lines). The lines have been built without road crossings at grade. Tracks are strictly off-limits with penalties against trespassing strictly regulated by law. It uses tunnels and viaducts to go through and over obstacles rather than around them, with a minimum curve radius of 4,000 meters (2,500 meters on the oldest Tōkaidō Shinkansen); and
2. Trains getting higher speed on existing track. Most high speed trains in Europe are in this category like French TGV. TGV track construction is similar to that of normal railway lines, but with a few key differences. The radii of curves are larger so that trains can traverse them at higher speeds without increasing the centripetal

[10] See http://en.wikipedia.org/wiki/Railway_electrification_system
[11] See http://en.wikipedia.org/wiki/25_kV_AC_railway_electrification

acceleration felt by passengers. The radii of LGV curves have historically been greater than 4 km (2.5 miles).

The two paths lead to two methods in building the tracks for HSR. The first one is upgrading the existing tracks. This allows the trains to reach secondary destinations or city centers without building new tracks all the way to the station, reducing costs compared to high-speed networks with a different gauge than the surrounding conventional network. However, there are two major difficulties if new trains are to drive fast on existing tracks. First, the train has to be adapted in order to be able to run through relative sharp curves. While tilting technology on routes has been used to solve this problem, only few of the projects using the tilting technology lead to commercial services and most of them are failure. Second, the trains have to mix with slower services on tracks which restricted the speed. As a result, the trains on the existing tracks cannot exceed 155mph.

Increasing threshold train speeds above 155mph involves the second method that is building tracks to a separate very high standard that can be avoided affecting by slower local or freight trains and have the capacity to operate many high-speed trains punctually. Besides increasing the speed, the incompatible of the HSR track and conventional rail track also requires building the dedicated tracks for HSR. For example, all the high-speed lines have to be built to standard gauge. As a result, Japan and Spain, whose conventional rails are built on the narrow-gauge tracks, need to build the separate standard gauge tracks to meet such requirement. Obviously, the construction costs will be higher compared with the first methods.

For much of the 20th century, rail tracks used softwood timber ties and jointed rails (Figure 12). The rails were typically of flat bottom section fastened to the ties with dogspikes through a flat tieplate in North America and Australia, and typically of bullhead section carried in cast iron chairs in British and Irish practice. The intrinsic weakness of jointed rails in resisting vertical loading results in the ballast support becoming depressed and a heavy maintenance workload is imposed to prevent unacceptable geometrical defects at the joints. The joints require lubrication, and wear at the fishplate (joint bar) mating surfaces needed to be rectified by shimming, which makes the jointed track not financially appropriate for heavily operated railroads. Also, because of the small gaps left between the rails, when trains pass over jointed tracks, they make a "clickety-clack" sound. Unless it is well-maintained, jointed tracks do not have the ride quality of welded rail and is less desirable for high speed trains[12].

Source: http://en.wikipedia.org/wiki/Track_(rail_transport).

Figure 12: Railroad tracks on traditional wooden sleepers

The use of ballastless track (Figure 13, Figure 14) can overcome such heavy maintenance costs. In its simplest form this consists of a continuous slab of concrete (like a highway structure) with the rails supported directly on its upper surface (using a resilient pad). Ballastless track allows for smoother train rides at high speed and can reduce warping.

[12] See http://en.wikipedia.org/wiki/Track_(rail_transport)

The ballastless track is very expensive, and in the case of existing railroads requires closure of the route for a somewhat long period. However, its whole life cost can be lower because of the great reduction in maintenance requirement. Ballastless track is usually considered for new very high speed or very high loading routes, in short extensions that require additional strength (i.e. rail station), or for localized replacement in the case of exceptional maintenance difficulties.

Source**:** http://en.wikipedia.org/wiki/Track_(rail_transport).

Figure 13: Japanese HSR ballastless tracks

Source: http://en.wikipedia.org/wiki/Track_(rail_transport).

Figure 14: Chinese HSR ballastless tracks

3.4.4 Passenger car

A passenger car is a component of railway rolling stock that is designed to carry passengers. The rolling stock technology is related to the tracks. Usually, the more sophisticated the track is, the less sophisticated the rolling stock itself needs to be (Karen, 1996). In other worlds, running on the same tracks, the more sophisticated technology would bring higher speed to the rolling stock. For example, tilting technologies enable the trains to increase the speed on regular rails and counteract the passengers' discomfort caused by the centrifugal force when the trains rounds at a curve with very high speed.

Several construction details characterize passenger equipment and allow the trains to run at higher speed. One of the passenger cart technology is articulated cars, which are becoming increasingly common in Europe and US. Articulated cars are rail vehicles which consist of a number of smaller, lighter cars which are semi-permanently attached to each other and which share common trucks. This technology can save on the total number of wheels and trucks, reducing initial cost, weight, noise, vibration and maintenance expenses. Further, movement between passenger cars is safer and easier than with traditional designs. Finally, it is easier to implement tilting schemes such as the Talgo design which allow the train to lean into curves[13].

3.4.5 Signaling and control system

Railway signaling and control system is designed to control railway traffic safely and prevent trains from colliding. The conventional track side signaling systems, shown in figure 6, are insufficient for high speed rail, because the higher speed makes it impossible for the engineer/drivers to reliably read signals place at trackside. The required vigilance cannot be expected of a human, especially for long periods and in

[13] http://en.wikipedia.org/wiki/Articulated_car

adverse weather conditions. To increase the speed and capabilities, more advanced and complex signaling and control systems are needed.

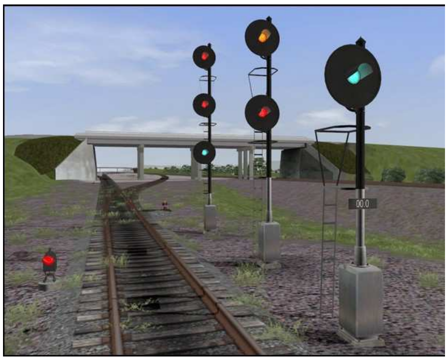

Figure 15: Conventional track side signaling system[14]

There are various options of improving the signaling and control systems to increase the speed of the train including increasing the distance between distant and home signals, adding additional aspects, and cab signaling. Increasing the distance between the home and distant signals would decrease capacity. Adding an additional aspect would make the signals harder to recognize. In either case, changes to the conventional signals would not solve the problem of the difficulty of seeing and reacting to the signals at higher speeds. To overcome all of these problems, cab signaling, a system by which signaling information is transmitted through the rails as electrical signals which are picked up by antennas placed under the train, was developed to increase the speed of the train and capacities of the system[15].

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[14] This asset represents trackside train traffic control signals of a type built by Union Switch and Signal Company.

[15] See http://en.wikipedia.org/wiki/Linienzugbeeinflussung

Several major forms of cab signaling system have been designed to make the train runs better including the European Train Control System (ETCS), the German Indusi, German LZB, British TPWS, and the French TVM.

ETCS is the train control component of the European Rail Traffic Management System (ERTMS)[16] and a functional specification that incorporates the former national standards of several European countries. The development of ETCS has matured to a point that cross-border traffic is possible and some countries have announced a date for the end of life of older systems. France will drop the usage of KVB on high-speed lines by 2017 in favor of ETCS Level 2. Switzerland will switch from ZUB/Signum to ETCS Level 1 for conventional rail in 2018. Germany will start replacing all PZB and LZB systems in 2015 to be finished by 2027. Additionally a number of non-European countries are starting to deploy ERTMS/ETCS on new tracks including China, Korea, New Zealand, India, Kazakhstan, Saudi Arabia, Libya, Algeria and Mexico. Australia will switch to ETCS on some dedicated lines starting in 2013.

The ETCS is divided into three levels and the definition of the level depends on how the route is equipped and the way in which information is transmitted to the train.

ETCS level 1 is a cab signaling system that can be superimposed on the existing signaling system. As shown in Figure 16, the train position is still detected by traditional trackside occupancy controlling devices which are linked with the interlockings. Line-side signaling is kept in general. Fixed or variable data is transmitted from track to trains by means of Eurobalises. The malus of the Level 1 is that the speed is restricted to 160 kmph only; the distance between the signals does not allow speeds higher than this.

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[16] ERTMS is a multinational standard that is progressively being developed in Europe with an aim to improve interoperability

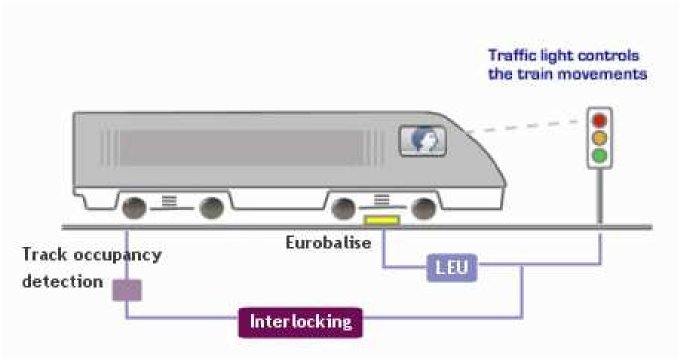

Figure 16: ETCS level 1

ETCS Level 2 (Figure 17) is a digital radio-based signal and train protection system. In application level 2, ETCS uses a GSM-R radio channel to exchange data between the trackside Radio Block Centre and the trains. The interlocking reports the status of the objects controlling the routes of the trains to the RBC which, in turn, generates the correct movement authorities for the different trains in the section. In normal operation, lineside signals are no longer strictly necessary. The traditional control of track-occupancy with fix block sections is still kept. Nevertheless, trains report their position to the radio block centre via the GSM-R communication channel. The ETCS level 2 was installed in Turkey's high speed line, designed for speed 155mph. In October 2011, it was commissioned on the high speed rail line of Spain, allowing the speed of the fastest trains to be increased to 193mph.

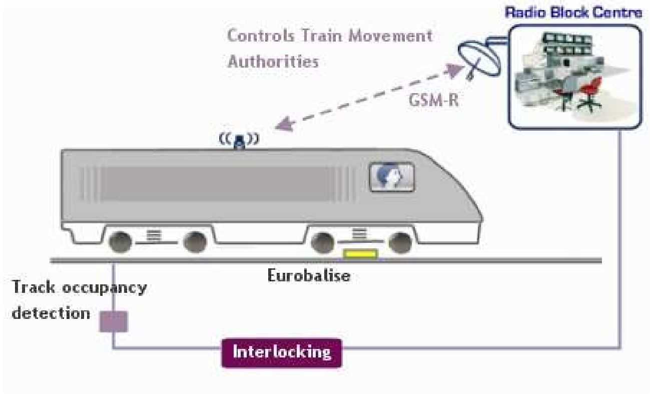

Figure 17: ETCS level 2

ETCS Level 3 (Figure 18) definition with low cost specifications (compared to ERTMS Regional) and the integration of GPRS into the radio protocol to increase the signaling bandwidth as required in shunting stations is now under development. In application level 3, ETCS replaces the line-side signals as well as the trackside occupancy checking devices as shown in the figure. The location of the train is determined by the train-side odometer and reported to the trackside radio block centre via the GSM-R radio transmission. In this configuration, train spacing is no longer controlled by the interlocking. However, the latter has to exchange information about the route setting with the radio block centre. This configuration offers a great simplification with cost reduction of the equipment in the track and an independence from rigidly structured fixed block sections. For this reason, ETCS level 3 has the potential to become the final universal optimal configuration of ETCS.[17]

[17] See http://en.wikipedia.org/wiki/European_Train_Control_System

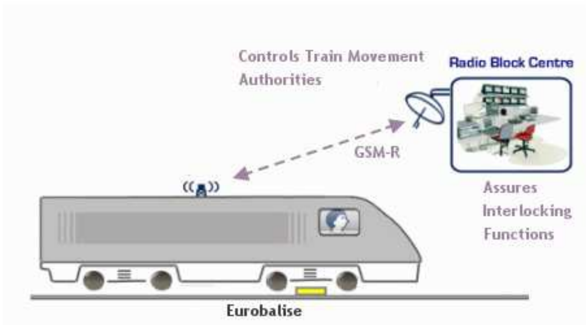

Figure 18: ETCS level 3

TVM is another form of cab signaling system designed as part of the French TGV project. TGV lines are divided into fixed blocks about 1500 meters (1 mile) long. (The earlier TVM 300 system uses longer blocks.) Blocks are shorter than a train's braking distance, so a braking sequence takes place over several blocks, nominally four. This relatively frequent subdivision allows running trains on shorter headways, which increases the capacity of a high speed line without placing additional requirements on the braking performance of the trains. TVM 300 is the first generation and applied on the South East High Speed Line in France. It supports a commercial headway of 5 minutes between trains. TVM 430 is the second generation of TVM and the design headway performance is 3 minutes and can be achieved under commercial conditions at 320 kmh. This system can be delivered in an integrated configuration using our SEI interlocking platform to support both ATC and interlocking functions, thus reducing the cost[18].

Linienzugbeeinflussung (LZB) is also a cab signaling and train protection system used on selected German and Austrian railway lines as well as the AVE in Spain. The LZB cab signaling system was first demonstrated in 1965, enabling daily trains to

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[18] See http://www.trainweb.org/tgvpages/signals.html

the International Transport Exhibition in Munich to run at 200 kmph. The system was further developed through the 1970s, released on various lines in Germany in the early 1980s and in German, Spanish, and Austrian high-speed lines in the 1990s with trains running up to 300 kmph. Meanwhile, additional capabilities were added to the system[19].

[19] See http://en.wikipedia.org/wiki/Linienzugbeeinflussung

CHAPTER 4

THE HIGH-SPEED RAIL INDUSTRY SUPPLY-CHAIN

In this chapter we detail the HSR final product, and provide taxonomy of the complex international supply chain. This allows us to examine in detail the characteristics of the components, technologies and firms, and their diverse global locations.

4.1 Taxonomy of the supply chain

As we noted in Chapter 3, the HSR contains numerous important components. Given the diversity and complexity of the components, it is useful to form taxonomy of the key components. Appendix A displays the supply-chain diagram of the international high speed rail industry. On the top right of the diagram appear the names of the major trainset manufacturing companies around the world. The composition of the HSR is highly complex, which is shown in figure 19. To keep the supply-chain taxonomy tractable, we categorize the high speed rail system into five broad component categories: (1) Mechanical Group; (2) Electronic Group; (3) Locomotive and Power Group; (4) Passenger Cart Group; and (5) Others. As noted in the supply-chain diagram, each category contains several major component and sub-component areas and the leading international companies are listed in each part.

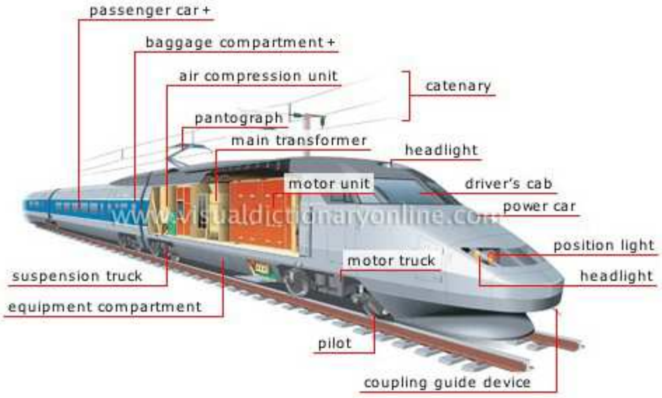


Figure 19: High speed trains components

4.1.1 Mechanical group

The Mechanical Group includes physical components to manage and support the train while running on the existing or dedicated tracks. The mechanism category is used as actuator input to generate the output forces and motive power for the train. This input is shaped by mechanisms consisting of gears and gear trains, belt and chain drives, cam and follower mechanisms, and linkages as well as friction devices such as brakes and clutches.

M1 category is the wheelset related component. A wheel set is wheel-axle assembly of a rail car. Suspension is the term given to the system of springs, shock absorbers and linkages that connects a vehicle to its wheels. Damper is a mechanical device designed to smooth out or damp shock impulse, and dissipate kinetic energy. The bogie is a frame assembly beneath each end of a railcar or locomotive that holds the wheelsets and serve to: (1) support the train's body weight; (2) ensure stability when trains run on straight and curved tracks; and (3) absorb vibrations generated by the track and reducing the effect of centrifugal forces that pull on persons when the train negotiates a curve at high speeds. To meet the requirement, the bogies usually comprise a high comfort suspension system for superior riding qualities. The figure 20 is the French TGV bogies.

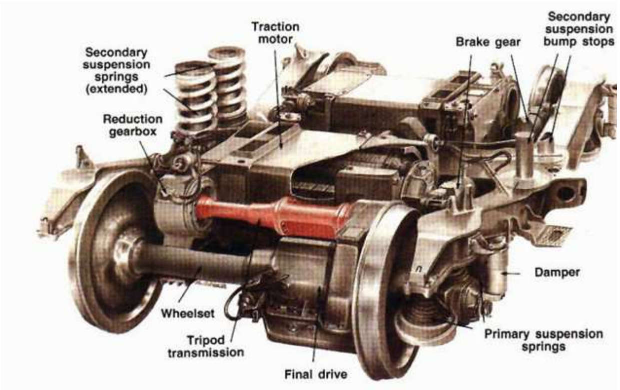


Figure 20: French TGV bogies

M2 category includes some connection component. Coupler is a mechanism for connecting rolling stock in a train. Gear is used to connect the coupler to the rolling stock. Brakes are used on the cars of railway trains to enable deceleration, control acceleration (downhill) or to keep them standing when parked. The higher the achievable braking rate, the longer the train can travel at a higher speed. Furthermore, a higher maximum braking rate increases the level of safety.

4.1.2 Locomotive and power group

Locomotive and Power Group provides the input forces or power of the train. This category includes the locomotive, electric motors and hydraulic system.

A locomotive is a railway vehicle that provides the motive power for a train. It is the power pack of the train. Nowadays, electric locomotive are common used in the HSR industry. A locomotive involves highly complex technologies and includes several components, which is shown in figure 21.

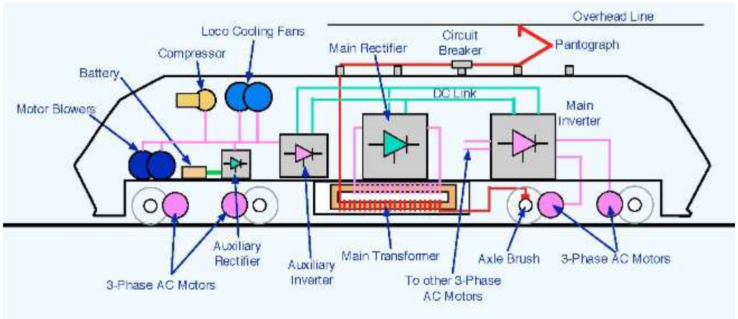


Figure 21: Electric locomotive parts

The L2 category is the railway electrification system. Electric locomotives unlike diesels do not produce their own power. They need electric power supplied by a central power plant that may be miles away. Even the popularity forms EMUs, which don't contain separate locomotives need the electrification system to supply the power.

A railway electrification system supplies electrical energy to railway locomotives and multiple units as well as trams so that they can operate without having an on-board prime mover. Transmission of the power is always along the track by means of an overhead wire or at ground level, using an extra third rail laid close to the running rail. The mechanics of the power supply wiring is not very simple. The wire must be able to carry the current (several thousand amps), remain in line with the route, withstand wind, extreme cold, heat and other hostile weather conditions. Overhead catenary systems have a complex geometry, nowadays usually designed by a computer.[20]

The L3 part called hydraulic system refers to system that transfers the energy from fluid and pressure. A hydraulic system consists of three parts: The generator (e.g. a hydraulic pump), driven by an electric motor, a combustion engine or a windmill; valves, filters, piping etc. (to guide and control the system); the motor (e.g. a hydraulic motor or hydraulic cylinder) to drive the machinery. For tilting trains, besides using the electrical system electrical actuation to perform carbody tilting to reduce centrifugal force in curves, hydraulic system also plays an important role in raising, lowering and relocation of the shuttering.

4.1.3 Electronic group

The Electronic Groups enable the rail service to operate safely over a given set of tracks including communications, signaling and train protection system and embedded computer system. The category contains several complex and fascinating subjects. The quality and technology of the signaling and control will determine the safety speed of the high speed rail. The more sophisticated the signaling control system is, the higher speed the high speed train can arrive.

4.1.4 Passenger cart group

The Passenger Cart Group includes the accessories of passenger coaches, head end power components and other design and maintenance services relating to the passenger cars. A locomotive has no payload capacity of its own, and its sole purpose is to move the train along the tracks, while the passenger cart can be used for carrying the

[20] See http://edu.dvgups.ru/METDOC/CGU/INOSTR/ANGL/METOD/U_P/frame/6.htm

passengers. Figure 22 shows the standard names used in the UK for passenger coach parts. According to this, we divide this category into seven sub-categories, which can be seen in the supply-chain diagram (Appendix A).

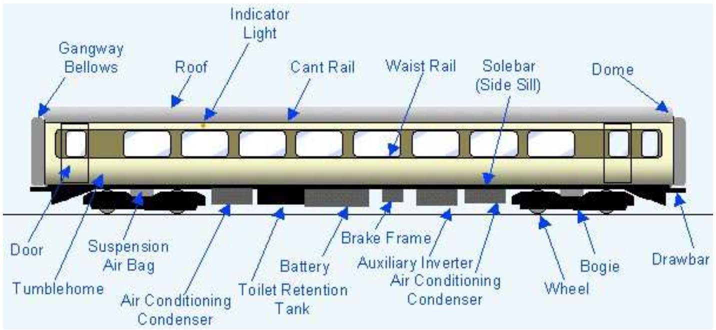


Figure 22: Passenger coach parts

4.1.5 Others

Others categories are infrastructure-related equipment and some aftermarket service including the maintenance and refurbishing service. Besides the trainset, the rail system need several other components to support, such as the slab track and inverted soundproof wall.

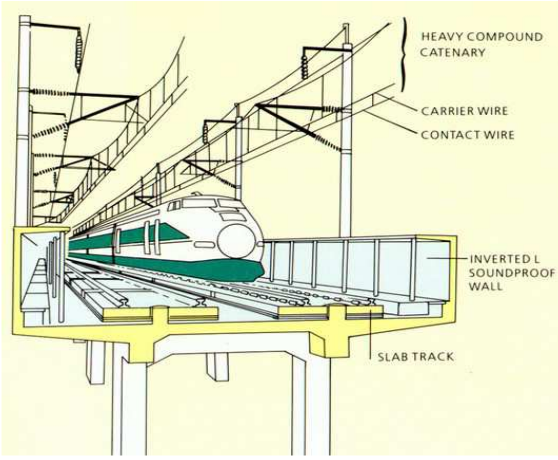


Figure 23: High speed rail networks

4.2 HSR market

The HSR market is one of the most complex markets in the world. Large numbers of firms are involved in the supply chain of HSR industry. On the one hand, there are more and more sophisticated companies who can manufacture the final HSR products, such as the Alstoms' TGV, Siemens' ICE and Bombardier's Regina. The emerging of some Chinese and South Korean companies makes the market even more competitive and complex. On the other hand, according to the discussions of section 3.4 and 4.1, HSR is composed of several parts and involved a lot of advanced technologies. This means even though the above big companies have mature technologies and production lines, it is impossible for them to create all the components by themselves, which brings a lot of components manufacturers in the supply chain of HSR industry.

In this section, we focus on studying the complex HSR market in terms of the major trainset suppliers, as well as the components suppliers. We first identify the distribution and activity of the major trainset suppliers and the evolving of their market share in the recent 10 years. Then, we identify the development of the business and find possible reasons for this development.

4.2.1 Major trainset suppliers

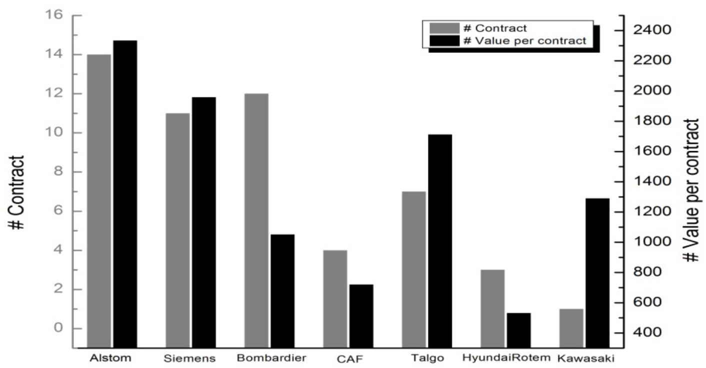
Appendix A provides information on the nine major trainset suppliers, who can assemble the components and provide the final high speed trainsets. Bombardier (Canada), Alstom (France) and Siemens (German) have been the leading international manufacturers/aggregators of rail and transet vehicles, but they are increasingly challenged by China's CSR and CNR. Other companies such as Kawasaki (Japan), CAF and Talgo (both from Spain), Ansaldo-Breda (Italy) and Hyundai Rotem (South Korea) also play important role internationally.

Several firms of the major trainset suppliers also have competences in several areas of HSR components manufacturing. For example, nearly all the companies are involved in the production of signaling system and locomotives, since these parts involve a lot of new technologies and high value-added. To maintain the competitiveness, the companies will choose to develop their own products in these two categories from long-term perspective. The production structures are highly complex in these companies. The global company Bombardier, for example, manufactures the entire electrical equipment, propulsion system and the power head (Locomotive and Power Group), bogies (Mechanical Group), the train control, signaling and communication system (Electronic Group), and the whole carbody (Passenger Cart Group). Alstom, another big international company, is also involved in nearly all of the categories in the supply chain. The multiproduct nature of these major trainset and other component making firms will be discussed later in section 4.3.2. The production may all occur in the same place or be processed in different manufacture sites. The details of the global production and assembly sites will be discussed in section 4.3.1.

4.2.2 Market share

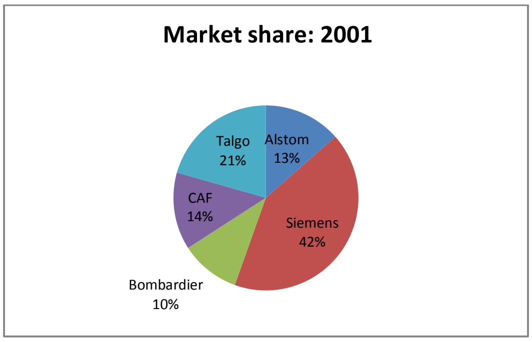
In this section, we study the market share of the major trainset suppliers by examining the international contract from 2001 to 2011. We contain 47 contracts signed from 2001 to 2011 in Appendix B (3 contracts are not in this period). We eliminated the contracts signed for their own countries project to study the market share of the trainset suppliers in international HSR market. Also, we focus on studying the steel-wheel

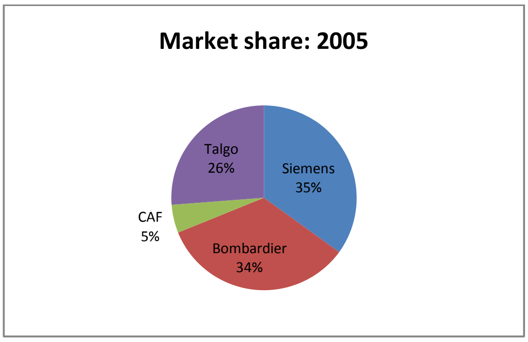
From figure 24, we can see that Alstom, Bombardier and Siemens signed more contracts than the other companies during the ten years and occupy the most part of the HSR market in most of the ten years, which is shown in figure 24. Though signed more of the international contract, Bombardier usually signed the contract with lower average value. This is probably because Bombardier has small size (this will show in later section) and less resources, which restrict the capability of the Bombardier to bid for the large value contract.

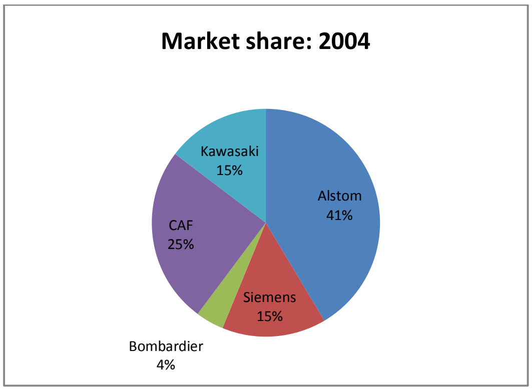


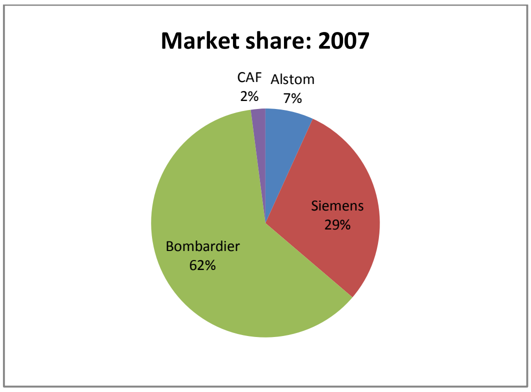
Source: Appendix B

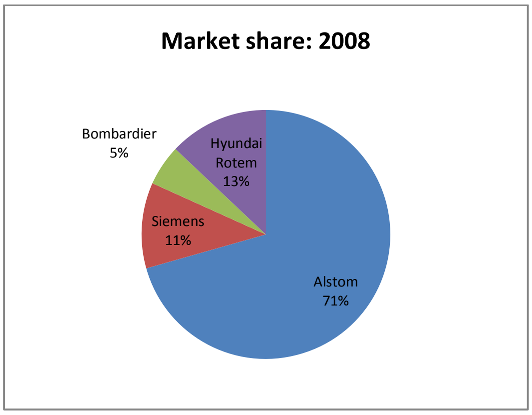
Figure 24: Contract number and value by company: 2001-2011

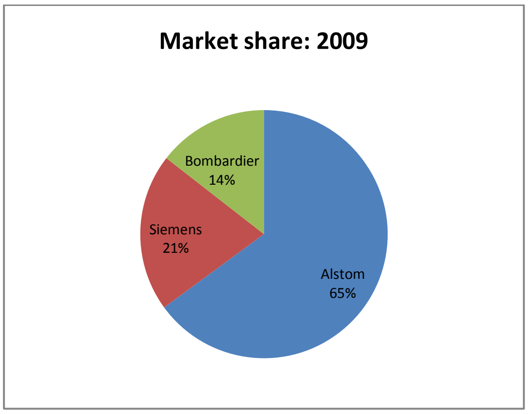


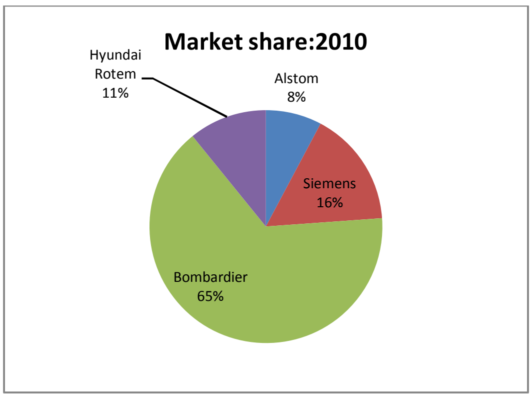


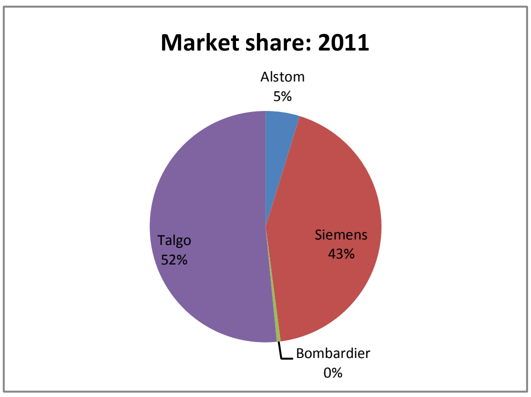










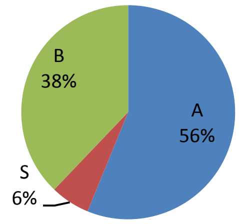
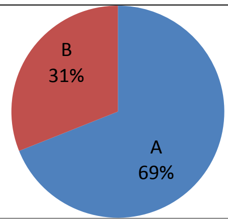
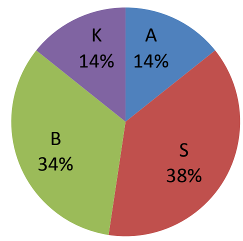


Source: Appendix B.

Figure 25: Market share (total contract value) by year

We also examine the HSR market in different countries. Table 2 summarizes the contract information by country. From table 2, we can see that Spain, Italy, Turkey, China's project is heated and many companies are involved in these projects. Companies would like to bid and participated in the project of these countries, because these countries have large demand, many companies want to enter the market to earn the potential profits. These countries usually develop their own HSR trains via cooperation with leading companies, who have mastered complete technologies to manufacture HSR earlier. In the Span, the projects before 2005 are completed via cooperation between Bombardier, Alstom or Siemens and local companies. From 2005, Spanish company Talgo and CAF can win the international contract independently and Spanish government began to award the contract to local company after that. Similarly, while Italy's company-AnsaldoBreda and Chinese company-CNR and CSR can enter the international market with their own HSR products, most of the HSR products in Italy and China are manufactured domestically.

Table 2: Contracts information

Country	Company	Year	#Train	Value	Market share (Train #)
Spain	Alstom (A)	2001	20	377	
		2004	75	2210	
	Siemens (S)	2004	10	Na	
	Bombardier (B)	2001	16	304	
		2005	30	786	
		2005	18	403	
UK	Alstom	2002	52	1702	
Italy	Alstom	2002	60	312	
		2004	12	299	
		2004	14	365	
		2008	25	957	
	Bombardier	2010	50	2100	
China	Alstom	2004	60	771	
	Siemens	2005	60	1587	
		2009	100	5700	
	Bombardier	2005	20	350	
		2009	80	4010	
		2010	40	761	
	Kawasaki	2004	60	1290	
Argentine	Alstom	2008	8	3700	
Morocco	Alstom	2010	14	530	
Porland	Alsotm	2011	20	941	
Uzbekistan	Talgo	2005	2	56	
Australia	Siemens	2006	23	346	
		2007	44	717	
Turkey	CAF	2005	10	224	
	Hyundai Rotem	2008	440	854	
		2010	80	438	

Source: Appendix B.

4.2.3 Business development in HSR

In terms of the whole supply chain, the growth of firms in this industry typically follows the demand in the home country. Table 3 shows the HSR networks worldwide by country. France and Germany have large demand for the HSR networks.

Correspondingly, French and German companies can be seen everywhere in the supply chain. China and Korea, the relatively new countries in HSR industry, also bring a lot of local companies to this industry due to their large local demand for HSR.

Table 3: High Speed Rail in 2011 by country

Country	Region	In operation (km)	Under construction (km)	Total Country (km)
Belgium	Europe	209	0	209
China	Asia/East	6158	14160	20318
Japan	Asia/East	2388	423	2811
France	Europe	1872	730	2602
Germany	Europe	1032	378	1410
Italy[4][5]	Europe	1296	92	1388
Netherlands	Europe	120	0	120
Russia	Europe	780	400	1180
Saudi Arabia	Asia/West	0	440	440
South Korea	Asia/East	412	186	647
Spain	Europe	2665	1781	3744
Switzerland	Europe	35	72	107
Turkey	Asia/West and Europe	457	1416	1873
Taiwan	Asia/East	345	0	345
United Kingdom	Europe	113	0	113
Uzbekistan	Asia/West	344	0	344

Source: http://en.wikipedia.org/wiki/High-speed_rail_by_country

Another important factor that influences the growth of firms is government investment. China's large government investment is a very important reason for the development of the business. Total investment in new rail lines grew from $14 billion in 2004 to $22.7 and $26.2 billion in 2006 and 2007. Total investments in new rail lines including HSR reached $49.4 billion in 2008 and $88 billion in 2009. In all, the state plans to spend $300 billion to build a 25,000 km (16,000 miles) HSR network by 2020. Internationally, a lot of attention has been paid to China's audacious investment in HSR.

CNR and CSR are growing into formidable global competitors. They are already selling light rail, commuter, and subway vehicles to a broad range of countries, and are increasingly active in bidding for high-speed projects.

Similar to China, the investments are a major boon to Spain's manufacturing and construction industries. Nearly 600 companies generate products or provide services for Spanish rail sector. Spanish firms are competitive in every aspect of rail, from design and construction to manufacture of rolling stock to signaling, ticketing, operations and equivalent provision.

Compared with China and Spain, the US federal government makes very little investment in rail. The United States once had a thriving intercity rail and urban transit network. By the 1950s, however, the federal government shifted its infrastructure spending decisively to highways and airports. Public transportation systems atrophied, and America's technological leadership in the manufacture of everything from subway cars to trams to high-speed trains passed to companies in Japan, France, Germany, and a few other European countries. By the 1970s and 1980s, the domestically owned passenger rail manufacturing industry had vanished. Today, the U.S. passenger rail industry remains underdeveloped. The U.S has little or no competencies in the manufacturing of the sophisticated components needed for HSR.

The local rail development is the third factor that influences the growth of firms in the HSR industry. Germany is one of the largest rail and transit markets in the world. Its rail manufacturing industry remains a global technology leader, underpinned by strong internal demand and even larger export sales. We can see a large number of German firms in the supply chain diagram. Besides Siemens and Bombardier, whose transportation headquarter is in Germany can provide the full trainset and some other important components, Germany also has companies such as ContiTech, Vossloh, Knorr-Bremse in the mechanic group, Telefunken, AF Friedrichshafen in the Electronics groups, AEG power Solution in the power Group, Hubner and Satek in the passenger cart group, and Thyssenkrupp for the rail station motility system. These companies not only provide the components for the local rail companies Siemens and Bombardier, but also export their components to other countries.

Long a world leader in rail industry, Japan developed the world's first HSR network. As the most experienced HSR nation in the world, with service dating back to 1964, Japan has developed a strong technological and managerial capacity for manufacture and operation of HSR service. Japan has long been self-sufficient in providing all dimensions of rail service, including manufacture of rolling stock, which creates many world famous firms in the supply chain diagram, such as Kawasaki and Hitachi Transport System.

4.3 Firms in HSR industry

A large numbers of firms are involved in the supply chain of HSR industry. In this section we describe some key characteristics of these firms.

4.3.1 Multinational firms

Firms in the HSR supply chain are usually multinational. For example, Alstom has manufacturing sites in nearly 19 countries and has a presence in nearly one hundred countries.

Companies set their manufacturing sites internationally for several reasons. First, companies set the site in some countries to meet the local requirements, which is often necessary for them to enter the market. For example, most of the big companies have US transportation manufacture sites. They all aim to be important suppliers for the U.S. market, which includes various rail components as well as other forms of urban transit. According to the Buy America Regulation (See Appendix E), the U.S. Secretary of Transportation (authority delegated to the Federal Railroad Administrator) may obligate an amount to carry out a PRIIA funded project only if the steel, iron, and manufactured goods used in the project are produced in the United States. Too meet this regulation, companies build their manufacture sites in the United States. Siemens provides energy management solutions and seamless rail automation for railway systems in several US sites. Bombardier supplies passenger rail vehicles, propulsion and control equipment, rail control and signaling systems, and complete transportation systems to major transit and airport authorities across the United States. The vast majority of this equipment is built in their three manufacturing facilities in Plattsburgh (New York), Pittsburgh (Pennsylvania), and West Mifflin (Pennsylvania). Alstom offers a full range of products and services for the U.S. energy and rail transportation markets with a focus on delivering the right mix of products to support the construction of new systems utilizing the latest technology, while maximizing the lifecycle and operational efficiency of existing power plant and railway assets. CAF USA is one of the U.S. rail transportation market leaders in the design, manufacture, maintenance and supply of equipment and components for railway systems. Elmira (New York) is home to CAF USA's American railcar production facility. All the other companies all have their US manufacture sites for the important components of rail in the US.

Another reason to establish an international manufacturing network is to make full use of the local resources. For example, through Alstom has it’s headquarter of the transportation sector in France, the company finishes most of the HSR projects in its Italian facilities. After Alstom acquired the Italian company Fiat Ferroviaria, who own the tilting technology, most of the technology and facilities are in Italy. Labor and materials in Italy are also much cheaper than in France, enabling it to operate and compete efficiently in global markets.

4.3.2 Multiproduct firms

Appendix C lists the core products of selected components manufacturers. As it shows, firms in the supply chain are, in most cases, multiproduct firms, which provide more than one types of products. The term multiproduct covers a complex array of products and services that can be provided by a firm. We consider the following examples from the HSR industry:

1. A firm produces one core product which has several different applications. The Czech Republic company, Bonatrans, for example, simultaneously produces wheelsets for passenger transport, locomotive, urban transport and freight transport. Though Bonatrans produces wheelset only, they are totally different products which are produced to meet the demand for different applications.
2. A firm produces only one core product for single use, however, in different types. For example, Germany Company Satek manufactures the small toilet cubicle and large toilet cubicle. The small toilet cubicle and large toilet cubicle are both specialized sanitary cabins for the railway vehicle but in different size. So this can be viewed as another kind of multiproduct.
3. A firm produces several kinds of core products. American company Westinghouse Air Brake Technologies Corporation (Wabtec) produces several products for the railway industry such as brake equipment, freight car truck component, rail door assemblies and signaling design. This is a more complex example as the firm is obviously a multiproduct firm, but also diversified in the sense that it prodices different categories of products.

For most big companies, they do not fall into one single category and the categorization of for these companies is complex.

Knorr-Bremse, for example, produces different types of brake systems which can be applied to the rail as well as a wide range of commercial vehicles. This company also produces other products such as automatic door systems, rail vehicle air conditioning systems and torsional vibration dampers for internal combustion engines. For Konrr-Bremse, it has several core products and some of the products can be used for multiple applications. Similarly, Kolowag produces wheelsets as well as wagons. For wagons, it produces a diverse array of passenger and freight wagons. Ansaldo STS produces signaling and automation system for rail companies and for transit operators. It also produces Automatic Train Control System (TVM) and European Railway Traffic Management System (ERTM) systems for the high speed rail industry.

Kontron, for example, has a rather complex product portfolio. The company’s production of embedded computer system demands different technology for global and local application in rail industry. For the same application, Kontron’s embedded computer systems are different across project. Furthermore, the computer systems can be applied to energy, medical and military uses. The embedded computer systems of Kontron are both in different type for the same application and also have different kind of applications. That is, a mix of product diversification and multiple products within each category.

The product portfolio for word leading companies like ABB is even more complex. ABB is a Swiss-Swedish multinational corporation, operating mainly in the power and automation technology areas. The company offers power system for rail industry as well as the marine industry. The power systems supplied can be totally different even in the same industry. For example, the power system applied to Alstom’s high speed rail is not exactly same with that of Siemens, though both of them are power system for high speed rail. Besides the power system, it can produce industrial robots which are used in a broad spectrum of railway applications as well as the automotive manufacture. The power systems and the robot are totally different products.
Many companies in HSR industry link economies of scale and scope to current technology and methods of production.

The multi-product nature will influence the cost structure of the firms, and thus influence their R&D strategy. This will future discuss in section 5.

CHAPTER 5

MULTIPRODUCT FIRMS

As briefly indicated in the discussion in section 4.3.2, the internal product structure of firms in this industry is highly complex, more so than is apparent at a cursory glance. For example, the degree of product differentiation and diversification is much higher in some firms than in others. Some firms produce different products in the same industry, while others offer an array of related products but for several different industries. In this section, we discuss these aspects and comment on the business strategies that may influence the production decision-making process of the multiproduct firms in this industry's supply-chain.

Among the important factors that result in firms pursuing a multiproduct strategy are production costs and synergies in technologies possessed by the firms. So in section 5.1, we will review theories about cost of multiproduct firms and applied it to HSR industry. After that, we will carefully study the R&D strategy, one of the most import business strategies of firms in HSR industry since large numbers of advanced technologies are involved in production process. R&D strategy is influenced by the cost issues in terms of economies of scale and scope and also one of the key determinations of product structure within firms.

5.1 Cost of multiproduct firms

The multiproduct strategy can be analyzed from the cost level. One of the important issues to consider in multiproduct setup is economies of scope and scale. This can be seen from two aspects in HSR industry (Pedro and Javier, 2005). First, is it more efficient for a single firm, rather than several separate firms, to supply different HSR components? Second, if different components are separated, will the supply of these components be more efficient within the context of a monopoly, or should two or more firms participate?

Cost function in multiproduct firms is different from that in single product firms. In this section, we will first review existing literature in economies scale and scope and then relate it to the high speed rail industry.

5.1.1 Economies of scale and scope: theoretical considerations

Economies of scale are common in single product firms, while economies of scope are new concept for the multiproduct firms. Whether exist or not in single product firms, the measurement and sources may be different when applied to the multiproduct setup. In this section, we will review the definition and measurement of economies of scale and scope theoretically.

Scale economies are often defined to be present when k-fold proportionate increase in every input quantity yields a k'-fold increase in output, where $k'>k>1$. Baumol (1977) define strict economies of scale as in the production of outputs in N are present if for any initial input-output vector $(x_1, \dots, x_r, y_1, \dots, y_n)$ and for w>1, there is a feasible input-output vector $(wx_1, \dots, wx_r, v_1y_1, \dots, v_ny_n)$ where all $v_i \geq w + \sigma$, $\sigma > 0$.

For single product firms we use the following expression to measure the degree of scale economies:

$$(1)\ S = \frac{C(y)}{yC'(y)} = \frac{AC(y)}{C'(y)} = \frac{\text{average cost}}{\text{marginal cost}}.$$

Returns to scale are increasing, decreasing or constant as S is greater, less or equal than unity. However, S cannot be applied to measure the degree of scale economies in multiproduct cases for the reason that a multiproduct cost function possesses no natural scalar quantity over which costs may be “averaged”. For the multiproduct firm, Baumol

(1977) and Panzar and Willig (1977) generate two basic measures in the set of multiproduct firms: Product-Specific Economies of Scale and Ray Economies of Scale. In such two frames of defining economies of scale, the main point is the definition of the average cost.

Ray economies of scale is a straightforward extension of the concept of single-product economies of scale. In defining the degree of scale economies over the entire product set, Baumol, Panzar and Willig (1982) first define the Ray Average Cost (RAC) to measure the average cost of the composite good defined as $\mathrm{RAC} = \frac{C(ty^0)}{t}$; where y^0 is the unit bundle for a particular mixture of outputs-the arbitrary bundle assigned the value 1--- and t is the number of units in the bundle $y = ty^0$. So the degree of scale economies defined over the entire product set, $N = \{1, \dots, n\}$ at y is given by(2)

$$(2)\ S_N(y) = \frac{C(y)}{y \cdot \nabla C(y)} \equiv \frac{C(y)}{\sum_{i=1}^{n} y_i C_i(y)},$$

where $C_i(y) \equiv \partial C(y)/\partial y_i$. Return to scale are said to be increasing, constant or decreasing as S_N is greater than, equal to or less than unity, respectively.

The measure of multiproduct economies of scale by ray economies scale can only describe the behavior of costs as output expands or contracts along a given ray. It doesn't describe the full behavior of costs as output bundles change. So Panzar and Willig (1977) propose another dimension of economies scale that is product-specific economies of scale.

For product-specific economies of scale, instead of defining average cost as the single product, we use the concept of Average Incremental Cost (AIC) as part of the measurement of product-specific economies of scale.

The average incremental cost of product i is defined as $AIC_i(y) \equiv \frac{IC_i(y)}{y_i}$, where the incremental cost of the product $i \subseteq N$ ($IC_i(y)$) is given as $IC_i(y) \equiv C(y) - C(y_{N-i})$ and y_{N-i} is a vector with a zero component in place of y_i and components equal to those of y for the remaining products. Then, we can use the (3) to measure the degree of scale economies specific to product i at output vector y.

$$(3) \quad S_i(y) = \frac{IC_i(y)}{y_i C_i} \equiv \frac{AIC_i}{\frac{\partial C}{\partial y_i}}.$$

Returns to the scale of product i at y are said to be increasing, decreasing or constant as $S_i(y)$ is greater than, less than, or equal to unity, respectively.

When we extend the definition to a product set, the degree of scale economies specific to the product set $T \subseteq N$ at y is given by (4)

$$(4) \quad S_T(y) \equiv \frac{IC_T(y)}{\sum_{j \in T} y_i C_j(y)} \equiv \frac{1}{1+e_T},$$

$IC_T(y)$ is defined as the incremental cost of the product set $T \subseteq N$ at y which is given by (5):

$$(5) \quad IC_T(y) = C(y) - C(y_{N-T}),$$

where y_{N-T} is a vector with zero components associated with the products in T and components equal in value to those of y for product N-T, and e_T is the elasticity of average incremental cost of T at y.

After dividing the product set N into two disjoint subsets, T and $N - T$, one can define the multiproduct degree of scale economies as $S_N(y)$ which is denoted by (6)

(6) $S_N = \frac{\alpha_T S_T + (1-\alpha_T) S_{N-T}}{(IC_T + IC_{N-T})/C}$,

where $\alpha_T = \frac{\sum_{j\in T} y_i C_j}{\sum_{j\in N} y_i C_j}$.

Economies of scope relates to a different characteristic for the multiproduct firms. Economies of scope happen when the cost of producing output (products) 1 and 2 jointly is less than the total cost of separate production. The existence of economies of scope creates incentives for specialty firms to merge and become multiproduct firms.

Panzar and Willig (1981) define economies of scale as follows. Let $N = \{1,2, \dots, n\}$ denote the set of products under consideration, with respective quantitiesy $= (y_1, \dots, y_n)$. Let y_s denote the n-vector whose elements are set equal to those of y for $i \in S \subset N$ and 0 for $i \notin S$. The function $C(y_S, w)$ denotes the cost of producing only the products in the subset S, at the quantities indicated by the vector y. Here, C(y ,w) is the usual multiproduct minimum cost function and w is the vector of factor prices. Let T= $\{T_1, \dots, T_l\}$ denote a non-trival partition of $S \subset N$. That is $\cup_i T_i = S$, $T_i \cap T_j = \phi$ for $i \neq j$; $T_i \neq \phi$, and l>1. There are economies of scope at y_s and at factor price w with respect to the partition Tif $\sum_{i=1}^{l} C\,(y_T, w) > C(y_S, w)$.

The economies of scope are weak if the inequality is weak (rather than strict), and diseconomies of scope if the inequality is reversed.

The degree of economies of scope at y relative to the product set T can be measured by (7):

(7) $SC_T(y) \equiv \frac{[C(y_T) + C(y_{N-T}) - C(y)]}{C(y)}$,

The degree of economies of scope measures the relative increase in cost that would result from a splintering of production of y into production lines T and $N - T$. Such a fragmentation of the firm increases, decreases, or leaves unchanged the total cost as SC_T is greater than, less than, or equal to zero, respectively.

Panzar and Willig (1981) obtain the multiproduct cost function, which embodies the least costly way of producing y_s by solving (8):

$$(8) \quad C(y_s) \equiv \min_k \sum_{i \in S} V^i(y_i, k_i) + \Psi(k, \beta),$$

Where V^i represents the minimum variable cost of producing the output y_i using k_i units of capital services. The quasi-public input cost function, $\Psi(k, \beta)$ represents the cost of acquiring the requisite vector k of capital services, where β represents relevant factor prices.

Panzar and Willig (1981) demonstrate that for any nontrivial partition of N, there are economies of scope if and only if Ψ is strictly subadditive in the relevant range, which illustrates the equivalence between the existence of economic of scope and the shared input.

Squires (1987) points out two sources of sharable inputs and therefore economies of scope exist: the interdependent production process and allocatable (quasi-) fixed factors. An interdependent production process leads to economies of scope through local cost complementarities. If the multiproduct cost function can be represented as $C(Q_1, Q_2)$, where Q_1, Q_2 are two different products, cost complementary is $\Delta MC_1/\Delta Q_2$<0, which means the marginal cost of producing good 1 declines as more of good 2 is produced. Risk minimization, the quasi-public nature and lumpiness of capital, the reuse of input by more than one product, economies of network and the high cost of achieving information and the organizational and strategic impediments to its market transfer are all considered as reasons for local cost complementarities (Bailey and Friedlaender, 1982).

Another possible source for shareable inputs relates to allocatable fixed factors which generate jointness and hence economies of scope. The existence of the allocatable fixed factors will make the marginal allocation of variable inputs depend upon the allocation of the fixed input, and generate product-specific fixed costs. For example, when we use the sheep to jointly produce mutton and wool, the cost would be less than we use part of sheep produce mutton and the others for wool. The shared factor, sheep, does lead to economies of scale, though conventionally, mutton and wool don't seems have any relationship with each other.

5.1.2 Economies of scale and scope: econometric considerations

To demonstrate the existence of the economies scale and scope in HSR industry, we first need to know how to empirically measure the economies of scale and scope for multiproduct firms in real world. To estimate the economies of scale and scope, we should estimate the cost function of the multiproduct firms, which the methodology is different from the single product firms. After reviewing the cost function form of the multiproduct firms, we give examples in estimating economies scale and scope in different industries to guide the analysis of the HSR industry.

Econometric Functional Forms

Since the early work of Cobb and Douglas (1928), empirical studies of production and cost have generally assumed that production process involves single output produced from aggregate capital and aggregate labor input. However, a number of empirical studies show the importance of material and energy inputs as well as heterogeneous labor and capital input and the existence of multiple output of the production process.

For a multiproduct firm, the total cost of production can be expressed as $C(Y, W)$, where Y is an m-dimensional vector of output levels, and W is an n-dimensional vector of input prices. The regularity conditions on C are that it should be non-negative, real valued, non-decreasing, strictly positive for non-zero Y, and linearly homogeneous[21] and concave in W for each Y.

For empirical study, one needs to specify the functional form for C. To make the estimation consistent with theoretical framework, MCF should be linearly homogeneous in input prices and output levels, be parsimonious in parameters, and contain the value zero in the permissible domain of output quantities. There are four forms that are possible candidates to represent the multiproduct cost functions.

First, Diewert (1971) proposed the generalized Leontief function form. Hall (1973) postulated the following "hybrid Diewert" multiproduct cost function (HDMCF):

$$(9)\ \ C = \sum_{i}^{m} \sum_{j}^{m} \sum_{k}^{n} \sum_{l}^{n} \alpha_{ijkl} (Y_i Y_j W_k W_l)^{\frac{1}{2}}.$$

HDMCF imposes the constant returns to scale assumption on the relationship between total cost and the output levels, satisfies the linear homogeneity of input prices requirements and permits zero output values. However, it is cumbersome due to the large numbers of parameter to be estimated. [22]

Second, Burgess (1974) used the following translog functional form to represent the multiproduct cost function (TMCF):

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[21] $C(W, Y)$ is linearly homogenous in input price if $C(Y, \lambda W) = \lambda C(Y, W)$

[22] When restricted to constant return to scale, HDMCF has $(m(m+1) + n(n+1))/4$ parameters to be estimated. TMCF has $m(m+1)/2 + n(n+1)/2$ parameters to be estimated. So the number or parameters to be estimated for HDMCF is exceed that for that for the TCM except when there are only two input and two output

(10) $C =$

$$\alpha_0 + \sum_i^m \alpha_i \ln Y_i + \sum_i^n \beta_i \ln W_i + \frac{1}{2}\sum_i^m \sum_j^m \delta_{ij} \ln Y_i \ln Y_j + \frac{1}{2}\sum_i^n \sum_j^n \Upsilon_{ij} \ln W_i \ln W_j + \sum_i^m \sum_j^n \rho_{ij} \ln Y_i \ln W_j.$$

Equation (10) satisfies the linear homogeneity of input prices when imposing an appropriate linear restriction.[23] When restricted to be linearly homogeneous in prices, the TMCF dominates both the QMCF and HDMCF in terms of numbers of parameters to be estimated.[24] However, for the third requirement, since all of the output in TMCF is in logarithmic form, it cannot permit zero output values, hence will not satisfy the third requirement.

Third, Lau (1974) suggest the third form is the following quadratic MCF(QMCF) that is also very flexible:

$$(11)\quad C = \alpha_0 + \sum_i^m \alpha_i Y_i + \sum_i^n \beta_i W_i + \frac{1}{2}\sum_i^m \sum_j^m \delta_{ij} Y_i Y_j + \frac{1}{2}\sum_i^n \sum_j^n \gamma_{ij} W_i W_j + \sum_i^m \sum_j^n \rho_{ij} Y_i W_j.$$

Though the number of parameter to be estimated is less than the HDMCF but larger than TMCF and the third requirements about the zero output value can be easily satisfied, the function is not linearly homogeneous, which is contrary to the first requirement.

Fourth, considering the flaws of the previous three functional forms, Cave, Christensen and Tretheway (1980) proposed the following generalized translog Multiproduct Cost Functions (GTMCF) that avoids some of these problems:

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[23] For example, we can impose the restriction: $\sum_i^n \alpha_i = 1$, $\sum_j^n \gamma_{ij} = 0$, $\sum_j^n \delta_{ij} = 0$. In addition, assume all the technical change to be Hicks neutral, so that the cost and revenue shares are invariant with respective changes in the technology index.

[24] TMCF only have $m + n + 1$ parameters to be estimated

$$(12)\quad C = \alpha_0 + \sum_i^m \alpha_i\left(\frac{Y_i^\lambda - 1}{\lambda}\right) + \sum_i^n \beta_i \ln W_i + \frac{1}{2}\sum_i^m \sum_j^m \delta_{ij}\left(\frac{Y_i^\lambda - 1}{\lambda}\right)\left(\frac{Y_j^\lambda - 1}{\lambda}\right) + \frac{1}{2}\sum_i^n \sum_j^n \Upsilon_{ij} \ln W_i \ln W_j + \sum_i^m \sum_j^n \rho_{ij}\left(\frac{Y_i^\lambda - 1}{\lambda}\right) \ln W_j.$$

Though the GTMCF has one more parameter than the TMCF, it is still far more parsimonious in the parameters than HDMCF. By imposing the same restrictions as the TMCF specification, the linear homogeneity condition can be met. Furthermore, by removing the logarithmic form from the output level, the output level can be equal to zero, which makes the third requirements holds in this case. To estimate the above equation efficiently, one always applies the shepard's lemma to achieve the cost share equations which form the multivariate regression system jointly with the total cost function.

Evidence on economies of scale and scope: selected estimates

Jara-Diaz et al. (2002) uses the QMCF to estimate the cost function for the infrastructure service of Spanish ports. They used data from a pool that covers 26 Spanish ports from 1985 to 1995. The dependent variable is the total annual cost (TC) for infrastructure and its administration, includes labor (G_L), amortization (G_k), and other expenses (G_I) directly obtained from port report. The explanatory variable including five products and three indices for input price.

Their total cost function is given by (13):

$$(13)\quad C = f(CGC, NCGC, DB, LB, CANON, l, m, c),$$

where CGC, NCGC, DB, LB, CANON represents the different output of the ports service[25]; l is the labor input price which is calculated as the total labor expenditure over the total number of employees; m is intermediate input price index and is constructed as the sum of consumption, services externally provided plus other expenses, and an index of total activities represented by the annual revenue. Finally, c is total capital price obtained as its actual economic value divided into the total dock length as a proxy for the amount of physical capital.

The estimated cost function is as follows:

$$(14)\quad C(w,Y) = \alpha_0 + \textstyle\sum_i^m \alpha_i(y_i - \overline{y_i}) + \sum_i^n \beta_i(w_i - \overline{w_i}) + \sum_i^m \sum_{j\geq i}^m \alpha_{ij}(y_i - \overline{y_i})(y_j -$$

yj)+inj≥inβij(wi−wi)(wj−wj)+imjmδij(yi−yi) (wj−wj)+ε,

$\overline{y_i}$ and $\overline{w_i}$ are represented the sample-average variables. Y represents the output vector and W represents the input vector.

Application of Shephard’s lemma yields the input share equation (15):

$$(15)\quad G_i = w_i x_i^* = w_i(\beta_i + 2\beta_{ii}(w_i - \overline{w_i}) + \textstyle\sum_{j\neq i}^n \beta_{ij}\left(w_j - \overline{w_j}\right) + \sum_{j\neq i}^m \delta_{ij}\left(w_j - \overline{w_j}\right),$$

Using the coefficient of the total cost function, they calculate the following marginal costs for the five products for all the ports at their corresponding mean values of output and prices:

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[25] CGC is the containerized general cargo; NCGC is non-containerized general cargo; DB is dry bulk; LB is liquid bulk; CANON is the total rent received which used as a proxy of output representing other activities that induce expenses in infrastructure.

$$(16)\quad m_i = \alpha_i + 2\alpha_{ii}(y_i - \overline{y_i}) + \sum_{j\neq i}^{m}(y_j - \overline{y_j}) + \sum_{j}^{n}(w_j - \overline{w_j}),$$

Then using the total cost function and the marginal cost function for each product, they calculate the degree of economies of scale. Also, since zero is in range of the variation for most observed outputs, they can calculate the degree of economies of scope directly by definition.

Empirical results show that increasing return to scale are present in general and are smaller for the largest ports. On the other hand, scope analysis suggests that specialization might not be appropriate in terms of port infrastructure and again smallest ports show the largest economies of scope. Findings at scale economies and scope economies

Kim (2001) used cross-section of 60 utilities for 1973 from the data that were collected during a survey of water utilities in the United States over a ten-year period by the US Environmental Protection Agency (USEPA) to estimate the multiproduct joint cost function for water supply industry using the translog cost function specifications. He assumes there are two kinds of products for the water supply industries, one residential and another non-residential.[26]

The total cost function is given by:

$$(17)\quad C = C(Y_R, Y_N; W, Z),$$

where Y_R and Y_N denote the residential and non-residential outputs respectively. W is a set of input which is composed as the input prices of labor (W_L), capital (W_k) and energy

[26] Residential water is the water delivered to residences for the purpose of normal living and includes that used by all single- and multi-family dwelling units and apartments. Non-residential water is the water delivered to industrial, commercial, wholesale and other users.

(W_E). Z describes a set of “operating” variable including the capacity utilization (Z_U) [27] and service distance (Z_M)[28]. Output is measured in terms of amount of water treated, in millions of gallons per day. Labor cost is obtained by dividing the gross payroll by the number of yearly man-hours. Capital costs constructed here are long-term interest plus depreciation charges, which cannot consider as the true economic costs and therefore must be considered as approximate costs of capital. Energy costs are estimated by dividing total power expenditures by yearly kilowatt-hour usage. Capability utilization represents the relationship between the average rate of plant usage and capacity, which in this research is measured by the load factor for a water system. Service distance is the total number of miles of pipe in the utility service area.

The input share equation can be obtained while the Shephard’s lemma:

$$(18)\quad S_j(Y, W, Z) = b_j + \sum_q b_{jq} W_q + \sum_i d_{ij} \ln\ Y_i + \sum_k f_{jk} \ln Z_k,$$

where $S_j = \frac{W_j X_j}{C} = \partial \ln C \,/\, \partial \ln W_j$, the share of the total cost accruing to input j. Since the cost function should be linearly homogeneity in input prices, the sum of S_j is constrained to be unity.

To evaluate the product-specific economies of scale for residential output and nonresidential output, one needs the AIC for the two products. That is:

$$(19)\quad AIC_R(Y, W, Z) = \frac{[C(Y_R, Y_N; W, Z) - C(0, Y_N; W, Z)]}{Y_R};$$

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[27] Since water utilities are extremely capital-intensive, relatively small differences in capacity utilization rates can result in substantial differences in input usages and other product characteristics of the utility. For this reason, the capacity utilization rates are incorporated in the model.
[28] Considering spatial variation of demand, service distance is explicitly included.

$$(20)\quad AIC_N(Y, W, Z) = \frac{[C(Y_R, Y_N; W, Z) - C(Y_R, 0; W, Z)]}{Y_N}.$$

As a result, besides the joint cost function, the calculation also requires the stand-alone cost function for $C(0, Y_N; W, Z)$ and $C(Y_R, 0; W, Z)$.

However, all of the variables in the translog forms enter as a logarithmic form which makes it difficult to estimate the functions of zero level residential or non-residential output. To solve it, he estimates the cost at an arbitrary small level of output - say 10% of the output at the sample mean.

The overall degree of economies of scale can be obtained as the inverse of the sum of cost of elasticity of a single product. The cost elasticity of the ith output can be expressed as follows:

$$(21)\quad \varepsilon_{CY_i}(Y, W, Z) = \alpha_i + \sum_p \alpha_{ip} \ln Y_p + \sum_j d_{ij} \ln W_j + \sum_k e_{ik} \ln Z_k.$$

Result shows that the water supply industry is subject to constant return to scale. Regarding product-specific economies of scale, the water supply utility industry suffers substantial economies of scale for non-residential water supply but suffers diseconomies of scale for residential water supply.

The Appendix D provides additional details on estimates.

5.1.3 Economies scale and scope in the HSR industry

Appendix D shows that the economies of scale and scope exist in nearly all industries. Considering the production procedure of the rail industry, the economies scale and scope are likely to exist in HSR industry. In this section, we discuss the possible existence of economies scale and scope of the firms in the HSR supply-chain diagram.

The fixed factors used to produce single product can leads directly to economies of scale. For example, many firms use assemble line production with human labor that is economical for single product in large scale, which can best lead to the economies of scale. That's why the major trainset suppliers are usually in large size. If the fixed factors exist in producing multiple products, the economies of scope will come up in production. For example, Czech Republic's company Bonatrans can use the same assembly line to produce bearing systems, brake disks on wheels and axles, noise absorbers, etc, while producing the wheelset. Also, the heating facilities are flexible to handle different kinds of wheelsets like regular rail wheelsets and the high speed rail wheelsets. Suppose that, if the company only produce single product, these shared factors cannot be fully used and will lead to less profit compared with the multiproduct production.

Besides sharing the tangible assets, some intangible shared factors like research activities and other forms of economies knowhow are also a key source for economies of scale and scope. If the company has mature technology for a specific product, the company will invest only less proportion of R&D to produce similar products for industries, since a lot of the technology may be similar. Furthermore, the production of different products required similar knowledge may create high transaction cost while produced by different companies separately, which makes the transfer difficult. As a result, internal trading within a single firm is less costly compared with trading between different firms. For example, Kontron offers a variety of Box PCs which are used in a variety of industries including medical, security, gaming and transportation. The Box PCs are designed to meet the configuration requirements of all OEM solutions, thereby reducing development costs. Similarly, ABB has the engineering capability, experience and its own technologies to deliver "turnkey" system integration of electrical Balance of Plant specifically tailored to different power plant types, such as oil & gas fired combined cycle power plants, coal fired boiler power plants and hydro power plants as well as industrial sized turbine and boiler power applications. The R&D strategy of multiproduct firms will discuss in depth in section 5.2.

The products jointly produced by a single firm correlate with each other. Some intermediate products may become the input for other product. In this case, economies of scope will arise because such intermediate products manufactured by the firms are freely available for use in provision of a second product. Take Bonatrans as an example again. Bonatrans develops, manufactures and delivers a complete range of wheelsets, wheels, axles and tires for all types of railway vehicles. The wheels, axles and tires can be aggregated to form the wheelsets. So the cost will be reduced since Bonatrans can get the intermediate component of the wheelsets flexibly.

5.2 R&D in multiproduct firms

HSR industry involves a lot of advanced technologies, which requires large number of R&D investment while firms developing these technologies. The R&D strategy of the multiproduct firms will determine the product structure within firms and influence the economies of scale and scope. Firms need to make several decisions on R&D investment. First, they need to decide the composition of two types of R&D, which are product R&D and process R&D. The product R&D refers to the R&D used to improve the quality of existing products and create the new products, while the process R&D is R&D aiming at lowering the cost of making existing products[29]. Firms are different in choosing the composition of these two types of R&D due to the cost and other issues. Second, since firms are multiproduct, they will need to decide the distribution of the R&D among products. In this section, we will review literatures to

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[29] See https://editorialexpress.com/cgi-bin/conference/download.cgi?db_name=esam06&paper_id=272

study the factors that may affect the R&D strategies within the firms and use the theoretical foundation to explain the R&D strategy of firms in HSR industry.

5.2.1 Theoretical considerations

Firms are different in the degree of process and product innovation in which they engage. For example, in petroleum refining firms, almost three-quarters of total R&D is dedicated to process innovation. However, in the pharmaceutical industries, only one-quarters of total R&D go to process innovation. Also, American firms are always criticized for not devoting a greater share of R&D to improve their manufacture process and focusing more on short term R&D project. In contrast, Japanese firms are not conducting enough basic research and focusing more on process innovation. The existence of such differences has long been studied.

Link (1982) found the property of the product will influence the choice of the R&D portfolio and proposed that the greater product complexity increases the effort dedicated to process innovation. However, Cohen and Klepper (1994) believe there may be more at work in determining the composition of R&D than only exogenous industry-level conditions. Most theoretical and empirical research suggest that firm size, market structure and industry concentration may influence the composition of R&D.

Cohen and Klepper (1994) proposed theory to show how firms size conditions influence the relative amount of process and product innovation undertaken by firms. In the paper, the profit for the firms that conducting the process R&D can be represented as:

$$(22)\quad \pi_1 = a_1 q p c_1(r_1) - r_1,$$

where a_1 denotes the length of time before process cost saving are matched. q is the firm's output when it conducts process innovation. r_1 is the firm's spending on process

R&D , and $pc_1(r_1)$ represent the decrease in the firm's average cost from its process R&D.[30]

The profit function for firms with product R&D can be represented as

$$(23) \quad \pi_2 = a_2(hq + K)pc_2(r_2) - r_2,$$

where a_2 reflects the length of time before the new product variant is imitated.r_2 is the firms spending on product R&D, and $pc_2(r_2)$ is the price-cost margin earned on the new product variant. h denotes the fraction of firm's existing buyers that purchase the firm's new product and K is the additional output from which the firm earns rents through licensing and sales to new product.

The two profit function preliminarily indicates the share of process R&D share tends to increase with firm size. From π_1, the returns to process R&D are directly proportional to the firms' output, while in π_2 the returns to product R&D do not rise in proportion to q. The relationship between p and q further demonstrates the trends further. The basic idea is that the returns to innovative activity are generally tied to firm size because firms typically expect to exploit their innovations chiefly through their own output and to grow slowly over time due to innovation. Product innovations may be expected to yield greater returns from licensing and to spawn more rapid growth in output than process innovation. Consequently, the returns to product innovation should depend less on the returns to process innovation, causing large firms' R&D cost spreading advantage is particular pronounced for process relative to product R&D.

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[30] To reflect the idea that more process R&D yields greater manufacturing cost reductions but at a declining rate, they assume that $pc'(r_1) > 0$ and $pc''(r_1) < 0$ for all $r_1 \geq 0$. Similarly, $pc(r_2)$ has the same property

Cohen and Klepper (1994) only focus on the firm size within a given product market and not on the overall size of a multiproduct firm. Yin and Zuscovitch (1997) incorporate product innovation and process innovation into a duopoly model of multiproduct firms to study the relationship between the firm size and the incentive for product and process innovation. As most R&D literature, they assume that firms participated in the duopoly model would play two-state game: they first determine their process and product innovation strategies x^i and y^i simultaneously. Then based on the R&D strategies, they will engage in Cournot competition in the second stage game. The equilibrium can be got from the standard subgame-perfect Nash equilibrium.

In their models, demand is in linear form and the large firms are defined as the firms with low marginal cost. When the new product is introduced to the market, the inverse demand for both commodities becomes:

$$(24) \quad p^i = l - m(q^{a1} + q^{a2}) - n(q^{b1} + q^{b2}),$$

where $m > n > 0$; that is, commodity a and b are substitute the effect of a commodity's quantity on the price is greater than the effect of the substitute.

Once innovation takes place, firm i's profit in the second stage subgame is

$$(25) \quad \pi^i(\vec{q}, C^i) = (p^a - C^i)q^{ai} + (p^b - c)q^{bi},$$

where $\vec{q} = (q^{a1};\ q^{a2};\ q^{b1};\ q^{b2})$ is the output vector; $C^i = c^i - y^i$is firm i's post-innovation unit cost of good a; and c is the unit cost of the new product b, which is assumed to be the same for both firms.

In the first stage the payoff for firm i is [31]

$$(26)\ V^i(x^i, x^j, y^i, y^j, c^1, c^2)$$
$$= x^i[x^j\pi^i(\overrightarrow{q_1}, C^i) + (1 - x^j)\pi^i(\overrightarrow{q_2}, C^i)]$$
$$+ (1 - x^i)[x^j\pi_i(\overrightarrow{q_3}, C^i) + (1 - x^j)\pi^i(\overrightarrow{q_4}, C^i)] - f(x^i) - g(y^i)$$

Besides the static model, they also make dynamic adjustment based on the real world situation that innovation activities need time to produce outcomes. By taking the other ways of R&D as exogenous while studying one type R&D, they derived the existence of a unique equilibrium where large firms invests less in product innovation and more in process innovation than the small firm. Also, the increasing of one type R&D for one firm leads to the reduction of the rival's marginal benefit from investing in this type of R&D. They also propose that the effect of market power on innovation strategy depends on the extent to which a new technology replaces the existing one. Finally, they prove that in the post-innovation market, the large firm is the leader for the old good while the small firm is the leader for the new good in the sense of expected output.

Intuitively, firm's initial market share will influence the composition of R&D in terms of product and process R&D. Large firms possessing more market share will benefit more from the cost reducing process innovation than the small firms. However, they will bear more profit less in terms of the old products when a new substitute comes up. Also, for the small firms, product innovation will help them overcome the competitive disadvantage, which provides them incentive to invest more on product

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[31] $\overrightarrow{q_k}\ k = 1, 2, 3, 4$ characterize the equilibrium output vectors of four cases as follows: (i) both firms succeed in introducing the new product; (ii) firm i succeeds, but its rival fails; (iii) firm i fails, but its rival succeeds; (iv) both firms fail.

R&D. In other world, large firms rely on a cost gap to generate efficiency gains, while small firms prefer to seek transitory profits from a shift in demand structure.

Petsas and Giannikos (2005) develop a differentiated-goods duopoly model in which firms engage in Cournot-Nash quantity competition to study the same question. In their model, labor is assumed to be the only primary factor of production. Firm size is measured by the firm's sales and the firm's sales are proportional to the number of goods produced. Moreover, instead of studying the static case, the paper focuses more on the evolution of the technological progressive industries from birth through maturity. Firms are assumed not to attend the production process until product innovation has slowed sufficiently.[32]

Based on the assumptions above, the model shows that the number of goods produced by a firm is a decreasing function of its in R&D cost from product innovation and increasing function for the process innovation. The results support the product life cycle (PLC) theorem that the firm starting with product R&D increases the incentive to switch from product to process innovation as the number of goods produced increases and thus its size increases. Once the firm is in the process R&D, it will continue to perform process R&D indefinitely, which means large firms have no incentive to do product R&D.

There are also several papers studying the R&D investment of monopoly market. Lambertini (2003) study the monopolist R&D portfolio to determine the incentive for the multiproduct monopolist to choose between process and product innovation. In this paper, total cost of the firm is given by:

[32] To some degree, this assumption is reasonable. However, some industries like automobile, tires and antibiotics contradicts the assumption: history of these industries indicates that great improvements were made in the production process well before the emergence of any key dominant design.

$$(27)\quad C(Q,k) = c(k)\sum_{i=1}^{n} q_i + \xi k^2 + \theta nF,$$

where $Q \equiv (q_1 q_2, \dots, q_n)$ and $F > 0$ is the fixed cost of introducing a product; θ is scope economies parameter in production with $\theta \in [0,1]$ for $n > 1$ and $n = 1$. Variable k represents the level of process R&D.[33] By maximizing the monopoly the profit, the first order result is

$$(28)\quad c'(k) = -\frac{4\xi[1+\gamma(n-1)]}{n[\alpha-c(k)]},$$

which indicates the that the monopolist's incentive towards process innovation is decreasing in the number of products supplied in equilibrium.

Lin (2004) pointed out that Lambertini (2003) didn't take into account the effects of a change in n on k. Considering that, Lin (2004) discuss a special case which assume the cost function form as $C(k) = \bar{c} - k$. The first order condition becomes as

$$(29)\quad 1 = -\frac{4\xi[1+\gamma(n-1)]}{n[\alpha-c(k)]},$$

which provides the result as

$$(30)\quad k(n) = \frac{a-\bar{c}}{4\xi[((1-\gamma)/n)+r]-1},$$

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[33] Note that k pertains to the (common) marginal cost of production for each product, $c(k)$. It is assumed that $c' < 0$, $c'' \geq 0$ and there is no uncertainty in R&D

In this case, k(n) is an increase function of n which contradicts Lambertini (2003) and shows that the incentive toward process innovation is increasing in the number of product supplied. The paper also gives the explanation for such result. The idea is that since cost reducing R&D lowers the unit cost of R&D, a firms' incentive to invest in process R&D is positive to the level it produces. In the model, the monopolist output is obviously with n and thus the incentive is also positive related to the number of varieties. Lambertini and Mantovani (2005) model the optimal behavior of a multiproduct monopolist investing both in process and product R&D in a dynamic setting. The finding of the paper includes: first, they find the incentive of investing in process and product R&D will increase as the number of varieties increase; secondly, if the reservation price is sufficient low, firms will devote a larger amount of resources to process innovation rather than the product innovation irrespectively of the product range and associated level of differentiation.

Some literatures focus on solve the other strategies in R&D investment. Lin (2009) attempts to investigate the incentive for multiproduct firms to investment in non-drastic[34] cost-reducing R&D. The paper considers the decision about which product firms' R&D investment should target and how much these investment should be.

In the multiproduct monopoly model, the paper assumes the monopoly produces two products and defines the product which involved low initial level of the unit cost while producing as the core product. With the assumption of the linear demand and quadratic R&D cost function, the model shows that a multiproduct monopoly conducts more on process R&D in its core product than in its non-core products. Also, if the products are closer substitutes, the firm will invest less in R&D for both product and the

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[34] An innovation is drastic if the patentee is unconstrained by outside competition and can therefore engage in monopoly pricing.

monopolist tends to choose a more specialized R&D portfolio. In this case, the firms will have a simple product structure.

In the multiproduct duopoly model, it seems that all the three effects including direct effect, business-stealing effect and cross market effect[35] is more beneficial for a firm's core product than for its non-core product. If the total R&D cost is given as the quadratic form as the monopoly model, the pattern of R&D portfolio found for a multiproduct monopoly also holds for a multiproduct duopoly that each firm in the duopoly model would like to invest more in its core product and the degree of R&D specialization increases as the products becomes more similar.

However, the model also shows some differences to the monopoly model. In the duopoly model, the degree of R&D specialization is higher than that of the monopoly model, which means the market competition will lead to a more specialized R&D portfolio. Firms' R&D investment are strategic substitutes in the same product and strategic complements[36] across the products, which indicates that a multiproduct firm can adjust its R&D portfolio to avoid competition in the same product market but fights back in other competing products. A firm will cut its R&D investment in a product if its rival increases its R&D effort in that product, but will increase its R&D investment in another competing product.

Unlike the single product firms, the multiproduct firm can internalize the negative externalities that their R&D investment generate for each other by reducing their R&D efforts for all products and refocusing such efforts on different R&D projects.

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[35] Direct effect of R&D investment states the cost-reducing R&D investment in a product raises the level of a firm's profit from that product. Business-stealing effect of R&D investment presents a firm's cost-reducing R&D investment in a product forces its rival firm to lower its Cournot output. Cross market effect means a firm's R&D investment in a product leads to an output adjustment by a rival firm in a competing product, which is unique for the multiproduct firms.

[36] The decisions of two or more players are called strategic complements if they mutually reinforce one another, and they are called strategic substitutes if they mutually offset one another.

5.2.2 Empirical Analysis

Although much empirical work has been conducted to examine the determinants of R&D investments at the firm and industry levels, research focus on the multiproduct firms is rather limited.

There are several empirical studies that based on the single product framework. With the data for 108 firms spanning twelve manufacturing industry group, Mansfield (1981) studied the relationship between firm size and industry concentration, on the one hand, and the composition R&D expenditure. The paper estimated the model in each industry as follows:

$$(31)\quad \ln b_i = \phi_1 + \upsilon_1 \ln S_i + z_{1i},$$

$$(32)\quad \ln l_i = \phi_2 + \upsilon_2 \ln S_i + z_{2i},$$

$$(33)\quad \ln n_i = \phi_3 + \upsilon_3 \ln S_i + z_{3i},$$

$$(34)\quad \ln p_i = \phi_4 + \upsilon_4 \ln S_i + z_{4i},$$

where b_i, l_i, n_i and p_i are the amount spent on basic research, projects lasting 5 or more years, entirely new products and processes and projects with less than a 50-50 estimated chance of success separately by i^{th} firm in the industry. S_i is its 1976 sales, which are used to represent the firm size.

Least-squares estimation shows that in most industries, increases in firm size are associated with more than proportional increases in amount spent on basic research, projects lasting 5 or more years, less than that on new product and process and little consistency tendency for increases in size of firm to be associated with more or less than proportional increases in the amount spent on R&D projects with less than a 50-50 estimate chance of success. The result indicates that largest firms tend to carry out a disproportionately large share of the basic research and long term R&D in most industries. However, they don't want to spend more on more risky R&D or the R&D aimed at totally new product and process innovation.

Cohen and Klepper (1994) use the FTC's Line of Business program data to test their hypothesis concerning the relationship between firm size and process R&D expressed as a share of total R&D effort. Following Scherer (1982, 1984), they distinguished process from product patents by assuming that process patents are those that were employed in their industry of origin and product patents represent the balance. Based on this, the paper used the percentage of process patents as the dependent variable.[37] To deal with the sampling error[38], they use additive industry dummies to control fro industry effect and modify the heteroscedasticity adjustment in the pooled regressions by weighting each business unit observation by $[\mathrm{T}/(\hat{p}(1-\hat{p}))]^{1/2}$, where T is the number of patents assigned to the business unit and $\hat{p}$ is the fraction of total patents in the industry of the business unit that are classified as process patents. By estimating a linear relationship model, they demonstrate that the process innovation is positively related to the total business unit sales. They also use the quadratic firm to test the increase with process innovation is at a decreasing rate.

All these two paper care more about the influence within the single product not the multiproduct cases. Limited papers are studied at the assumption of multiproduct firms. Baysinger and Hoskisson (1989) applied data from the universe of US industrial corporations included in Standard and Poor's COMPUSTAT services data base to

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[37] The percentage of process patents will undoubtedly differs from the fraction of R&D effort dedicated to process innovation due to sampling and measurement error. While Cohen and Klepper (1994) argues in the following that the measurement error will not bias the tests of their hypothesis regarding the relationship between firm size and process share.

[38] Sampling error arise for two reasons: first, on average, they only have 16.3 business unit for each of their 36 industries. Second, they don't observe p for each business unit, but can only estimate it from the patents assigned to the business units. Because the number of patents assigned to many of the business units is quite small, this introduces considerable noise into industry estimates.

identify how the choice of diversification strategy systematically affects R&D intensity in large multiproduct firms. They used regression analysis and dummy variable regression to provide information on the overall and categorical specification. The details of the empirical work can be found from the appendix. Results show that average intensity of spending on R&D differs across firms with different diversification strategies. The result of the regression analysis tends to support the hypothesis that the R&D intensity in diversified M-forms will be negatively related to a continuous measure of total diversification. Dummy variable regression shows that R&D intensity is significantly higher in the dominant-business categories relative to the related-link category and the unrelated category is significantly lower than the related-link category in R&D intensity. Firms implementing related-linked and unrelated strategies may maintain their efficiency in terms of production and information costs but may induce short-term, risk averse behavior at the division level in the process. Intense R&D seems to be specialty of dominant-business and, to some degree, related-constrained firms. In such organization it may easier for top management to reward division managers on the basis of both the quality of their strategic decisions and the outcomes of those decisions.

5.2.3 R&D in HSR industry

The above discussion shows that the size of the firm will influence the composition of R&D in terms of process and product R&D. All the literatures agree on that large firm will tend to conduct more on process R&D, while smaller firms tend to invest more on product R&D. This can explain one of the common strategic partnerships in HSR industry. While working on HSR project, one big company providing engineering, manufacturing or product development services, will partner with a smaller, entrepreneurial firm or inventor to create a specialized new product[39]. For example, while building the German ICE, Siemens cooperated with several local components manufactures. Siemens supplies capital, and the necessary product development, marketing, manufacturing, and distribution capabilities, but not in charge of supplying many specialized technical or creative expertise, which is done by the small local component suppliers.

Many small size components suppliers in the supply-chain diagram focus more on product innovation. For example, the share of Bonatrans design products is growing significantly. While in the mid 1990s Bonatrans' designs represented only approximately 4% of total deliveries from Bonatrans, in 2009 the share exceeded 47%. This documents the shift from mere manufacturer towards provider of comprehensive services. The Bonatrans research team is engaged in development of new materials, products and technologies that improve the utility value of our products for our customers and that respond to current and future needs of customers.

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[39] See http://en.wikipedia.org/wiki/Strategic_partnership

CHAPTER 6

BUSINESS STRATEGY IN HSR MARKET

Based on the above analysis, it is clear that HSR is a complex industry and involves numerous advanced technologies, products and services. Consequently, an individual company often needs to form partnerships and alliances with other companies in the industry to bid for and complete projects. Thus, partnerships and alliances become one of the important business strategies in bidding for the international HSR contracts. In this chapter we examine issues related to such collaborations and study contracts and partnerships in international HSR contracts.

6.1 Definition of partnership

Partnership, or consortium, is defined as purposive strategic relationships between independent firms, who share compatible goals, strive for mutual benefits, and acknowledge a high level mutual interdependence (Mohr and Spekman, 1994). The cooperative behaviors characteristic of partnerships include long-term purchasing agreements, joint marketing programs, shared research and development programs, and equity-based relationships. Partnerships may be horizontal (between suppliers) or vertical (between suppliers and buyers) (Vlosky and Wilson, 1997).

There are two forms of partnerships[40]: (1) general partnership and (2) limited partnership. In a general partnership, the partners divide responsibility for management, liability and their share of the business' profits or losses. Shares are assumed to be equal unless a written agreement states differently. Joint venture is a common general partnership, but the partnership is formed for a clearly defined or limited period of time or is formed for a single project. In a limited partnership, most of the partners (to the

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[40] See http://www.justia.com/business-formation/docs/forms-of-partnership.html

extent of their investment) have limited liability, along with limited input in management decisions. While this can encourage and help obtain investors for short-term projects or for investing in capital assets, this form of ownership is not often used for operating service or retail businesses. Limited partnerships have a more complex and formal structure than general partnerships.

A formal partnership between two commercial enterprises is called strategic partnership. One common strategic partnership involves one company providing engineering, manufacturing or product development services, partnering with a smaller, entrepreneurial firm or inventor to create a specialized new product. Typically, the larger firm supplies capital, and the necessary product development, marketing, manufacturing, and distribution capabilities, while the smaller firm supplies specialized technical or creative expertise. Another common strategic partnership involves a supplier manufacturer partnering with a distributor or wholesale consumer. Rather than approach the transactions between the companies as a simple link in the product or service supply chain, the two companies form a closer relationship where they mutually participate in advertising, marketing, branding, product development, and other business functions.[41]

Many research on partnership posited theories to support the partnership. The formulation of the partnership is motivated primarily to gain competitive advantage in the marketplace. First of all, partnership can take a form to access new technologies or markets and companies can provide a wider range of products or services via certain partnership. Second, partnership can minimize the transaction costs and increase economies of scale in joint research or production. Last but not least, partnership firms access knowledge beyond their boundaries (Powell, 1987; Jakki and Robert, 1994) .

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[41] See http://en.wikipedia.org/wiki/Strategic_partnership

Partnerships, however, can also cause complications in business relationships. For example, partnerships may cause one company rely too much on the other and lose autonomy (Mohr and Spekman, 1994).As an example, on 24 March 2001, Siemens won one half of RENFE's tender to supply 32 high-speed trains for the Madrid-Barcelona high-speed rail line, offering a modified version of the ICE 3 high-speed train used by German Railways (Deutsche Bahn) for its InterCity Express service. The ICE 3 trains were a joint production with other Germany-based train manufacturers, who refused to supply parts or sell licenses to Siemens for the AVE Class 103. This caused a delay (for which Siemens eventually paid €21 million), during which Siemens had to re-develop the missing components. Giving up the partnership finally helped Siemens build the complete high speed rail manufacturing platform[42].

Free riding is another problem in partnerships. Some firms may bear a proportionally higher fraction of the necessary time and effort to secure collective resources while others may try to free-ride on those efforts (Mesquita and Lazzarini, 2007). Further, partnerships may increase the complexity of the project and cause the problem of information asymmetry (Provan, 1984; Williamson, 1975; Mohr and Spekman, 1994).In the following part of this section, we will examine the partnership in HSR market.

6.2 Partnerships in HSR markets

In 1963, Japanese became the first country to own the high speed rail network-Shinkensan. Later in 1967 and 1985, France and Germany developed their own high speed rail networks. Until then, only some Japanese companies like Kawasaki, French company Alstom, and German company Siemens had the capability to manufacture the

[42] See http://en.wikipedia.org/wiki/AVE_Class_103

trainset. During that time, international collaborations were somewhat rare. Countries typically choose to develop their HSR using their local companies. However, due to the complex nature of the HSR projects, there were a lot of partnerships within the countries. For example, Germany’s ICE was jointly produced by a large number of German-based companies besides the leader Siemens.

After this initial period, many European and Asian countries like Italy, Spain, China and Korea subsequently built their high speed rail networks via import, partnership and technology transfer. Most recently, Turkey, Saudi Arabia, Morocco and United States have developed plans for HSR network. However, as these countries develop their high speed rail systems, we note that very mature high speed rail technology has already been developed in other countries and can be manufactured by the companies mentioned earlier (see, for example, the supply-chain taxonomy in Appendix A). Therefore, the best way to develop high speed rail network is likely to be based on existing platforms, possibly adapted to local use and conditions. Due to this, and other complexities of technologies and investments, more and more partnerships are created to develop the HSR networks.

Three common ways are used to develop HSR industry in the current set of countries:

1. Countries choose to order the high speed trains from or outsource the HSR project to the companies who already own the mature trainset directly. Examples include United States, Morocco and Turkey. Countries of this kind select from the existing HSR networks or high speed trainset that is best for their own needs and award the contract to the companies’ manufacturing such HSR networks or high speed trainset. The companies awarded the contract then decide whether to build the partnership or not.
2. In some countries, where traditional rail is highly developed, some local companies with rich experience in rail build the consortium with the companies

owning the complete platform and develop their own high speed rail brand via cooperation. Examples include Spain and Italy. Often such partnerships lead to longer-term collaborations as we see in China where the more traditional companies such as Alstom and Siemens are now collaborating with CNR to bid for projects overseas.

3. Countries use technology transfer to get parts or most of the HSR manufacturing technology. Examples include South Korea and China. As compared to the first type of countries noted above, these countries usually have larger demand for HSR. This strategy may enable the host country to relatively quickly establish a manufacturing and technology base in an area in which it had no competencies before. In the longer run, these transferred technologies may lead to the countries developing their own versions and modifications for domestic use or exports.

If the company can achieve higher profit via working in the partnership than manufacturing by its own, the company will choose to collaborate with others. Usually, the market structure, contract characteristics and size, and the company characteristics will determine the formation of partnership.

First, a more competitive market may brings more partnership. In the early stages of the HSR industry, only a few companies had the capability to manufacture the high speed rail. So the competition is not that fierce. Companies can win the bidding without partnership. Recently, with more companies mastering the technology to manufacture the full trainset, the market has become more competitive. When the new countries who want to invest in HSR open the project contract bidding, more companies can bid for this project, making it difficult for a given company to win the project. Especially, some emerging companies from China and Korea can manufacture cheaper HSR networks. Companies need to control time and budget and improve quality to win the bidding. Partnerships are an effective way to maintain the companies' competitiveness in the bidding process.. Companies can avoid spending time and money in some processes which they are not good at, which lowers the production cost and makes the construction more efficient. Also, with the partnership, the consortium can provide high quality project if they can make the most of their competitive advantage.

Second, the contract characteristics related to value and the size of the trainset order are also important for the company to determine whether to form partnership or not. The order size and the value can reflect the complexity and working load of the project. Normally, the more complex the project is, the more difficult it may be for a single company to finish the project, and thus it is more likely for the company to form a partnership. Further, the order size of the contract also reflects the demand from the country. If the country needs more high speed trains, the country may let most parts be manufactured by the local company locally. If the local company does not have the capability to manufacture the whole trainset, partnerships will need to be formed with another company that can make up for the missing components or companies with mature high speed rail platform. In this way, the company can develop their own platform via cooperation or technology transfer.

Third, the characteristics of the company itself will determine the formation of partnership. As mentioned above, if the company needs to develop the high speed train due to the high demand but does not have the capability to manufacture the whole network, the company will automatically choose a partnership or join other consortium led by a mature HSR manufacture to bid for the contract. For some companies which own the complete platform and can manufacture the trainset independently, there are two possible reasons for them to form partnerships. On the one hand, companies want to gain market access to the market with large demand for HSR. So they should sign the technology transfer agreement or cooperate with the local company to meet the requirement for the bidding. On the other hand, even though the company can manufacture the whole trainset by itself, the resource of the firm may restrict the timing and budget of the process. As a result, small firms usually form partnership to reduce the cost and increase efficiency.

CHAPTER 7

SOME INSIGHTS FROM HSR CONTRACTS

Here we examine 10 years of international high-speed rail contracts data covering the period 2000-2010. This will enable us to learn more about the partnerships and draw inferences. Since there is very little information about vertical partnerships, here we only focus on the horizontal partnerships.

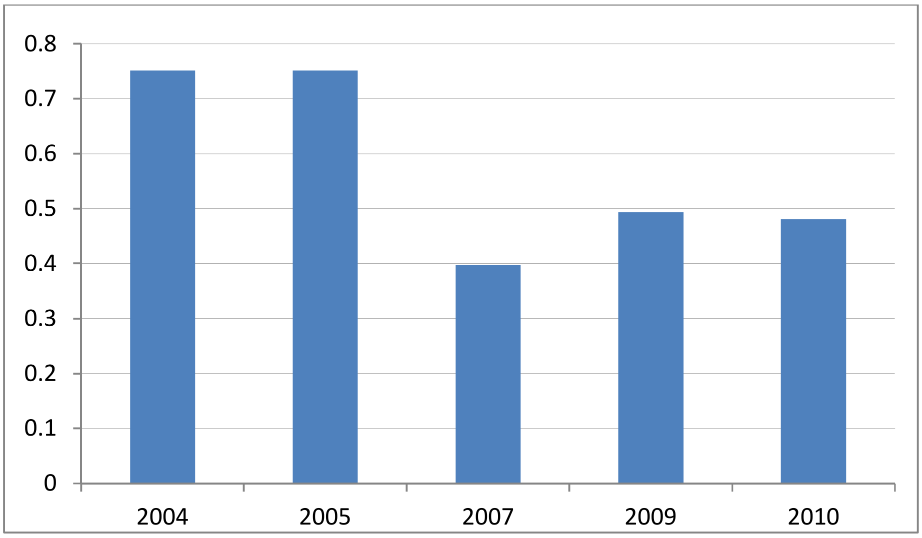
The contracts data reveal many partnerships between companies with mature HSR platform and companies whose headquarters are located in the project country. Partnership of this type include Alstom/CAF consortium and Bombardier/Talgo consortium in Spanish project, Alstom/Hyundai Rotem consortium in South Korea project, Alstom/CNR Changchun Railways consortium, Siemens/CNR Tangshan consortium, Bombardier/CSR Sifang consortium, Kawasaki/Nanche Sifang consortium, Bombardier/AnsaldoBreda consortium in Italy project. The local companies may not have the complete platform and rich experience in the production of HSR at first. However, after the cooperation, some of them may develop their own platforms and manufacture their own brand of high speed trains.

The partnership will help local companies gain the technology and help the foreign company gain the market access. For example, Alstom /CAF consortium designed and manufactured the RENFE’s class 120 for Spain. Based on that, CAF manufactured the TCDD HT65000 independently for the Turkish project after cooperating with Alstom. CAF is currently developing the Oaris modular platform for top speeds above 300 kmph. Similarly, Talgo developed its own brand of high speed trains Talgo 250 and Talgo 350 after cooperating with Bombardier in the Spanish project and is currently developing its own train AVRIL with higher speed.

China and South Korea both used technology transfer to gain the technology for manufacturing HSR. The Korea-France project was a massive bi-cultural undertaking.

The project's process of technology transfer entailed sending 1,000 Korean engineers to France for training in detail drawing, process designing, key parts manufacturing and testing, and quality control. Though the technology transfer did not provide for a complete control of manufacturing processes and some parts had to be imported, this undoubtedly played an important role in the development of Hyundai Rotem in manufacturing high speed train.

Five years ago, Chinese companies did not have HSR manufacturing capabilities. Today, CSR and CNR can both manufacture HSR for China independently, as well as export HSR to some other developing countries. The giant leap of Chinese HSR is attributed to the technology transfer through the partnership between Chinese manufacturers and world leading HSR manufactures. Until 2011, China has one of the largest HSR market with 6,185 km lines in operation and 14,160 km lines under construction. Siemens of Germany, Alstom of France, Bombardier based in Germany and Kawasaki of Japan all want to access the market and share the profits from these large contracts. Technology transfer is an important part of gaining access in China because to win contracts in China, all the companies had to adapt their HSR trainsets to China's own common standard and assemble units through local joint ventures (JV) or cooperate with Chinese manufacturers. Bombardier, the first foreign train-maker to form a joint venture in China, has been sharing technology for the manufacture of railway passenger cars and rolling stock since 1998. Since Bombardier transferred all the technology of manufacturing HSR to China, the partnership matured and a large number of contracts go to the BST joint venture between Bombardier and CSR Sifang. In contrast, since Japanese did not engage in technology transfer to China, Kawasaki's cooperation with CSR did not last as long. Within two years of cooperation with Kawasaki to produce 60 CRH2A sets, CSR began in 2008 to build CRH2B, CRH2C and CRH2E models at its Sifang plant independently without assistance from Kawasaki. We can also see from the contracts table that in the technology transfer contracts, the share of the foreign companies will become less and less. This is because the local company gains more and more technology in manufacturing HSR networks via the technology transfer and participate more in the new contract manufacture. For example, from 2004 to 2010, Bombardier was awarded five major contracts by MOR China. Bombardier's share (Figure 26) are over 70% in the first two contracts in 2004 and 2005, while decreasing to less than 50 percent in the following three contracts from 2007 to 2010. Similarly, Siemens share of project is decreasing in the China projects and the role it plays has become less significant.



Source: Appendix B.

Figure 26: Bombardier share in the Chinese projects, 2004-2010

The partnerships enable more and more companies able to manufacture trainsets independently and make the market more competitive. In 1994, when South Korea began to develop the HSR networks, only Alstom, Siemens and Mitsubishi bid for the project. However, in 2011, when Florida opened the bidding, 9 consortiums led by Talgo, Bechtel, Hyundai Rotem, Misubishi, GE and CSR Sifang, Siemens, Alstom and Bombardier participated in the bidding process. The increasing competition of the HSR market brings more challenge for the company to win the contract. To maintain the competitiveness in the market, the companies need to form partnership to win in the bid. From the observed contracts, most of the contracts are awarded to the partnership during these two years.

The contract value and the order number are usually higher in the projects done with partnerships. Spanish projects are most built by Alstom/CAF consortium, Bombardier/Talgo consortium and Siemens. RENFE, the Spanish national railway company awarded the contract to Alstom/CAF consortium in 2001 and 2004, ordering 50 trains totally worth €2,217mn. RENEFE also awarded Bombardier/Talgo consortium contract with the order of 64 trains worth totally €1,992mn. However, Siemens was only awarded 26 high speed trains worth €705mn. As for the Turkish project, TCDD first awarded the contract to single company CAF with the order number of trainset 10 and 2 and later to the Hyundai Rotem/Tuvasas joint venture when the contract order number increase to 440 and 80. Another example can be seen in Siemens' contracts. Siemens rarely forms partnerships. The mere one partnership was formed with Bombardier in the German project. The order and the amount of the contract are among the largest of all the contracts in the table. From the contracts of Alstom, projects without partnership are all small in size, like Finland and Russia's project contract which orders only 4 trains in 2007, Morocco's project valued only $400mn. The order size and project value of the two projects are much lower when compared with Argentina and Saudi Arab's project.

Often, the size of the company determines the formulation of partnerships. Siemens, Alstom, Bombardier all have the complete HSR manufacturing platform. However, the share of project with the partnership is totally different among these three firms. Siemens forms partnership only in two contract of the 12 contract, while Bombardier forms the partnership nearly in all the project besides 3 contracts with

Sweden. Table 4 gives us a preliminary impression of the size of Siemens, Alstom and Bombardier. Siemens is the biggest company and Bombardier is the smallest one. This shows that small company are more likely to form the partnership than the big company.

Table 4: Revenue of Siemens, Alstom and Bombardier

(in € million)	2011	2010
Siemens	73,515	68,978
Alstom	20,923	19,650
Bombardier	13,391	13,360

Source: Siemens, Alstom and Bombarider's annual report.

Overall, we can draw the following suggestive conclusions from the HSR industry:

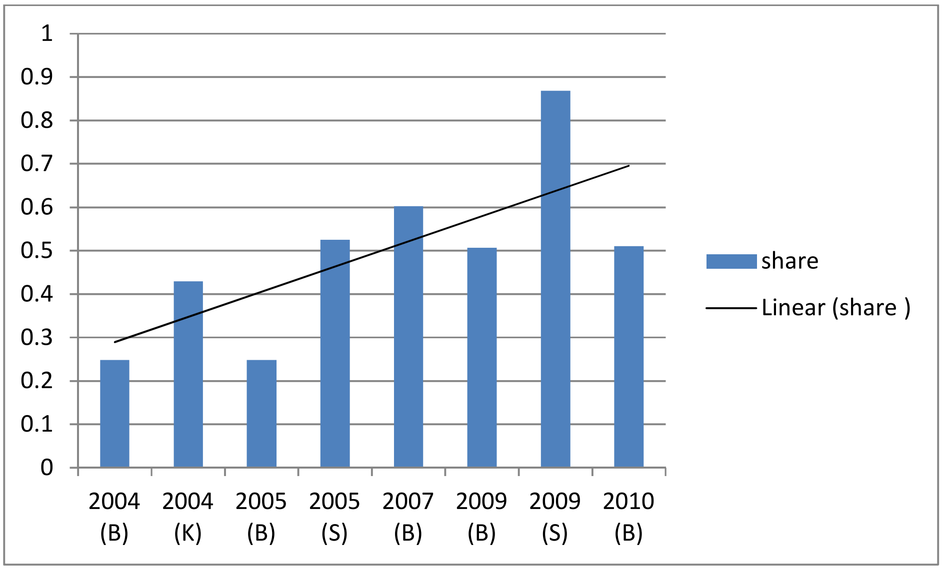
1. Companies tend to form partnership to increase their competitiveness when markets are more competitive;
2. Companies tend to form partnerships when they are awarded large contract in terms of the order numbers of trainset and the total value;
3. Companies will form partnership with local firms through Technology Transfer Agreements or simply cooperation to gain market access, if the market demand is sufficiently high;
4. If the firms don't have a rich experience in HSR, they will tend to cooperate with another firm which has a lot of experience and technology in building HSR;
5. Even the country with mature HSR manufacture platform, companies will build the partnership to meet the requirement for the bidding; and
6. Small companies, restricted by their resources, are more likely to form partnerships than the big companies.

CHAPTER 8

GOVERNMENT STRATEGIES FOR HSR INVESTMENT

Having examined the supply-chain, technologies and firms, we provide an analysis of the extent to which new HSR investments by countries can take place primarily based on domestic content and production versus imported content. In examining this issue, we find that the size of the HSR order (number of trainsets) is an important determinant of the extent of domestic content and production. While some components will almost always be manufactured elsewhere and imported (See Appendix C), a larger order size allows for various components to be manufactured domestically.

Take China as an example. China has large demand for HSR, which can be reflected from the contract signs with the international big trainset suppliers. Achieving indigenous high-speed rail technology has been a major goal of Chinese state planners. Chinese train-makers, after receiving transferred foreign technology, have been able to achieve a considerable degree of self-sufficiency in making the next generation of high-speed trains by developing indigenous capability to produce key parts and improvising upon foreign designs. We picked the contracts for Chinese project from Appendix B and counted the amount goes to the local manufacturer in figure 27. From figure 27, the share of the local manufacture is increasing from 2004 to 2010, which shows that more parts are manufactured domestically.



Source: Appendix B.

Figure 27: Shares manufactured domestically in Chinese project

Another example is US. Appendix E summarizes the details about buy American regulation of Federal Railroad Administration (FRA) and FTA. According to the regulation, the Secretary of Transportation (authority delegated to the FRA) may obligate an amount to carry out a PRIIA funded project only if the steel, iron, and manufactured goods used in the project are produced in the United States.[43] FRA believes

[43] From 49 C.F.R. § 661.5(d): For a manufactured product to be considered produced in the United States, (1) All of the manufacturing processes for the product must take place in the United States; and (2) All of the components of the product must be of U.S. origin. A component is considered of U.S. origin if it is manufactured in the United States, regardless of the origin of its subcomponents. From 49 C.F.R. § 661.3: Component means any article, material, or supply, whether manufactured or unmanufactured, that is directly incorporated into the end product at the final assembly location. End product means any vehicle, structure, product, article, material, supply, or system, which directly incorporates constituent components at the final assembly location, that is acquired for public use under a federally-funded third-party contract,

that high speed and intercity rail passenger equipment can and should be manufactured in the United States and will do everything to ensure that its grant funds are spent domestically and where there is not currently domestic production, will do what it can to encourage domestic projection. The High-Speed Intercity Passenger Rail (HSIPR) program aims at bolstering American passenger rail expertise and resources. The Buy America requirements reinforce this goal, and aid in encouraging a domestic market in the rail sector.[44]

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and which is ready to provide its intended end function or use without any further manufacturing or assembly change(s).

[44] http://www.fra.dot.gov/Pages/251.shtml

APPENDIX A

INTERNATIONAL SUPPLY CHAIN

Trainset

Major Trainset Suppliers
- Alstom (France)
- Siemens (Germany)
- Bombardier (Canada)
- CAF (Spain)
- Talgo (Spain)
- Hyundai Rotem (S.Korea)
- Kawasaki (Japan)
- CSR. (China)
- CNR (China)

Mechanical

M1: Bogies, Suspension, Wheels, Axles, Dampers
Bombardier (Canada)
Bonatrans (Czech Republic)
Siemens (German)
Firth Rixson Metals (UK)
Hutchinson Paulstra (France)
Kolowag (Bulgaria)
RVR (Latvia)
MTC (Spain)
RBC Bearings (France)
SKF Group (Sweden)
Tangshan Railway (China)
Contitech Railway (Germany)
Freudenberg Schwab (Germany)
Mediterr Shock Absorbers (Italy)
ITT/Koni Enidine (USA)
ORX Rail (USA)
Vossloh Rail Vehicles (Germany)
Talgo (Spain)
Yujin Machinery (Korea)
GHH-Valdunes (France, Germany)
ContiTech (Germany)

M2: Brakes, Coupler, Draw Gear, Connection Systems
Dellner Group (Sweden)
Knorr-Bremse (Germany)
MTZ Transmash (Russia)
Voith Turbo Scharfenberg (Germany)
Wabtec (USA)
Yujin Machinery (Korea)
Ningbo Ebong (China)

Electronic

E1: Computer Hardware, Software, Control, Monitoring
EKE Electronics (Finland)
Esterel Technologie (France)
Kontron (Germany)
Leroy Automation (France)
Traintic, ITS (Spain)
ZTR (USA, Canada)
Henan Splendor Science & Technology (China)

E2: Signaling, Communications
Siemens Mobility (Germany)
Bombardier (Canada)
HollySys(China)
Ansaldo STS (Italy)
Alstom (France)
Eliop Seinalia ,CAF group(Spain)
Vossloh Cogifer (Germany)
Wabtec (USA)
HeNan Splendor Science & Technology (China)
Thales Group (France)
Invensys Rail Group(UK)
Nippon Signal Co. LTD. (Japan)

E3: Controls, Electromechanical Equipment, Drives
Alstom (France)
Eliop Seinalia, CAF group (Spain)
AQ Wiring System (Sweden)
ZF Friedrichshafen (Germany)
Wabtec (USA)
SKF Group (Sweden)

E4: Operation Control, Passenger Information Display, Entertainment
Alstom (France)
Hitachi Transport System (Japan)
Telefunken Racoms (Germany)
Nomad Digital (UK)

Locomotive and Power

L1: Locomotives and Related
Alstom (France)
Siemens (Germany)
Bombardier (Canada)
Kawasaki (Japan)
Hyundai Rotem (S. Korea)
Talgo (Spain)
EMD (USA)
Caterpillar (USA)
Wabtec (USA)
GE (USA)

L2: Electrification, Traction, Power Supply
ABB (Switzerland)
Alstom (France)
SKF Group (Sweden)
Bombardier (Canada)
AEG Power Solutions (Germany)
Schneider Electric (Germany)
GINO (Germany)
Ingeteam Traction (Spain)
EMD (USA)
Eaton (USA)

L3: Hydraulic and Related Systems
Eaton (USA)
Enerpac (France)
Beijing Changyu Lihua hydraulic systems engineering (China)

Passenger Cart

P1: Gangway System
Hubner (Germany)
Hutchinson Paulstra (France)

P2: HVAC, Cooling Systems, Compressors
Merak (Spain)
Noske-Kaeser (Germany)

P3: Passenger Coaches
Alstom (France)
Bombardier (Canada)
Isoflex (Sweden)
Kawasaki (Japan)
RVR (Latvia)

P4: Galley, Buffet Car, Restaurant Equipment
Kugel Edelstahlverarbeitung (Germany)

P5: Door System, Locks, Lighting, External Components
Pickersgill-Kaye (UK)
Traslec (UK)
Yujin Machinery (Korea)

P6: Fire Safety, Detection, Suppression
Consilium (Sweden)

P.7: Toilet Equipment
Satek (German)

Other Categories

O.1: Interior Design
Pininfarina (Italy)
Priestmangoode (UK)
Bombardier (Canada)
Alstom(France)
Siemens (Germany)

O.2: Rail Station Mobility Systems
Thyssenkrupp (Germany)

O.3: Aftermarket Services
EMD (USA)
Vossloh Rail Services (Germany)

O.4: Infrastructure & Planning Services
Alstom (France)
Vossloh Fastening Systems (Germany)
Eiffage (France)
URS Corporation (USA)

O.5: Concrete and related Product
China ACM (China)

APPENDIX B

INTERNATIONAL HIGH-SPEED RAIL CONTRACTS

INFORMATION SUMMARY

Notes:

1. The table is preliminary and will be updated as more information becomes available on existing contracts as well as new contracts.

2. Information presented in this table are based on materials that were available from the various company websites, national rail administrators, and industry reports that were publicly available.

3. In column 2, 'capacity' refers to passenger capacity.

4. For the contract amounts, ***'mn'*** refers to millions and ***'bn'*** refers to billions.

5. The abbreviation TTA denotes "Technology Transfer Agreement".

6. The Saudi Partners for the Alstom (2009) contract are: Al Arrab Contracting Company Ltd, Al Suwailem Company, Saudi Consolidated Engineering Company (Khatib & Alami).

7. In instances where the contract had a partner – e.g., say Alstom was the main supplier with Bombardier as a partner – then the table below reports two rows referring to this contract, one with an entry for Alstom and another with an entry for Bombardier. While this produces some duplication (in instances where the contract had a partnership), the benefit is that this system more clearly signals the contracts for each of the major trainset suppliers the national rail authorities contract with.

1. Company/ Partnership	**2. Contract with Year/ delivery Train/ speed Trains/ cars/ capacity**	**3. Total Cost Project share Maintenance contract Competing bids**	**4. Manufacturing and other contract related information**
Alstom/ Eukorail, Hyundai Rotem	KHSRCA Korea 1994/ na KTX1/ 300 46/ 20/ 965	na Alstom's share is $2.1bn (€1.5bn) na Compete with Siemens and Mitsubishi[45]	Infrastructure and rolling stock were created via TTA, which paired up Korean companies with core system supplier Alstom and its European subcontractors for different subsystems. 46 trains were built - the initial twelve in France by Alstom, the remainder in South Korea by Rotem. The core system technology encompass the catenary, signaling and rolling stock.

[45] the Korean government first announced the project, three international train manufacturers -Germany's ICE bullet train built by Siemens, Mitsubishi with the Japanese Shinkhansen and France's Alstom TGV -- tendered bids. Initially, consultant engineers told the Korean government that the German and Japanese technology was superior, but the French high-speed train manufacturer Alstom was eventually

			In line with the core system contract condition that over 50% of the added value has to come from South Korea after technology transfer, the remaining 34 of the 46 trainsets ordered were built under license by Rotem in South Korea itself.
Alstom/ Bombardier	Amtrak USA 1996/ 1999-2000 Acela Express/ 240 20/ 8/ na	Na Bombardier's share is 75% and Alstom 25% na Compete with Siemens (American ICE) and ABB (X2000)	The Acela Express was largely built on United States soil, as stipulated in the Amtrak contract. Bombardier's plants in Barre, Vermont, and Plattsburgh, New York, performed much of the manufacturing. Alstom also furnished some components made in France. (The funding scheme for the project is rather unusual as it puts very little burden on Amtrak.) Bombardier is financing the $611 million to purchase the trains (including additional electric locomotives) and part of three new maintenance facilities, as well as to operate and maintain the equipment for 20 years. Amtrak's ability to repay Bombardier will come from additional revenue that the Acela Express is expected to create in service, estimated by Amtrak at $200 million per year.
Alstom/ CAF	RENFE Spain 2001/ 2003 Alaris/ 270 20/ 4/ 237	€440mn ($377mn) na Full maintenance of the new fleet for 14 years Na	Alstom, the consortium leader, was responsible for providing the traction system and 50% of the mechanical equipment for these high-speed regional trains. Trains will be largely built in Alstom industrial units in Spain.
Alstom/ None	Virgin Trains UK 2002/ na Pendolino/ 225 na/ na/ na	€1.8b Unable to get information.	Unable to get information.
Asltom/ Bombardier, AnsaldoBreda	Trenitalia Italy 2002/2005-2007 ETR 500/300 60/na/na	€330mn Alstom's share of the work is €60mn Na Na	ALSTOM is in charge for the supply of bogies, transformers and auxiliary converters. The work will be carried out at ALSTOM's factories in Sesto and Savigliano. The other consortium members are Ansaldobreda, which will supply body shells, traction equipment and bogies; Firema, which will supply body shells and traction equipment; and Bombardier, which will supply electrical equipment.
Alstom/ None	Trenitalia Italy 2004/ 2007 Pendolino/ 250 12/ 7/ 430	€240mn na na na	Manufactured at Alstom site in Italy, with components from Alstom EU Sites.
Alstom/ None	Cisalpino Italy and Swiss 2004/ 2007-2008	$356mn Na	Trains built at Alstom's Savigliano plant in Italy.

selected. Allegations of kickbacks to Korean government officials dogged the project, and by early 2000, prosecutors were following up on allegations of millions of dollars of illegal money transfers to Alstom lobbyists.

	Pendolino/ 249 14/7/430	Na Na	
Alstom/ CAF	RENFE Spain 2004/ 2006-2009 Shuttle, Variable Gauge/ 250 30(Shuttle)/ na/ na; 45(variable gauge)/ na/ na	€1,777mn (Supply €937mn) Alstom leads consortium and share of the contract is €1,027mn na Alstom-CAF provide maintenance services for 14 years (€840mn)	Alstom Santa Perpetua plant and CAF's Beasain and Zaragoza plants will share the work of building body shells and assembling the trainsets. Alstom leads the consortium for the supply and maintenance of 30 trains (shuttle) and its participation in the order is €476 million. It also participates in the mechanical construction, electric equipment supply and maintenance of the 45 variable gauge units, worth €551 million. Alstom total share of these contracts, including maintenance, is €1,027 million.
Alstom/ CNR Changchun Railway	MOR China 2004/ 2007 CRH5/ 250 60/ 8/ na	€620mn na na na	First three sets manufactured at Alstom factory in Italy. Next 6 sets were delivered in complete knock down form and assembled by CNR Changchun Railway Vehicle. Remaining 51 sets built by CNR Changchun through technology transfer from Alstom.
Alstom/ None	Karelian Trains Ltd (Russia and Finland) 2007/2009-2010 Pendolino/ 220 4/na/352	€120mn na na na	An option for four future trains.
Alstom/ None	SNCF French 2007/ 2009-2014 Duplex TGV/ 320 55/ na/ na	$2.8bn na na na	Unable to get information.
Alstom/ None	NTV Italy 2008/ na AGV/ 360 25/ 11/ 500	€650mn na 30 years maintenance contract (not included in the above amount) Na	Unable to get information. Manufactured in Alstom Italy site
Alstom/ Isolux Corsan, Iecsa and Emepa	Argentine Railways 2008/ na double-decker TGV(Cobra)/ 250-300 8/ na/ 509	$3.7bn Alstom's share is $1.7bn na Compete with Siemens, and Spanish consortium (CAF, Obrascon Huarte Lain)	Alstom is responsible for technical studies, engineering design and construction of railway, and sourcing appropriate high speed rolling stock. High speed line is split into 2 sections. The first section will be a 250-300 line. Second section will be 160 diesel power.
Alstom/ CRCC(China) and Saudi Partners.	Saudi Arabia Govt. 2009/ na na/ na na/ na/ na	$18bn na na na	Alstom is in charge of phase I. Design and construction contract for Phase I Package 1 – Civil Works for the project was awarded in March 2009 to Al Rajhi Alliance. which comprises China Railway Construction Corporation (CRCC), Al Arrab Contracting Company Ltd, Al Suwailem Company and the French power and rolling stock company Alstom Transport. It is cooperating with the consultant

			Saudi Consolidated Engineering Company (Khatib & Alami - K&A). Scott Wilson Group will provide project management support.
Alstom/ None	ONCF Morocco 2010/ 2015 Double-decker/ 320 (the first 200km) 160-220 (others) 14/ 8/ 533	€400mn na na na	The 14 trainsets will be developed and built in France at Alstom Transport's La Rochelle workshops (pilot site) and its sites in Belfort (power cars), Le Creusot (Bogies), Ornans (engines) and Tarbes (traction drive), as well as Villeurbanne (electric control system), Charileroi in Belgium, Sesto in Italy and Montreal in Canada (on-board IT and passenger information). The trainsets' power cars and passenger cars will be delivered separately to the ONCF's Moghogha factory just north of Tangiers, where trainset assembly operations will be carried out. Technical tests will be carried out at the Moghogha site as well as ONCF network. The trains will run at 320 kmph and at 25 kV between Tangiers and Kenitra - the first 200 km section of Morocco's very high-speed network. Between Kenitra and Casablanca, the trainsets will run on the traditional network at speeds of 160 kmph or 220 kmph at 3 kV, depending on the running speeds set by the Moroccan operator in 2015.
Alstom/ Siemens	Eurostar French 2010/ na Velaro e320 /320 10/ na/ na	$1bn na na na	Unable to get information.
Alstom/ None	PKP Poland 2011/ 2014 na/ na 20/ na/ na	€665mn na 17 years maintenance and construction of new maintenance depot Na	Manufactured at Alstom site in Italy.
Alstom/ None	Iraq Govt. 2011/ na na / 250 na/ na/ na	Unable to get information.	Unable to get information.
Siemens/ Thyssen Transrapid and Transrapid international	SMTDC China 2001/ na Maglev/ 431 na/ na/ na	DM 1,293bn na na na	Trainset and tracks built by Siemens.
Siemens/ None	RENFE Spain 2001/ 2005 ICE3(Velaro E)/ 350 26/ na/ 405	€705mn na 14 years maintenance Compete with Alstom, Talgo-Adtranz	Unable to get information.
Siemens/ None	RENFE Spain 2004/ na ICE3(Velaro E)/ 350	na na na	Unable to get information.

	10/8/404	Compete with Alstom-CAF	
Siemens/ CNR Tangshan	MOR China 2005/ na Velaro CN(CRH3)/ 300 60/ 8/ 601	RMB 1,3000mn Siemens' share is €669 mn na na na	TTA provisions require majority of components and sub-systems to be sourced in China by the end of the initial building.
Siemens/ None	Austrian Railways 2006/ na ICE trailer(Railjet)/ 230 23/ 7/ 469	€250-€300mn na na na	Railjet is the name of the high speed rail in Austria but it is based on the Siemens ICE model.
Siemens/ None	Russian Railway 2006/ na ICE3/ 250 8/ 10/ 600	€276mn na 30 years of service contract worth another €300mn Na	Development and construction is being carried out by Siemens at Erlangen and Krefeld in Germany.
Siemens/ None	Austrian Railways 2007/ na ICE trailer(Railjet)/ 230 44/ 7/ 469	Approx. €498-€548mn na na na	Unable to get information.
Siemens/ None	DB Germany 2008/ 2011-2012 ICE/ 320 15/ 8/ 485	€500mn na na na	Unable to get information.
Siemens/ CNR Tangshan, CNR Changchun Vehicle	MOR China 2009/ 2010 CRH/ 350 100/ na/ 1026	$5.7bn Siemens share is €750mn na na	In this contract, Siemens acts as a component supplier, with only 18% of the content actually made by the company. Siemens is in charge of technical assistance and the supply of electrical equipment and bogies for the new trains; Tangshan and Changchun Vehicle use the technology from the previous TTA and is currently assembling 300 kmph CHR3 Velaro trainsets under a technology transfer agreement with Siemens.
Siemens/ Alstom	Eurostar French 2010/ na Velaro e320 /320 10/ na/ na	$1bn na na na	Unable to get information.
Siemens/ Bombardier	DB Germany 2011/ 2013-2016 ICx/ 250 300/ 7(10)/ 499(724)	Total order value for the 220-train deal is approx. €6bn Bombardier's share is €1.3bn for the initial 130 trains and €3bn for the combined order for 220	Bombardier will supply all of the bodyshells for the ICx fleet from its Görlitz plant, whilst the driving vehicles will be assembled at Hennigsdorf. Bombardier is also to supply Flexx Eco unpowered bogies for the trailer cars from its Siegen facility. DB also has an option to order another 80 sets 'at any time' during the validity of the framework contract, which runs to 2030.

		na na	
Bombardier/ Alstom	Amtrak USA 1996/ 1999-2000 Acela Express/ 240 na/ na/ na	na Bombardier’s share is 75% and Alstom 25% na Compete with Siemens (American ICE) and ABB (X2000)	The Acela Express was largely built in the US as stipulated in the Amtrak contract. Bombardier's plants in Barre, Vermont, and Plattsburgh, New York, performed much of the manufacturing. Alstom also furnished some components made in France. (The funding scheme for the project places very little burden on Amtrak.) Bombardier is financing the $611 million to purchase the trains (including additional electric locomotives) and part of three new maintenance facilities, as well as to operate and maintain the equipment for 20 years. Amtrak's ability to repay Bombardier will come from additional revenue that the Acela Express is expected to create in service, estimated by Amtrak at $200 million per year.
Bombardier/ Talgo	RENFE Spain 2001/ na Talgo/ 350 16/ na/ na	€339mn Bombardier’s share is €138mn na na	Unable to get information.
Bombardier/ CSR Sifang (Bombardier Sifang Transportation)	MOR China 2004/ 2006-2007 CRH1A/ 200 20/ 8/ 670	$350mn Bombardier’s share is $263mn na na	The trains, which can reach a maximum speed of 200 kmph, will be designed by Bombardier in Västerås, Sweden. Bombardier will manufacture the bogies in Siegen, Germany and will provide part of the propulsion from its site in Västerås. The carbody production and final assembly will be undertaken in China under BSP’s responsibility.
Bombardier/ CSR Sifang (Bombardier Sifang Transportation)	MOR China 2005/ 2006-2007 CRH1A/ 250 20/ 8/ na	$350mn Bombardier’s share is $263mn na na	The trains will be designed by Bombardier in Västerås, Sweden. Bombardier will manufacture the bogies in Siegen, Germany and will provide part of the propulsion from its site in Västerås. The carbody production and final assembly will be undertaken in China under BSP’s responsibility.
Bombardier/ Talgo	RENFE Spain 2005/ 2008-2010 AVE S-102/ 364 30/ na/ na	€655mn ($786mn) Bombardier’s share is approximately €243mn ($290mn) In 2008, Bombardier Transportation, in consortium with Talgo, was awarded 14 years contract with RENFE, the Spanish National Rail Operator for the maintenance of 45 AVE S-130 high speed trains. Maintenance activities will be carried out until 2022 at RENFE’s depots in Santa Catalina and Fuencarral, both in Madrid. Bombardier’s share in this contract is about €128mn ($202 mn)	Bombardier will be responsible for manufacturing the running dynamics, the entire electric equipment of the powerhead including the proven and reliable MITRAC 3000 propulsion system with traction, auxiliary converter and drive system, and the very high-speed bogies. Bombardier will also carry out the final assembly and testing of its scope of work, while the production of the passenger coaches will be under Talgo’s responsibility. The production of a large part of the propulsion system will be undertaken at Bombardier’s plant in Trápaga (Spain). After the mechanical assembly at Talgo’s workshop, the assembly of the powerheads will be completed at Bombardier’s site in Kassel (Germany) and at RENFE’s workshop in Málaga (Spain). The manufacture of the passenger coaches and the coupling of the complete trains will take place in Talgo’s Las Matas plant and at RENFE’s Malaga site.

		na na	
Bombardier/ Talgo	RENFE Spain 2005/ 2007-2009 Talgo 250/ 250 18 high speed trains+10 power head/ na/ na	€338mn ($403mn) Bombardier's share of contract is €122mn ($145mn) na na	Bombardier's scope of supply will include the manufacture of the entire electrical equipment, the propulsion system, the train control and communication systems and an exhaustive signaling system. Bombardier will also participate in the final assembly and testing of the trains and the power heads. The production of a large part of the propulsion system will be undertaken at Bombardier's plant in Trápaga, Spain. Production of the mechanical components, including the variable-gauge bogies, will be under Talgo's responsibility.
Bombardier/ CSR Sifang (Bombardier Sifang Transportation)	MOR China 2007/ 2009-2010 EMU (CRH1B, CRH1E)/ 250 40/ 16/ na	€1bn ($1.5bn) Bombardier's share is €413mn ($596mn) na na	The new high-speed EMU trains will be manufactured at BSP production facilities in Qingdao, China. Bombardier MITRAC propulsion systems for the trains will be jointly produced by Bombardier CPC Propulsion System Co. Ltd., a Bombardier joint venture based in Changzhou, and Bombardier facilities in Europe. MITRAC propulsion systems are included in more than 23,000 rail vehicles worldwide.
Bombardier/ None	SJ AB Sweden 2008/ 2010 Bombardier Regina/ 210 20/ 4/ na	€221mn ($349mn) na na na	Project management and lead engineering will take place in Västerås, Sweden, where the Bombardier Mitrac propulsion system will also be designed and manufactured. In Germany the vehicles will be engineered and assembled at Bombardier Hennigsdorf site; the carbodies will be manufactured in Görlitz, and the bogies in Siegen. Contract includes option for 20 additional trains.
Bombardier/ CSR Sifang (Bombardier Sifang Transportation)	MOR China 2009/ 2012-2014 CRH380D/ 380 CRH380DL/ 380 20/ 8/ na 60/ 16/ na	RMB 27.4bn ($4.01bn) Bombardier's share is RMB 13.5bn na na	The Zefiro 380 trains will be manufactured at Bombardier Sifang Transportation production facilities in Qingdao, China. Engineering will take place in Qingdao and at Bombardier centers in Europe with project management and components provided from sites in Europe and China.
Bombardier/ CSR Sifang (Bombardier Sifang Transportation)	MOR China 2010/ 2010-2011 CRH1/ 250 40/ 8/ 604	RMB 5.2bn (€591mn, $761mn) Bombardier's share is RMB2.5bn (€289mn, $373mn) na na	Unable to get information.
Bombardier/ None	SBB Sweden 2010/ 2012-2019 Bombardier Twindex/ na 59/ na/ na	Swiss Fracs 1.8bn ($1.6bn or €1.3 bn) na na na	The Twindexx project will be managed from Zürich, while Villeneuve – the only rail production site in western Switzerland – will be responsible for producing the vehicles together with Görlitz. Görlitz is also taking the lead in the engineering process. The Winterthur site will design the bogies, while production will take place in Siegen, Germany. The Swedish site of Västeras will be responsible for the drive system with the super-efficient permanent magnet motors. Contract includes options for >100 additional Twindexx trains.
Bombardier/ AnsaldoBreda	Trenitalia Italy 2010/ 2013	€1.54bn ($2.1bn) Bombardier's share is €652mn ($889mn).	The work will be divided between Bombardier's Italian factory near Genoa, and Ansaldo's factory near Florence. Bombardier will have roughly 60 per cent of the work and will be responsible for the

	Bombardier Zefiro (V300 Zefiro)/ 360 50/ na/ 600	€30.8mn for each train na Compete with Alstom's AGV and Pendolino, and CAF's Oaris	propulsion and electrical system. Ansaldo will be responsible for the train body and final assembly. Bombardier will ensure the control equipments and the propulsion system, while AnsaldoBreda the body and the final assembly at its facility in Pistoia.
Bombardier/ None	Västtrafik Sweden 2011/ 2013 Regina/ na 6/ 3/ na	$101mn na na na	The European rail traffic management system (ERTMS) will be developed and engineered by Bombardier in Stockholm, Sweden, and assembled at Bombardier's Hennigsdorf site in Germany. The car bodies will be produced in Görlitz, and the bogies in Siegen of Germany. The delivery of the trains is scheduled for 2013.
Bombardier/ Siemens	DB Germany 2011/ 2013-2016 ICx/ 250 300/ 7(10)/ 499(724)	Total order value for the 220-train deal is approx. €6bn Bombardier's share is €1.3bn for the initial 130 trains and €3bn for the combined order for 220 na na	Bombardier will supply all of the bodyshells for the ICx fleet from its Görlitz plant, whilst the driving vehicles will be assembled at Hennigsdorf. Bombardier is also to supply Flexx Eco unpowered bogies for the trailer cars from its Siegen facility. DB also has an option to order another 80 sets 'at any time' during the validity of the framework contract, which runs to 2030.
CAF/ Alstom	RENFE Spain 2001/ 2003 na/ 270 20/ na/ 237	€440mn na Includes maintenance of new fleet for 14 years Na	Alstom, as the consortium leader, will be responsible for providing the traction system and 50% of the mechanical equipment for these high-speed regional trains. The trains will be largely built in Alstom industrial units in Spain.
CAF/ Alstom	RENFE Spain 2004/ 2006-2009 Shuttle, Variable Gauge/ 250 30(shuttle)/ na/ na 45(variable gauge)/ na/ na	€1,777mn (Supply € 937mn) Alstom leads the consortium and total share of these contracts, including maintenance, is €1,027mn Alstom-CAF will provide maintenance services for 14 years. (Worth €840 mn) Na	Alstom Santa Perpetua plant and CAF's Beasain and Zaragoza plants will share the work of building body shells and assembling the trainsets. Alstom will lead the consortium for the supply and maintenance of 30 trains (shuttle) and its participation in the order is €476 million. It also participate in the mechanical construction, electric equipment supply and maintenance of the 45 variable gauge units, worth €551 million.
CAF/ None	TCDD Turkey 2005/ na TCDD HT65000/ 250 10/ 6/ na	€180mn na na na	Unable to get information.
CAF/ None	TCDD Turkey 2007/ na TCDD HT65000/ 250 2/ 6/ na	€37mn na na na	Unable to get information.
Talgo/ Bombardier	RENFE Spain 2001/ na	€339mn Bombardier's share is	Unable to get information.

	Talgo/ 350 16/ na/ na	€138mn na na	
Talgo/ Adtranz (Bombardier)	RENFE Spain 2001/ na Talgo/ 350/ 330 16/ na/ na	€ 660mn Split with Talgo, each in charge of building 16 trainsets na Compete with Siemens and Alstom	The trainsets consist of Talgo passenger cars modified in order to allow speeds of up to 350 kmph (220 mph) with power cars at each end which provided by the ADtranz (later Bombardier Transportation)
Talgo/ Bombardier	RENFE Spain 2005/ 2007-2009 Talgo 250/ 250 18 high speed trains+10 power head/ na/ na	€338mn ($403mn) Bombardier's share of contract is €122mn ($145mn) na na	Bombardier will provide manufacture of the entire electrical equipment, the propulsion system, the train control and communication systems and an exhaustive signaling system. Bombardier will also participate in the final assembly and testing of the trains and the power heads. The production of a large part of the propulsion system will be undertaken at Bombardier plant in Trápaga, Spain. Production of the mechanical components, including the variable-gauge bogies, will be under Talgo's responsibility.
Talgo/ Bombardier	RENFE Spain 2005/ 2008-2010 AVE S-102(Talgo 350)/ 364 30/ na/ na	€655mn ($786mn) Bombardier's share is approximately €243 mn ($290mn) na na	Bombardier will manufacture the running dynamics, the entire electric equipment of the powerhead including the proven and reliable MITRAC 3000 propulsion system with traction, auxiliary converter and drive system, and the very high-speed bogies. Bombardier will also carry out the final assembly and testing of its scope of work, while the production of the passenger coaches will be under Talgo's responsibility. The production of a large part of the propulsion system will be undertaken at Bombardier's plant in Trápaga (Spain). After the mechanical assembly at Talgo's workshop, the assembly of the powerheads will be completed at Bombardier's site in Kassel (Germany) and at RENFE's workshop in Málaga (Spain). The manufacture of the passenger coaches and the coupling of the complete trains will take place in Talgo's Las Matas plant and at RENFE's Malaga site.
Talgo/ Ingeteam	Uzbekistan Railways 2009/ 2011 Talgo 250/ 250 2/ 8/ 257	€40+ mn na Includes maintenance contract Na	Includes the supplying of the rolling stock and the equipment for maintenance.
Talgo/ RENFE, ADIF, OHL and eight other companies	Saudi Arabia Govt. 2011/ na Talgo 350/ na 33/ na/ na	€6.5mn($9.4 bn) na na Compete for more than a year with a French group made up of Alstom, and the French national operator SNCF.	Talgo in charge of phase II. Talgo would be responsible for supplying 33 trains similar to those used on Spanish high speed lines. Renfe and Adif would operate trains and manage the line for 12 years.
Talgo/ None	RZD Russia na/ na na/ 322	€100mn na na	Unable to get information.

	7/ na/ na	na	
Hyundai Rotem/ Tüvasas	TCDD Turkey 2008/ 2011-2014 EMU/ na 440/ 5/na	€580mn na na Compete with Alstom, CAF, and a consortium of Bombardier, Siemens and Nurol (Turkish Co.)	Part of the railcar production will be carried out in the plant of Eurotem, Hyundai Rotem's Turkish joint venture.
Hyundai Rotem/ Tülomsas	TCDD Turkey 2010/ 2014 Electric Locomotive/ na 80/ na/ na	€330mn with Islamic Development Bank to provide $220mn TTA will see local content reach 35% na Compete with Bombardier, AnsaldoBreda, Chinese supplier, and Hyundai Rotem (the lowest bidder)	Unable to get information.
Hyundai Rotem/ None	Ukrainian Railway 2010/ 2012 EMU/ 160 (Slower HSR) 10/ 9/ 579	$304mn na na Compete with Bombardier and Siemens	Unable to get information.
Kawasaki/ Nippon Sharyo, Hitachi	THSRC Taiwan 1999/ 2007 700 series Shinkansen (THSR 700T)/ 300 30/ na/ 989	$15bn (€11.5bn) na na Taiwan High Speed Rail Consortium (THSRC) competed with Chunghwa High Speed Rail Consortium (CHSRC). THSRC's bid was based on the high-speed technology platform of Eurotrain, a joint venture of GEC-Althom, the main manufacturer of the French TGV, and Siemens, the main maker of the German ICE. CHSRC's bid was based on Japanese Shinkansen technology supplied by Taiwan Shinkansen Consortium (TSC), a joint venture between several Japanese companies.	Unable to get information.
Kawasaki/ Nanche Sifang	MOR China 2004/ 2006	¥140bn Kawasaki's share will	Kawasaki will make design changes and supply the first three finished trains and the following six as knocked-downs. The expected delivery of

Locomotive	E2-1000 Shinkansen (CRH2B)/ 200 60/ 8/ na	be ¥80mn na na	finished trains was February 2006. After that, Nache Sifang will build the remaining 51 trains in China by using the production technology transferred by Kawasaki.
CNR Changchun Railway/ Alstom	MOR China 2004/ 2007 CRH5/ 250 60/ 8/ na	€620mn na na na	The first three sets was manufactured by Alstom's factory in Italy, the next 6 sets were delivered in complete knock down form and assembled by CNR Changchun Railway Vehicle. The remaining 51 sets were built by CNR Changchun through technology transfer from Alstom.
CNR Tangshan/ Siemens	MOR China 2005/ na Velaro CN(CRH3)/ 300 60/ 8/ 601	RMB1,300mn na na na	TTA provisions require majority of components and subsystems to be sourced in China by the end of the initial building.
CSR Sifang/ Bombardier (Bombardier Sifang Transportation)	MOR China 2004/ 2006-2007 CRH1A/ 200 20/ 8/ 670	$350mn Bombardier's share is $263mn na na	The trains will be designed by Bombardier in Västerås, Sweden. Bombardier will manufacture the bogies in Siegen, Germany and will provide part of the propulsion from its site in Västerås. The carbody production and final assembly will be undertaken in China under BSP's responsibility.
CSR Sifang/ Bombardier (Bombardier Sifang Transportation)	MOR China 2005/ 2006-2007 CRH1A/ 200 20/ 8/ na	$350mn Bombardier's share is $263mn na na	The trains will be designed by Bombardier in Västerås, Sweden. Bombardier will manufacture the bogies in Siegen, Germany and will provide part of the propulsion from its site in Västerås. The carbody production and final assembly will be undertaken in China under BSP's responsibility.
CSR Sifang/ Bombardier (Bombardier Sifang Transportation)	MOR China 2007/ 2009-2010 EMU(CRH1B,CRH1E)/ 250 40/ 16/ na	€1bn ($1.5bn) Bombardier's share is €413mn ($596mn) na na	The new high-speed EMU trains will be manufactured at BSP production facilities in Qingdao, China. BOMBARDIER MITRAC propulsion systems for the trains will be jointly produced by Bombardier CPC Propulsion System Co. Ltd., a Bombardier joint venture based in Changzhou, and Bombardier facilities in Europe. MITRAC propulsion systems are included in more than 23,000 rail vehicles worldwide.
CSR Sifang/ Bombardier (Bombardier Sifang Transportation)	MOR China 2009/ 2012-2014 CRH380D/ 380 CRH380DL /380 20/ 8/ na 60/ 16/ na	RMB 27.4bn ($4.01 bn) Bombardier's share is RMB 13.5bn na na	The ZEFIRO 380 trains will be manufactured at Bombardier Sifang Transportation production facilities in Qingdao, China. Engineering will take place in Qingdao and at Bombardier centers in Europe with project management and components provided from sites in Europe and China.
CSR Sifang/ Bombardier (Bombardier Sifang Transportation)	MOR China 2010/ 2010-2011 CRH1/ 250 40/ 8/ 604	RMB 5.2bn (€591mn, $761mn) Bombardier's share is RMB 2.5bn (€289mn, $373mn) na na	Unable to get information.
CRCC/ Alstom and Saudi Partners	Saudi Arabia Govt. 2009/ na na/ na	$18bn na na	Alstom in charge of phase I. Design and construction contract for Phase I Package 1 – Civil Works for the project was awarded in March 2009 to Al Rajhi Alliance which

	na/ na/ na	na	comprises China Railway Construction Corporation (CRCC), Al Arrab Contracting Company Ltd, Al Suwailem Company and the French power and rolling stock company Alstom Transport. It is cooperating with the consultant Saudi Consolidated Engineering Company (Khatib & Alami - K&A). Scott Wilson Group will provide project management support.
Nanche Sifang Locomotive/ Kawasaki	MOR China 2004/ 2006 E2-1000 Shinkansen (CRH2B)/ 200 60/ 8/ na	¥140bn Kawasaki's share ¥80mn na na	Kawasaki will make design changes and supply the first three finished trains and the following six as knocked-downs. The expected delivery of finished trains is February 2006. After that, Nache Sifang will build the remaining 51 trains in China by using the production technology transferred by Kawasaki.

APPENDIX C

SELECTED COMPONENTS MAKERS

Component Maker (Country)	**Products (Broad categories)**	**Sell To Companies (Examples)**	**Contracts in Countries (Examples: Solo or in local partnership)**	**Other Details**
1. ABB (Switzerland)	Electrical and electronic components. Traction transformers, motors, convertors and related products.	Alstom, AnsaldoBreda, Bombardier, CAF, Siemens, Stadler, Talgo.		Sell via trainset company. Also sell directly to railway operator.
2. Vossloh (Germany)	Supplier of high-speed points and crossings for many infrastructure operators; High speed rail fastening systems.	Alstom	China, German, France	
3. Bonatrans (Czech Republic)	Wheelsets, axles, noise absorbers. Largest European supplier.	Bombardier, Alstom, Siemens, Kawasaki, Hyundai Rotem, Deutsche Bahn (DB).	Austria, Finland, Germany, Belgium, France, Switzerland, Poland, Slovakia, Hungary, North America, India, China, Korean, Morocco, Egypt, Malaysia.	
4. Kontron (Germany)	Deliveries of embedded computers.	Bombardier, Alstom,	France, United Kingdom,	
5. Wabtec (USA)	Railway braking equipment and related components; freight car truck components; draft gears, couplers and slack adjusters; air compressors and dryers; signal design and engineering services; friction products, including brake shoes and pads; rail and bus door assemblies; track and switch products, and traction motors.		China, United Kingdom	
6. AnsaldoSTS (Italy)	Technology company. Produces signaling and automation systems for use by rail and rapid transit operators.	Deutsche Bahn AG, Alstom, Bombardier, Kawasaki Railcar	Belgium, China, France, Germany, Italy, South Korea, Spain, UK	
7. HollySys (China)	Leading provider of automation and control technologies and applications in China; , high-speed railway signaling system of Train Control Center(TCC) and Automatic Train Protection (ATP)	Ministry of Railways of China	China	
8. Eaton (USA)	Global technology leader in diversified power management solutions that make electrical, hydraulic and mechanical power	Alstom	Italy; Europe (Alstom Trainset)	
9. Kolowag	Wheelset.		Switzerland, German, Poland, France,	

(Bulgaria)			Slovakia, Turkey, Czech Republic	
10. RBC Bearings (France)	Spherical plain bearings and elastomeric bearings for rail passenger vehicles; Supply completely assembled connecting rods for antiroll bars systems; Manufacture and market highly engineered precision plain, roller and ball bearings in many sizes for sophisticated applications.		France, Spain, Portugal, Benelux, Turkey	
11. Freudenberg Schwab (German)	Vibration control components and systems		China ??	The website will soon post the involved project
12. Dellner Group (Sweden)	Offering production and after market services for train connection systems, dampers and gangways; designs, develops, manufactures, and markets mechanical, electrical, and pneumatic coupler systems internationally..		Asia, Europe and North America	
13. Knorr-Bremse (Germany)	World's leading manufacturer of braking systems for rail and commercial vehicles; Other lines of business include automatic door systems, rail vehicle air conditioning systems and torsional vibration dampers for internal combustion engines.	BST, CSR Sifang, JR East, Russia Railway RZD, Chinese Ministry of Railway, Thalys, Alstom, Siemens, Bombardier, Talgo	China, Japan, Russia, Brazil, USA, France, Spain, Italy,	
14. EKE Electronics (Finland)	Designs and manufactures train control and management systems and train communication networks.	ÖBB, Siemens, Alstom, Bombardier, Virgine train, Channel Tunnel Shuttle	Australia, Brazil, Austria, Israel, Romanian, UK, Sweden, US, China, France, UK, Finland, Hongkong	
15. Traintic (Spain)	Develop Intelligent Transport Systems (ITS) to support sustainable mobility;	CAF, TCDD, RENFE	Turkey, Spain	Technological affiliate of CAF
16. Ingeteam Traction (Spain)	Electrical engineering; traction system; auxiliary, battery charger and control cabinets; High voltage cell and electronic control system.	Talgo	Uzbekistan	
17. Eliop Seinalia (Spain)	Provides rail traffic signaling	ONCF, Fomento de Construcciones y Contratas (FCC).	Spain, Turkey, Morocco, Egypt	Technological subsidiary of the CAF Group
18. Nomad Digital (UK)	Provides Internet links to trains around the world; Passenger WiFi Service	Amtrak, VIA rail, Talgo, Stadler	USA, Canada, UK, Swiss	
19. Merak	Design and production of Heating,	Alstom, Siemens	As of today has more than 45.000	Acquisition of all Merak shares by

(Spain)	Ventilation and Air Conditioning (HVAC) equipment for railway vehicles; European pioneer of HVAC technology in high-speed trains		units running all over the world with over 200 different designs; China, Russia, France	Knorr-Bremse in 2005.
20. ISOFLEX (Sweden)	Original manufacturer of the passenger rail coach and translucent window insulation material, MONIFLEX	BST, Siemens, Alstom, Ansaldobreda	Austria, China, Czech Republic, Finland, Germany, UK, Hungary, India, Italy, Norway, Poland, Spain, Sweden	
21. Kugel Edelstahlverarbeitung (Germany)	Stainless steel processing	Siemens, Bombardier	Austria, Netherland, Switzerland and wordwide	
22. Consilium (Sweden)	World's leading suppliers of fire and gas detection, navigation and emission monitoring systems	LU, MOR, DSU	China, Sweden, UK, Denmark.	
23. Satek (Germany)	WC cabins, sanitary cabins, washbasins, tank facilities and automatic doors	Bombardier, Siemens, Stadler		
24. Pininfarina (Italy)	World-class design house that is best known for its work in the car industry	Eurostar	Italy, Swiss, Danish, France, Turkey.	
25. URS Corporation (USA)	Planning environmental management, engineering design, construction, program and construction management, and operations and maintenance	California high speed rail authority, HS2 Ltd.	USA, UK.	
26. China ACM (China)	A leading provider of ready-mix concrete and related technical services		China	
27. Ningbo Ebong Auto Parts Co. Ltd. (China)	Specializes on manufacturing mechanical products		North America, South America, Eastern Europe, Southeast Asia, Africa, Mid East, Eastern Asia, Western Europe	
28. Henan Splendor Science & Technology Co., Ltd (China)	Railway signaling and control system; Railway Monitory system	CSR	China	
29. YUJIN MACHINERY LTD. (Korea)	Design, produce, and distribute brake system, main compressor, pantograph, and mechanical and electric coupler		Korea, China, Brazil	

APPENDIX D

SELECTED ECONOMIES SCALE AND SCOPE STUDIES AND ESTIMATES

Papers	Industry	Data	Specification Estimated	Estimate of Scale	Estimate of Scope
Kim(1987)	Water Supply Industry	Cross-section of 60 utilities for 1973	Translog function form[a]	Overall: constant return to scale Economies of scale for small utility and diseconomies for scale for large utility The average overall scales of elasticity is 0.9926, the large ones is 0.87503 and the small ones is 1.33296 Product-Specific (1) non-residential: substantial economies of scale . $\frac{\partial lnMC_N}{\partial lnY_N} = -0.19684$ (2) residential: diseconomies of scale $\frac{\partial lnMC_R}{\partial lnY_R} = 0.50298$	
Fillippini and Koller(2011)	Swiss postal Market	Cross-section of the year 2006 with 2466 Swiss operating postal outlets	Non-Homothetic form [b]	Strong economies of scale especially for postal outlets with low output volume, for rural offices and agencies. The mean economies of scale for class one is 1.071 and that for class two is 1.079.[46] The mean economies of scale for urban area is 1.115 and that for rural area is 1.349	Strong economies of scope especially for postal outlets with high output volume, for rural offices and agencies. The mean economies of scope for class one is 0.380 and that for class two is 0.117. The mean economies of scope for urban area is 0.665 and that for rural area is 1.154
Triebs et al.(2011)	Electric Utility	Unbalanced panel data for US local government owned electric utilities from 2000 to 2003	Flexible technology quadratic model[c]	Economies of scale are lower for specialized firms and almost neutral for generation only firms.	(1) Economies of scope are driver both by differences in cost level and differences in technology. Allowing for different technology often drastically lowers the estimates for

[46] Class one incorporate postal office with high cost and high output level.

					economies of scope. (2) The firm would increase its cost by 4.6 percent if it was to break up into two specialized firms.
Cummins(2010)	Insurance Industry	US insurers over the period 1993–2006	DEA estimation method Frontier analysis to measure economies of scope[d]		(1) The cost scope economies are more than offset by revenue scope diseconomies in P-L firms[47]. (2) Both cost and revenue scope diseconomies are present for L-H insurers[48].
Berger et al. (1987)	Banking Industry	1983 FCA Bank data	Translog function form[e]	Slight diseconomies of scale Ray Scale economies increase from 0.8 to 1.0 as bank increase in size.	Slight diseconomies of scope near the sample mean. Unrealistically large scope diseconomies are found for large banks which is arbitrarily approximate to -1.[49]
Diestch (1993)	French commercial bank industries	Data of all the commercial depository banks of year 1980 and 1989	Translog function form[f]	Results show that economies of scale exist in French commercial bank industries	Economies of scope exist in French commercial bank industries.
Huang and Wang (2001)	Taiwan banking Industry	Panel data on 22 Taiwan's domestic banks (11 are public banks) from 1981 to 1992	Translog function form Stochastic frontier cost function[g]	(1) Economies of scale exist (2) Exclusion of x-inefficiencies[50] from cost function would bias the economies of scale downward	(1) Economies of scope exist (2) Exclusion of x-inefficiencies from cost function would confound scope of economies with x-efficiency.
VÁRADI et al.(2001)	Higher education	1994-1995 730 private and 820 public colleges and universities of united States	Quadratic functional Form[h]	In private IHEs[51], economies of scale are present up to a point that is above the average size of an average private IHEs.	(1) Economies of scope are present in the private IHEs. (2) For public IHEs, there are no economies of scope, but the results are not robust at all.
Cohn et al.(1989)	Higher education	Cross-sectional survey of 1887 IHEs for academic year 1981-1982	Fixed cost quadratic functional form[i]	(1) Ray Economies of scale appears both in public and private IHEs, at least up to a point. For public sectors, ray economies of scale exhausted at the average level, while	(1) Ray Economies of scope appears both in public and private IHEs, at least up to a point. For public sectors, ray economies of scope exhausted at the average level, while it remains

[47] P-L means property-liability segment
[48] L-H means life-health segment
[49] This may be caused by the difficulty of extrapolating the estimated model to zero output.
[50] X-efficiency means investigate economic efficiencies and x-inefficiency means investigate economic inefficiency
[51] IHEs means "Institutions of higher education"

				it remains even at six times of average level for private sectors (2) Product-specific economies of scale are only exists in public sectors for research and graduate enrollments.	even at six times of average level for private sectors (2) At the output level that ray economies disappears, product-specific economies of scope continues to exist in both sectors
De Groot (1991)	American Research University	147 American Doctorate granting universities in fiscal year 1983	Translog cost function[j]	(1) There are considerable economies of scale for the average institution in the primary processes of producing teaching and research. There are even larger economies of scale in production of supportive services (like libraries and administrative service) (2) The effects of ownership and intensity of state regulation on economies of scope are not significant	(1) Economies of scale are found for the joint production of undergraduate and graduate instruction. (2) The effects of ownership and intensity of state regulation on economies of scope are not significant
JARA-DIAZ et al.(2002)	Spanish Port's infrastructure	286 observations on 26 ports during 11 years from 1985 to 1995	Quadratic function form[k]	Increasing returns are present in general and are smaller for the largest ports	(1) Scope economies analysis shows that port specialization is not appropriate in terms of port infrastructure (2) Smallest ports show the largest economies of scope
Bloch et al.(2001)	Australian Telecommunication industry	1926-1991 annual data	Quadratic function form[h]	There is no ray economies of scale	Australian telephone service exhibits economies of scope

Note:

[a]. $lnC(Y,W,Z) = \alpha_0 + \sum_{i=R}^{N} a_i lnY_i + \sum_{j=L}^{K,E} b_j lnW_j + \sum_{k=U}^{M} c_k lnZ_k + \frac{1}{2}\sum_{i=R}^{N}\sum_{p=R}^{N} a_{ip} lnY_i lnY_p + \frac{1}{2}\sum_{j=L}^{k,E} b_{jq} lnW_j lnW_q +$

$\frac{1}{2}\sum_{k=U}^{N}\sum_{r=U}^{M} C_{kr} lnZ_k lnZ_r + \sum_{i=R}^{N}\sum_{j=L}^{k,E} d_{ij} lnY_i lnW_j + \sum_{i=R}^{N}\sum_{k=U}^{M} e_{ik} lnY_i lnZ_k + \sum_{j=L}^{k,E}\sum_{k=U}^{M} f_{jk} lnW_j lnZ_k$

Y_R and Y_N denote the residential and non-residential outputs respectively. W is a set of input which is composed as the input prices of labor (W_L), capital (W_k) and energy (W_E). Z describes a set of "operating" variable including the capacity utilization (Z_U) and service distance (Z_M).

[b]. $C_i = \alpha_{i0} + \sum_m^M \beta_{mi} Q_{mi} + \frac{1}{2}\beta_{mmi} Q_{mi} Q_{mi} + \sum_{m(m\neq n)}^M \sum_n^M \beta_{mni} Q_{mi} Q_{ni} + \gamma_{pci} P_{ci} + \frac{1}{2}\gamma_{P_C P_C{}_i} P_{Ci} P_{C^i} + \sum_m^M \lambda_{mi} P_{ci} Q_{mi} + \delta_{1i} dBM_i + \delta_{2i} dRA_i + \varepsilon_i$

where C represent the total cost and $Q_1 - Q_6$ represents the six outputs . The first five outputs are measured by the following parameters: letters, parcels, payment services, account management services, and sale of further products. The sixth output is the variable that represents standby periods during the opening time of these post offices. P_c is the price of capital, and dBM and dRA are the business model and the region

[c]. $lnC = I\left[\alpha_0^I + \sum_{i=1}^{N^I} \beta_i^I lnq_i + \sum_{j=1}^{G^I} \gamma_i^I lnw_j + \frac{1}{2}\sum_{i=1}^{N^I}\sum_{j=1}^{N^I} \rho_{ij}^I lnq_i lnq_j + \frac{1}{2}\sum_{j=1}^{G^I}\sum_{K=1}^{G^I} \lambda_{jk}^I lnw_j lnw_k + \sum_{i=1}^{N^I}\sum_{j=1}^{G^I} \theta_{ij}^I lnq_i lnw_j + \sum_{l=1}^{Z^I} \xi_l^I Z_l + \sum_{l=1}^{Z^I} \tau_i^I Z_l^2\right] + U\left[\alpha_0^U + \sum_{i=1}^{N^U} \beta_i^U lnq_i + \sum_{j=1}^{G^U} \gamma_i^U lnw_j + \frac{1}{2}\sum_{i=1}^{N^U}\sum_{j=1}^{N^U} \rho_{ij}^U lnq_i lnq_j + \frac{1}{2}\sum_{j=1}^{G^U}\sum_{K=1}^{G^U} \lambda_{jk}^U lnw_j lnw_k + \sum_{i=1}^{N^U}\sum_{j=1}^{G^U} \theta_{ij}^U lnq_i lnw_j + \sum_{l=1}^{Z^U} \xi_l^U Z_l + \sum_{l=1}^{Z^U} \tau_i^U Z_l^2\right] + D[\alpha_0^D + \sum_{i=1}^{N^D} \beta_i^D lnq_i + \sum_{j=1}^{G^D} \gamma_i^D lnw_j + \frac{1}{2}\sum_{i=1}^{N^D}\sum_{j=1}^{N^D} \rho_{ij}^D lnq_i lnq_j + \frac{1}{2}\sum_{j=1}^{G^D}\sum_{K=1}^{G^D} \lambda_{jk}^D lnw_j lnw_k + \sum_{i=1}^{N^D}\sum_{j=1}^{G^D} \theta_{ij}^D lnq_i lnw_j + \sum_{l=1}^{Z^D} \xi_l^D Z_l + \sum_{l=1}^{Z^D} \tau_i^D Z_l^2]$

where I, D and U are three dummy variables which take the value one if the firms are integrated or specializes in downstream and upstream activity respectively. The single upstream output is net electricity generated (yG) and the three distribution outputs are energy sales (yD1), number of customers (yD2), and distribution network length (yD3).w_k,w_L, and w_O are input prices represented the capital, labor and others.

[e]. The overhead cost function is as follows:

$$lnOPC_0 = \alpha_0^0 + \sum_{i=1}^{5} \beta_i^0 lnN_i + \frac{1}{2}\sum_{i=1}^{5}\sum_{j=1}^{5} \delta_{ij}^0 lnN_i lnN_j + \sum_{i=1}^{5} \theta_i^0 lnA_i + \frac{1}{2}\sum_{i=1}^{5} \theta_{ii}^0 (lnA_i)^2 + \sum_{i=1}^{5} \mu_i^0 lnA_i lnN_i + \sum_{m=1}^{2} \alpha_m^0 lnw_m + \frac{1}{2}\sum_{m=1}^{2}\sum_{n=1}^{2} \gamma_{mn}^0 lnw_m lnw_n + \sum_{m=1}^{2}\sum_{i=1}^{5} \rho_{mi}^0 lnw_m lnN_i + \sum_{m=1}^{2}\sum_{i=1}^{5} \pi_{mi}^0 lnw_m lnA + \lambda_B^0 lnB + \frac{1}{2}\lambda_{BB}^0 (lnB)^2 + \sum_{i=1}^{5} \lambda_{Bi}^0 lnBlnN_i + \tau_H^0 HlnB + e^0$$

where OPC_0 total non-interest overhead operating expenses for deposit and loans. N_i represents number of account type i including the demand deposit (N_1), time and saving deposit (N_2), real estate loans (N_3), commercial loans (N_4) and installment loans(N_5). A_i is average size of account i . w_1 represents the labor cost and w_2 is the capital cost. B is the number of full-service and limit service banking office. H is dummy variable and takes the value one if the bank is owned by a multi-bank holding company and 0 otherwise.

[f]. $lnC = \alpha_0 + \sum_{i=1}^{4} \alpha_i lny_i + \sum_{j=1}^{3} \beta_j lnp_j + \frac{1}{2}\sum_{i=1}^{4}\sum_{k=1}^{4} \delta_{ik} lny_i lny_k + \frac{1}{2}\sum_{j=1}^{4}\sum_{h=1}^{4} \gamma_{jh} lnp_j lnp_n + \sum_{i=1}^{4}\sum_{j=1}^{3} \delta_{ij} lny_i lnp_j$

y_i is the quantity ith output. The outputs include deposit, loans, long-term securities and interbank market activity (interbank liabilities net of interbank asset). x_j quantity of jth factor input. p_j is price of jth factor input. Three factors are identified in this study that is labor service, real capital and financial capital.

[g]. $lnC = \alpha_0 + \sum_{j=1}^{3} \alpha_j lnY_j + \sum_{i=1}^{3} \beta_i lnp_i + \frac{1}{2}\sum_{j=1}^{3}\sum_{k=1}^{3} \delta_{jk} lnY_j lnY_k + \frac{1}{2}\sum_{i=1}^{3}\sum_{k=1}^{3} \gamma_{ik} lnp_i lnp_k + \sum_{i=1}^{3}\sum_{j=1}^{3} \rho_{ij} lnP_i lnY_j + \epsilon$

Y_i is the ith output. There are three outputs which are investment (Y_1), short-term loans (Y_2) and long-term loans (Y_3). p_i is the ith input price and the three inputs are deposit, labor and capital.

[h]. $C_i = \alpha_0 CONSTANT_i + \alpha_{f1} DBAC_i + \alpha_{f2} DDOC_i + \alpha_{f3} DRES_i + \alpha_1 BAC_i + \alpha_{11} BAC_i^2 + \alpha_2 DOC_i + \alpha_{22} DOC^2 + \alpha_3 RES_i + \alpha_{33} RES_i^2 + \alpha_{12} BAC_i DOC_i + \alpha_{13} BAC_i RES_i + \alpha_{23} DOC_i RES_i + \alpha_4 QUA_i + \alpha_5 END_i + \alpha_6 DHOSP_i + v_i$

where BAC, DOC and RES are variables measuring undergraduate, graduate and research output. $DBAC$, $DDOC$ and $DRES$ are dummy variables for respective variables not being zero. QUA is the quality proxy, END stands for the value of endowment of the IHE. $DHOSP$ is dummy equals 1 if a hospital is affiliated with the IHE.

[i].$C = \alpha_0 + \sum_i \alpha_i F_i + \sum_i b_i Y_i + \frac{1}{2}\sum_i \sum_j c_{ij} Y_i Y_j + \vartheta$

The F_i is dummy variable which equals one for positive amounts of the output Y_i and it capture differences in fixed costs that arise across IHEs which produce different product sets. Y_i is a set of output that includes undergraduate full-time equivalent (FTE) enrollment (UD), graduate FTE enrollment (GR) and research output (RES).

[j].$logC(q_1, q_2, q_3) = k + \sum_i a_i logq_i + \sum_{i \leq j} a_{ij} \log(q_i) \log(q_j)$

C is total variable cost. q_1 is undergraduate instruction output; q_2 is graduate instruction output; q_3 is research output.

[k]. Their total cost function is given by:

$$C = f(CGC, NCGC, DB, LB, CANON, l, m, c)$$

where *CGC, NCGC, DB, LB, CANON* represents the different output of the ports service[52]; l is the labor input; m is intermediate input price index. *c* is total capital price obtained as its actual economic value divided into the total dock length as a proxy for the amount of physical capital. The estimated function is as follows.

[52] CGC is the containerized general cargo; NCGC is non-containerized general cargo; DB is dry bulk; LB is liquid bulk; CANON is the total rent received which used as a proxy of output representing other activities that induce expenses in infrastructure.

$$C(Y) = \alpha_0 + \sum_i^m \alpha_i (y_i - \overline{y_i}) + \sum_i^n \beta_i (w_i - \overline{w_i}) + \sum_i^m \sum_{j \geq i}^m \alpha_{ij} (y_i - \overline{y_i})(y_j - \overline{y_j}) + \sum_i^n \sum_{j \geq i}^n \beta_{ij} (w_i - \overline{w_i})(w_j - \overline{w_j}) + \sum_i^m \sum_j^m \delta_{ij} (y_i - \overline{y_i})\,(w_j - \overline{w_j}) + \varepsilon$$

[l]. $lnc = \ln\left[\alpha_0 + \alpha_i q_i + \frac{1}{2}\sum_i \sum_j \alpha_{ij} q_i q_j + \sum_i \Gamma_i T q_i + \phi_1 T + \frac{1}{2}\phi_2 T^2 + \sum_i \sum_k \delta_{ik} q_i lnr_k\right] + \sum_k \beta_k lnr_k + \frac{1}{2}\sum_k \sum_L \beta_{kL} lnr_k lnr_L + \sum_K \Omega_K lnTlnr_k + \lambda T75$

q_i is millions of the local (q_{LO}) and Toll (q_T) calls respectively. r_K refers to labor and capital price. T is technology change. $T75$ is dummy variable, which equals one if $t > 1975$

APPENDIX E

OVERVIEW OF BUY AMERICA REQUIREMENTS FOR U.S. FRA AND FTA

In 2009, President Obama, together with Vice President Biden and Secretary of Transportation LaHood, articulated a new "Vision for High-Speed Rail in America". The High-Speed Intercity Passenger Rail (HSIPR) program implements that vision, which includes a goal to bolster American passenger rail expertise and resources. The Buy America requirements reinforce this goal, and aid in encouraging a domestic market in the rail sector.[53]

The Passenger Rail Investment and Improvement Act (PRIIA) of 2008 authorized the appropriation of funds to establish several new passenger rail grant programs, including capital investment grants to support intercity passenger rail service, high-speed corridor development, and congestion grants. FRA consolidated these and other closely related programs into the HSIPR program, as funded through the American Recovery and Reinvestment Act of 2009 (ARRA). Spending authorized under PRIIA is subject to the Buy America provision of 49 USC § 24405(a).

According to the FRA's HSIPR Interim Guidance, Buy America provision at 49 U.S.C § 24405(a) applies to projects funded under Track 1 and Track 2, to service development program and individual and to projects funded under the FY 2010 DOT Appropriations Act. However, FRA's HSIPR program also includes projects whose funds were not authorized through PRIIA and funded through FY 2008 and 2009 Department of Transportation and related Agencies

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[53] http://www.fra.dot.gov/Pages/251.shtml

Appropriations Acts in Track 3 and Track 4. Therefore, these projects are not applicable to the section 22045(a) but must comply with Buy American Act. Amtrak's direct purchases have a separate statute governs which is 49 U.S.C. § 24305(f) and the 49 USC § 24405(a) is not applicable. As provided in 49 U.S.C. § 24405(a)(11), the PRIIA Buy America requirements apply only to projects for which the costs exceed $100,000. [54]

Section 24405(a) [55] provides that the Secretary of Transportation (authority delegated to the Federal Railroad Administrator) may obligate an amount to carry out a PRIIA funded project only if the steel, iron, and manufactured goods used in the project are produced in the United States.[56] The Secretary of Transportation may waive that if the secretary finds that: (A) applying that would be inconsistent with the public interest; (B) the steel, iron, and goods produced in the United States are not produced in a sufficient and reasonably available amount or are not of a satisfactory quality; (C) rolling stock or power train equipment cannot be bought and delivered in the United States within a reasonable time; or(D) including domestic material will increase the cost of the overall project by more than 25 percent. The Secretary of Transportation may not make a waiver for goods produced in a foreign country if the secretary, in consultation with the United

[54] http://www.fra.dot.gov/Pages/11.shtml
[55] http://www.fra.dot.gov/downloads/49USC24405a.pdf
[56] From 49 C.F.R. § 661.5(d): For a manufactured product to be considered produced in the United States, (1) All of the manufacturing processes for the product must take place in the United States; and (2) All of the components of the product must be of U.S. origin. A component is considered of U.S. origin if it is manufactured in the United States, regardless of the origin of its subcomponents. From 49 C.F.R. § 661.3: Component means any article, material, or supply, whether manufactured or unmanufactured, that is directly incorporated into the end product at the final assembly location.… End product means any vehicle, structure, product, article, material, supply, or system, which directly incorporates constituent components at the final assembly location, that is acquired for public use under a federally-funded third-party contract, and which is ready to provide its intended end function or use without any further manufacturing or assembly change(s).

States Trade Representative, decides that the government of that foreign country(A) has an agreement with the United States Government under which the Secretary has waived the requirement of this subsection; and (B) has violated the agreement by discriminating against goods to which this subsection applies that are produced in the United States and to which the agreement applies.

Amtrak is in compliance with the U.S.C. § 24305(f)[57] domestic Buying preference. According to that, Amtrak shall buy only (A) unmanufactured articles, material, and supplies mined or produced in the United States; or (B) manufactured articles, material, and supplies manufactured in the United States substantially from articles, material, and supplies mined, produced, or manufactured in the United States. This subsection applies only when the cost of those articles, material, or supplies bought is at least $1,000,000. On application of Amtrak, the Secretary of Transportation may exempt Amtrak from this subsection if the Secretary decides that (A) for particular articles, material, or suppliers (i) the requirements of this subsection are inconsistent with the public interest; (ii) the cost of imposing those requirements is unreasonable; or (iii) the articles, material, or supplies, or the articles, material, or supplies from which they are manufactured, are not mined, produced, or manufactured in the United States in sufficient and reasonably available commercial quantities and are not of a satisfactory quality; or (B) rolling stock or power train equipment cannot be bought and delivered in the United States within a reasonable time.

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[57] http://www.fra.dot.gov/downloads/49USC24305.pdf

FRA believes that high speed and intercity rail passenger equipment can and should be manufactured in the United States and will do everything to ensure that its grant funds are spent domestically and where there is not currently domestic production, will do what it can to encourage domestic projection. Where it is impossible for a grantee to find a fully complying bidder/offeror (and therefore a waiver from Buy America is requested), the grantee is encouraged to choose (as long as this choice is consistent with applicable procurement practices) as its contract award the bidder/offeror with the proposal containing domestic manufacture and the highest domestic content.

FRA will apply the statutory Buy America provision strictly and will issue a waiver only when the bidder/offeror has demonstrated by clear evidence that it has met the requirements for a waiver. Moreover, FRA considers the need to grant waivers under these circumstances as strictly temporary because it expects that achieving domestic manufacture and 100% domestic component content can and will occur in the very near future. By encouraging grantees to use manufacturers or suppliers who maximize domestic content, FRA hopes to achieve its goal of 100% domestic content in the near future.

FTA has its own Buy America statute, [58]which in many respects is identical to FRA's statute. However, the FTA's Buy America statute, at 49 U.S.C. § 5323(j)(2)(C)(i) and (ii), includes the specific additional waiver regarding a 60% component and American assembly allowance for rolling stock [59] that 49 U.S.C. 24405(a) (FRA's

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[58] http://www.fta.dot.gov/legislation_law/12921.html
[59] The FTA's Buy America exception says "when procuring rolling stock (including train control, communication, and traction power equipment) under this chapter— … the cost of components and

HSIPR Buy America statute) does not. Except that part, the general FTA and FRA Buy America provisions regarding the steel iron and manufactured goods used in its grant-funded projects are nearly identical. FRA will not use statutory authorities it doesn't have.

The FTA, throughout the 30 years it has administered its own Buy America statute, has implemented regulations and changes to those regulations which have resulted in a very detailed set of rules, guidance documents, and enforcement strategies.

The definitions and provisions at 49 C.F.R. §§ 661.3, and 661.5 implement FTA's Buy America general requirements covering steel, iron, and manufactured goods, except where 661.11 applies, which is FTA's regulation covering the procurement of rolling stock (including train control, communication, and traction power equipment).

FRA is developing its own regulations; however, in the interim, FRA has concluded that it is reasonable and appropriate to use applicable FTA rules for purposes of providing guidance to FRA's grantees, specifically 49 C.F.R. § 661.3 and 661.5 – and use them as guidance for both FRA-funded manufactured goods procurement generally and rolling stock, where appropriate. As explained above, FRA cannot apply § 661.11 to rolling stock procurements because of the differences in FRA and FTA statutory authority—though some of the analysis might be helpful in particular circumstances.

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subcomponents produced in the United States is more than 60 percent of the cost of all components of the rolling stock; and … final assembly of the rolling stock has occurred in the United States."

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