4 Technology Policy and A-Synchronic Technologies: The Case of German High-Speed Trains[1]

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4.1 Introduction

Public support for research and development (R&D) can be oriented towards various objectives: at early stages of the innovation process, exploration of technological opportunities is sought. Indeed, short run, profit oriented research strategies might lead to too early a focus and to lock-in to an inferior solution (Cowan 1991). At later stages, public support often seeks to foster the adoption of the new technology. There are situations where private incentives lead to under-adoption of the new technology (Farrell and Saloner 1986). Even though these objectives may be distinct, they can overlap, for instance when several technologies are supported simultaneously. The purpose of this chapter is to shed some light on the difficulties that could be encountered in such situations.

This we do by studying the case of the German high-speed train programme. Several stages have been identified since the launch of this programme in the early 1970s: in the first (1971–1977), innovations in the Magnetic Levitation (at that time a very "un-mature" technology) and Wheel/Rail technologies were pursued under the sponsorship of the Federal Ministry for Research and Technology (BMFT). The splitting of the

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"generic" programme into two separate projects took place in 1977. The BMFT was responsible for the further development of the Magnetic Levitation technology, with a short term marketing objective, while the Federal Ministry of Transports (BMV) took responsibility for the development of a more traditional Wheel/Rail system. We interpret this bifurcation as institutional specialization of the innovation oriented research ministry and the diffusion oriented transport ministry.

From that time, the two projects followed separate paths: the Wheel/Rail technology was marketed under the ICE label; the Magnetic Levitation (MagLev) technology became stable and incremental improvements were embodied in the various Transrapid versions. However, at the end of 2000, despite the maturity of the technology, the Transrapid was not adopted for the Hamburg–Berlin line. Some of the reasons given were the high costs of the technology, its small performance advantage over the existing ICE, and demand uncertainty. An alternative outlet for this technology, namely the 31.5 km Chinese project linking Pudong airport to the Long Yang road-station in Shanghai, was found only recently.

In our view, the difficulties encountered by the Transrapid are associated with the type of policy that was followed. While it may seem a "natural" way to cope with technology evolution, the German policy of providing parallel support for "a-synchronic" technologies (Wheel/Rail being is seen as the "old" technology and MagLev as the "new") raises several non-trivial issues. First, evaluation of the merits of the respective technologies must be conducted at "comparable levels of knowledge". At some point, acquisition of new knowledge requires commercial exploitation beyond the laboratory. Second, implementation of a transport system required high investment in network infrastructures. The need for compatibility with existing infrastructures heavily influences the operator's choice of a technology. Finally, we would argue that delays in technology adoption could have irreversible consequences, as (i) improvements to the unadopted technology do not occur and (ii) the "window of opportunity" for its diffusion might be missed.

4.2 The German High-Speed Train Programmes

The Wheel/Rail technology (presently marketed under the name ICE) followed an incremental development path with the primary consideration being compatibility with the existing rail infrastructure. To a large extent, innovations took place within a pre-defined framework. In contrast, MagLev was a radical innovation, at both system and component levels. According to Büllingen (1997), the MagLev technology emerged from an innovation process which sequentially followed fairly well defined stages: invention (1922–1940), innovation (1960–1967), consolidation (1968–1978), and, finally, implementation (1979–present).

Public support was important in converting what was primarily a technological challenge into an economic one. We therefore look first in our historical analysis at the implications of involvement of public institutions. Two main periods can be identified in the history of the German high-speed train: in the first (1971–1977), MagLev and Wheel/Rail technologies were developed within a global programme. The second period began in 1977 when the programme was split into two separate projects. MagLev was seen as a technological breakthrough project, and Wheel/Rail was considered to be a project of incremental innovation.

4.2.1 The Generic High-Speed Train Programme

The initial German high-speed train programme was launched after a study commissioned by BMV, which identified a need for high-speed guided transports.

4.2.1.1 The HSB Study (1969 – 1971)

The time that public authorities became involved in high-speed guided transports is clearly identifiable. In 1969, the HSB group (HSB is the German acronym for High-Speed Trains), which had been established two years earlier by Bölkow, Krauss-Maffei (KM) and the Deutsche Bundesbahn (DB), was commissioned by BMV to conduct a study with the objective of reducing the gap between the speeds of land and air transport.

The final report of the HSB group was delivered in 1971. Parallel development of the Wheel/Rail and the MagLev technologies was advocated. This raises several points. At that time, it was considered that due to its intrinsic characteristics (and especially the physical contact between wheels and rails), Wheel/Rail technology would not allow a commercial operating speed exceeding 300 km/h. The MagLev system (which had entered the consolidation phase, see Büllingen 1997) offered the possibility of higher commercial speeds (500 km/h was considered feasible). Despite this, both these technologies were seen as being possible substitutes for air transport for distances of less than 500 km. It should also be noted that the HSB study was based on the Hamburg–Köln–Stuttgart–Munich corridor (known as the “C line”, and which would later have a connection to Frankfurt).

The HSB group's recommendations had one major consequence, namely the involvement of the BMFT in a high-speed train research programme. In addition, the DB launched a programme for modernization of the rail infrastructure (this programme was known as the "Ausbauprogramm 1970"). The modernized network was designed to support speeds up to 300 km/h.

4.2.1.2 The "Technologies for Transport Systems" Programme

The purpose of the BMFT funded research programme was to find medium and long term answers to the problems raised by the increasing demand for transport. Based on the recommendations of the HSB group, the programme had two essential components:

- developing the MagLev technology up to technical maturity (from 1970 onwards);
- identifying the technical and economic limits of the Wheel/Rail technology (from 1972 onwards).

Five research stages were scheduled for each technology:

- Conceptual study
- Components study
- System development and experimentation
- Exhibitions under commercial conditions
- System validation by trials in "reality-like" environments.

The funding scheme adopted by the BMFT was the following:

- Financing of all research concerning the MagLev technology: this was justified by the high immaturity (at that time) of the technology, and the (commercial and technical) risks associated with it;
- Financing of academic research: the argument was that academic institutions had *a priori* no financial interest in either of the projects;
- Financing of 50% of the research undertaken by the private sector into Wheel/Rail technology, which had short term commercial perspectives.

The overall BMFT funding for the 1970-1991 period amounted to 1.56 milliard DM (approximately 780 million Euros) for the MagLev technology and 0.64 milliard DM (approximately 320 million Euros) for the Wheel/Rail.

The BMFT programme enabled the construction of a dual-purpose trial circuit in Donauried. The construction of a Wheel/Rail prototype was scheduled for 1977, with a target speed of 400 km/h. The MagLev technology remained unchanged at a speed of 500 km/h, establishing a trend that would be reconfirmed over time, namely a reduction in the (perceived) speed gap between the MagLev and the Wheel/Rail technologies. Paradoxically, this did not translate into the DB policy. In the mid 1970s, the high-speed ambitions of DB were revised: instead of the initially planned speed of 300 km/h, the redesigned network was only capable of supporting speeds up to 250 km/h. This conservative policy had dramatic consequences for the development of the high-speed Wheel/Rail system. At that time, the conventional E120 locomotive was able to achieve 200 km/h. Thus, the need for a breakthrough technological solution decreased as the revised target speed became achievable through incremental innovations.

The Donauried trial circuit project was abandoned in 1977. This can be explained in part by certain exogenous factors: low social acceptance of the project, a cut in the public budget, etc. However, it can also be seen as a willingness on the part of BMFT, as the main financial contributor to the project, to focus on breakthrough technologies. Although BMFT's financing of the Wheel/Rail research continued to increase up to 1980, institutional specialization had begun in 1977: BMFT increased its commitment to the MagLev technology, while the conventional Wheel/Rail players adopted an incremental approach to innovation.

In addition, the diffusion and the rapid growth of air transportation (increased number of airlines and routes and significant decreases in fares) were having an effect. This increased the pressure to develop high-speed trains, with the focus being on the competing alternative high-speed train technologies. Thus, high-speed train technologies were seen as defining a new generation of land transportation, the various alternatives being regarded as competitors of, but not exactly substitutes for, air transport.

4.2.2 High-Speed Trains in an Institutional Specialisation Context

From 1977 onwards, the MagLev and the Wheel/Rail technology projects followed different paths. A decision to build a 31,5 km long MagLev circuit in Emsland was made in 1977. In 1978, the DB provided what was at the time an unused line (the 23 km long Rhein–Fehre section) for the construction of a Wheel/Rail trial line.

4.2.2.1 Incremental Innovations to the Wheel/Rail Technology

The purpose of this trial line was to improve the knowledge about the effects of certain parameters (ground stability, rail inclination, etc.) on the Wheel/Rail system and to check the operational character of new information and guidance systems. The decision to interrupt the construction of the Rheine–Fehre section was quickly taken by BMFT. But when the French TGV came into service (in 1981), the DB launched the "Hochgeschwindigkeits Verkehr" programme, out of which was born the ICE project (1982). In 1991 (*i.e.,* 10 years later), the ICE train was put on the market on the Hannover–Würzburg and Mannheim–Stuttgart lines.

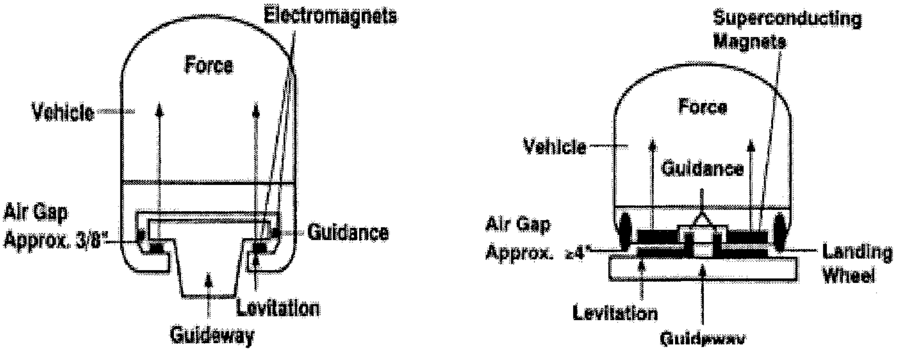
The ICE demonstrated the willingness of the DB to benefit from a solution, which was compatible with the existing infrastructure. This led to a partial disengagement of the BMFT. To an extent, the ICE development was seen as the answer to international competition constraints.

4.2.2.2 Emergence of the Transrapid: Elimination of Options and Implementation

In 1970, and following the HSB group's recommendations, the BMFT launched a research programme aimed at supporting development of the MagLev technology. The BMFT policy had two stages. The first involved preservation of the technological options. The second was characterized by a focus on two specific solutions, namely the Electro Magnetic System (EMS) technology (supported by the so-called Transrapid EMS consortium and by Thyssen-Henschel) and the Electro Dynamic System (EDS) technology (supported by the AEG-BBC-Siemens consortium). The main principles of the EMS and EDS technologies are depicted in Figure 4.1.

The decision to build a specific MagLev trial circuit in Emsland came about because of the adoption of the Thyssen-Henschel EMS technology. This final reduction of the "technology space" was justified by cost minimization considerations. Also, it could be argued that the exploration period had yielded "sufficient" knowledge concerning the comparative advantages of the competing technologies. Finally, in 1977, the BMFT expressed its desire to accelerate the pace of development of the technology in order to achieve rapid commercialization of the MagLev. Therefore, the decision favoured the least risky, most economic, technology, which, it was considered, could be implemented in the short term.

It is interesting to draw a parallel between what happened in Germany and the choice made by the Japanese in favour of the EDS technology (embodied in the MLX prototype). The difference can be explained by such factors as the lower sensitivity of EDS to earth tremors and Japan's larger potential market. However, it can also be seen as the result of a divergence in terms of the willingness to develop a breakthrough technology: the EMS had always been a more mature technology than EDS, and was generally seen as a “low breakthrough” technology[2].



(a) EMS (b) EDS

Source : http://inventors.about.com/library/inventors/blrailroad3.htm

Fig. 4.1. MagLev technologies

The BMFT decision gave rise to the emergence of the Transrapid International[3] (TRI) consortium in 1982. The MagLev technology then entered into the maturation stage characterized by a sequence of incremental innovations. This period officially ended in 1991 when the Deutsche Bahn confirmed the maturity of the technology.

4.3 The Role of Institutions in the Management of Options

Institutional specialization between the Ministry of Transport and the Ministry of Research allowed various options to be retained. Option preservation is particularly relevant in mission-oriented projects, which are subject to a conflict between increasing information and the degree of freedom concerning the future course of the project.

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[2] The EDS system relies on superconducting magnets, while the EMS employs electromagnets. A brief description of MagLev technologies can be found at <http://inventors.about.com/library/inventors/blrailroad3.htm>.

[3] Composed of Krauss-Maffei, Messerschmitt –Bölkow-Blohm and Thyssen.

4.3.1 The Importance of Maintaining Options

Experience reported by ECOSIP (1993) show that the dynamics of a project are constrained by a conflict between the willingness to reduce uncertainty (*i.e.*, to acquire various forms of knowledge) and the desire to preserve a sufficient degree of flexibility (or freedom) concerning the future course of the project. Those strategies that reduce the conflict between the level of knowledge and flexibility either delay the "freezing" of designs (*i.e.*, irreversibility), thereby maintaining options, or enable a faster reduction of uncertainty regarding possible options. ICTs, for instance, the use of virtual prototyping, can be seen as allowing these targets to be achieved more or less simultaneously.

The usual investment evaluation methods (such as those based on investment rate-of-return) are not suited to analysis of option preserving projects, since they do not account for the fact that a particular decision may shape the set of future opportunities. One method that can be used is to apply option theory (Kester 1984; Cohendet and Llerena 1989). On this basis, an investment will be considered if future options are given a high enough (subjective) value. Conversely, abandoning a particular technological option should be seen as a reduction in the future opportunity space, and evaluated as such. Unfortunately, difficulties in parameter measurement make the application of option theory problematic[4], but we consider that the mode of reasoning it involves is crucial for understanding the German policies under consideration. We argue that the option preservation policy should be linked to the institutional framework that surrounded high-speed train developments in Germany.

4.3.2 The Differentiated Role of Institutions

In the early phases of the projects (and essentially during the 1970s) neither the BMV nor the DB played an active role in the development of high-speed train technologies. All the projects we have mentioned were dependent on financial support from BMFT. It is fairly clear that BMFT's aim was primarily to promote exploration of different technological options (including the Wheel/Rail technology).

Basically, BMFT wanted to maintain all the technological options. In particular in the 1970–1977 period, BMFT's policy reflected a willingness to preserve all the options associated with the MagLev. Keeping all the op-

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[4] Bowe and Lee (2004) apply a real option methodology to evaluate the Taiwan high-speed rail project (THSRC).

tions meant that a final decision could be postponed allowing the projects to profit from new knowledge. Such a strategy can be particularly relevant in the case of breakthrough (and immature) technologies. Indeed, in this case, preserving all the options enabled the acquisition of knowledge relating to the various MagLev solutions. In 1977, the BMFT decided to put its main focus on the EMS solution. However, the BMFT continued to actively support the MagLev project (*e.g.*, by financing the Emslang trial circuit), even after the ICE project was launched in 1982. The BMFT had always been optimistic about the opportunities that a MagLev technology would open up, even though some economic and technological uncertainties persisted. Supporting the MagLev was seen as maintaining a short term option to make it possible to switch to a new trajectory were it to prove viable and profitable.

When the international competition and the technological trials showed that the high-speed Wheel/Rail system was workable and even economically interesting, the BMV and the DB adopted leading roles.

In this historical process, the BMFT was the manager of options and the BMV/DB jointly acted as the "adopting institutions". The BMFT was responsible for keeping the MagLev option alive until a higher level of maturity was reached. We would contend that this specialization by the different public institutions involved in the high-speed train projects favoured the preservation of technological options.

However, the necessity for options to be preserved only exists if there is the expectation of adding knowledge in the future, i.e. to the expected learning processes, either through continued research or through experimentations and/or commercialization.

4.4 Why and how Learning is Done ?

Learning appears to be a central element of technological evolution, and even more so in the context of breakthrough technologies. Whether done consciously or not, learning may serve several purposes. The first is to acquire information as to the approximate performance, and the potential of alternative technologies. We define this type of learning as "exploration". The second is to enhance the performance of a particular technology. We define this as "exploitation" (the distinction between exploration and exploitation was developed by James March (1991) in an organizational context). Whatever its general aim, learning may occur through several modes. For our purpose, we adopt a classification of learning modes based on their degree of "representativeness" of the real environment. Representativeness is the extent to which experiments are conducted in conditions that mirror the real life environment (Pisano 1996). How representative a learning mode should be is, in turn, related to the existence (or not) of the relevant scientific knowledge (Pisano 1996).

4.4.1 Exploration vs. Exploitation

By definition, exploration requires that a diversity of options prevails. Conversely, exploitation is the outcome of focused learning within a reduced set of options. Exploration and exploitation are usually considered as being sequential (exploitation follows exploration). This raises the issue of timing: when should exploration be stopped? From a decision theory point of view, the situation can be modelled as a stopping problem, the point being to identify the time when "enough" information (*e.g.*, as to the merits of the technologies) has been acquired. Formally, this issue may be solved by means of bandit theory (see Cowan (1991) for an application to the Technology Policy dilemma).

The question of timing is crucial for several reasons. First, it is argued that, eventually, both types of learning are subject to diminishing returns. Moving from exploration to exploitation learning is one way to overcome decreasing returns and follow an "optimal" learning curve. The distinction between exploration and exploitation learning is not sufficiently fine, however, to allow an analysis of how learning takes place in a breakthrough technology context. In the following, we look at the environment in which learning takes place.

4.4.2 The Learning Environment

Exploration and exploitation learning may occur in various environments. Following Pisano (1996), we focus on the ability of various environments to represent "reality". Table 4.1 presents a classification of learning environments in terms of their representativeness. The efficiency of a particular learning context depends on the knowledge structure that characterizes the sector being considered. In sectors where a strong base of scientific and organizational knowledge exists, problem identification and problem solving are likely to be conducted "in the laboratory". Conversely, in emerging sectors, characterized by a low level of relevant knowledge, problem identification and problem solving are likely to require commercialization.

Relevant elements of a sector knowledge structure include the theoretical understanding of fundamental processes, the ability to fully characterize intermediary and final products, and knowledge concerning possible scale and second order effects (Pisano 1996).

Table 4.1. Representativeness of learning environments (based on Pisano 1996)

Representativeness	Learning environment
High	
↑	Commercial exploitation
	Experimental running on "production" site
	Experimental running on R&D site
	Laboratory experiments
	Computer aided simulations
Low	

The choice of a specific learning environment can be trivial, as in the case of very mature technologies where low representativeness environments yield interesting outcomes. However, it can be a strategic decision, which may involve several trade-offs. Especially relevant for our study are the trade-offs between

- cost of experimentation and representativeness of its results;
- flexibility (due to, *e.g.*, technological or investment irreversibility) and representativeness of the learning environment.

As a further step in our analysis, we recapitulate some elements of the role of "doing" in the learning process.

4.4.3 Learning-by-Doing

The issue here is to what extent learning requires some form of "doing". Following Rosenberg (1982) or Habermeier (1990), it is commonly accepted that practice is an essential element of learning, since interactions between products and their use environments are often too complex to be predicted. Von Hippel and Tyre (1995) propose a further development of this proposition by analyzing the role of doing in processes of problem discovery and problem solving. Indeed, they argue that doing entails the juxtaposition of two complex elements (*e.g.*, a machine-tool and a factory environment). Doing provokes the "precipitation of symptoms" (*e.g.*, a weak performance), which, in turn, reveal unexpected interferences between the product and its use environment. It should be noted that this argument is far from being obvious: as doing implies increased complexity, it might well reduce one's ability to identify problems.

Following Von Hippel and Tyre (1995), we argue that in stable environments (*i.e.* environments that are under the control of the decision maker under either perfect expectations or knowledge of the probabilistic distribution of events), learning-without-doing can be achieved, provided a sufficient number of possible interactions within the system is investigated. Although not a necessary step for learning, doing remains a candidate learning device as it can reduce learning time and/or monetary costs. This is probably even more so in the case of highly complex systems (or technologies). However, the importance of doing seems much higher in unstable environments (*i.e.* environments that are out of the decision maker's control, where events are unexpected, and there is high non-probabilistic uncertainty). Here, symptoms emerge as the outcome of an endogenous conflict between the system (or the technology) and what Von Hippel and Tyre (1995) define as "autonomous problem solvers". This conflict gives rise to problems that are difficult (if not impossible) to anticipate and generates sets of solutions that are *a priori* non-predictable from the developers' standpoint.

In turn, we are led to conclude that assessing the weight of "doing" in the learning process requires an evaluation of the level of scientific knowledge and of the stability of the system environment.

We have argued that the timing of the switch from exploration to exploitation could have an influence on the competition between technologies. We can now push this argument further: considering complex systems (technologies), which benefit from a limited level of scientific knowledge, and which are developed within an unstable environment, an anticipated switch to practice can be considered as a source of competitive advantage as it can speed up the learning process. And, if this is the case, it means that the institutional specialization mentioned earlier also becomes crucial, because it is related to the nature of the learning processes.

4.5 Technology Competition

While it may seem a “natural” way to cope with technology evolution, the German policy of giving parallel support to “a-synchronic” technologies (Wheel/Rail is seen as the “old” technology and MagLev as the “new”) raises several issues. First, evaluation of the merits of the respective technologies must be conducted at “comparable levels of knowledge”. At some point, acquisition of new knowledge requires commercial exploitation beyond the laboratory. Second, the implementation of a transport system requires heavy investment in the network infrastructures. The operator’s choice of technology is inevitably influenced by the need for compatibility with existing infrastructures. Finally, delays in adoption of new technology might have irreversible consequences, as (i) improvements to the unadopted technology will not occur and (ii) the “window of opportunity” for its diffusion might be missed.

Even though the public authorities (BMV and BMFT) did not initially consider them as such, the Wheel/Rail and MagLev technologies should be seen as virtual competitors in the market for guided transport. Therefore, we would argue that the timing of the projects, especially in terms of commercial exploitation, has an influence on the eventual outcome of the competition between these technologies.

4.5.1 The Role of Learning

The description of the German experience in section 4.2 and the theoretical framework presented above are a first step in the appraisal of the German high-speed train technology policy.

Following the earlier arguments, we present a (very) schematic representation of the learning experienced for the systems considered in Figure 4.2. The first step refers to the simultaneous development of candidate solutions (exploration period), mostly “in the laboratory”. After a certain amount of information has been acquired concerning the merits of the technologies, elimination of candidate technologies enables acceleration of the learning process. This might be due to a concentration of financial efforts. A few technical solutions are first tested experimentally on a trial circuit. Finally, commercial exploitation enables learning on the basis of “real experience”.

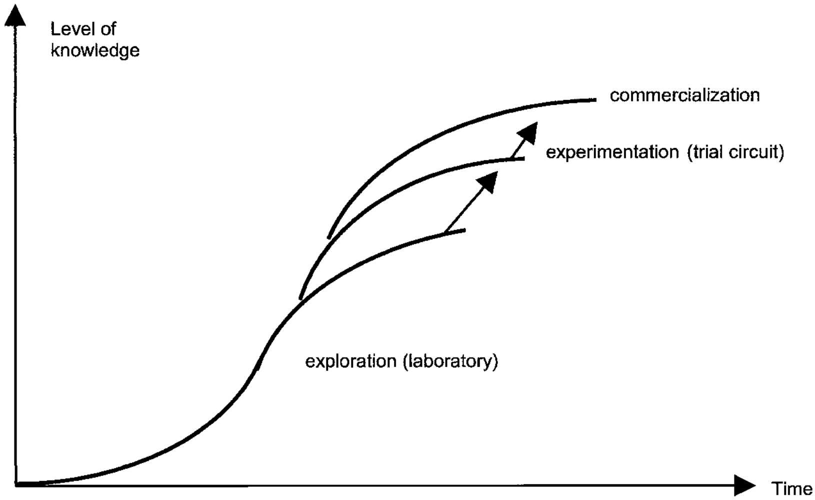

Fig. 4.2. Successive learning steps

Next we consider the parallel development of the Wheel/Rail and the MagLev technology as represented in Figure 4.3. Both projects were launched in 1971 as part of a global research venture, but, due to accumulated knowledge in similar applications, the Wheel/Rail technology underwent a rapid learning curve. The "Hochgeschwindigkeits Verkehr" programme launched in 1982 gave rise to the ICE project and the ICE train was put into service on the Hannover–Würzburg and Mannheim–Stuttgart lines in 1991. This meant that diminishing returns from the learning period were minimized.

The most important decisions (focusing on the EMS technology and construction of the Emsland trial circuit) concerning the MagLev technology were taken in 1977. We contend that commercial exploitation of the Transrapid would facilitate the acquisition of new knowledge. As long as there is no "real scale" development and commercialization, the MagLev technology will not embark on a new "learning curve".

The consequences of delaying the implementation of the Transrapid are manifold. First, it is still not possible to evaluate the merits of the MagLev and Wheel/Rail technologies on the basis of "common experiences". Second, after more than 500,000 km of cumulative trials, the MagLev displayed low returns to outlays on experimentation, while the ICE has remained the subject of (incremental) improvements (Jänsch and Keil 1999). This is likely to result in a "learning gap", which may have consequences for the opportunities of diffusion of the Transrapid, in particular in those markets where the technologies are in direct competition.

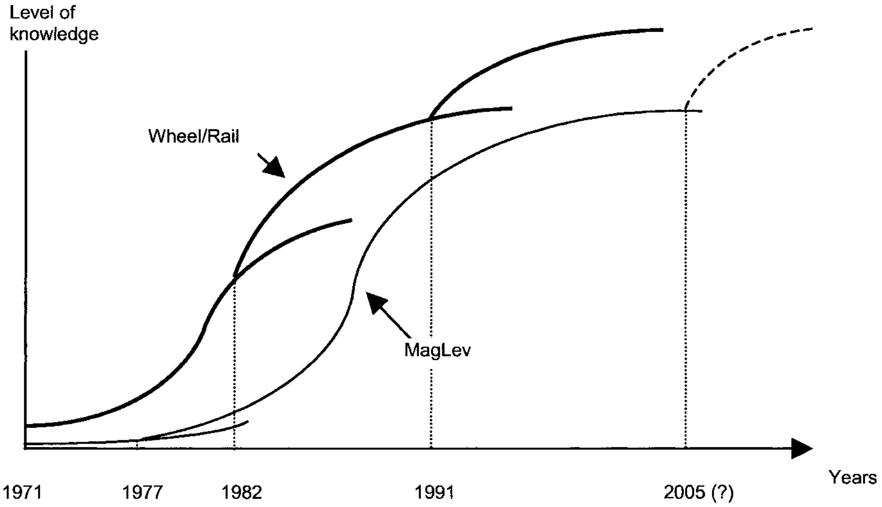

Fig. 4.3. Learning curves for the MagLev and the Wheel/Rail technologies

The German case demonstrates a contradiction, which can be observed more broadly at the European level. On the one hand, Wheel/Rail technologies, such as the French TGV and pendular systems in France, Italy, or Sweden, benefit from similarities with existing systems. In these cases, innovations raised some specific (technical or organizational) problems, but they were developed within (more or less) established boundaries. Therefore there was a degree of predictability, giving greater opportunity for learning-without-doing (see section 4.4). On the other hand, MagLev technologies, such as employed in the German Transrapid and the Swiss Swissmetro, did not benefit from previously acquired knowledge[5].

The effects of these differences are far-reaching. First, identification of the "relevant" MagLev technologies required the exploration of numerous *a priori* feasible options. This led to a costly and lengthy exploration period. Second, learning in a context where little previous knowledge exists requires highly "representative" learning environments. In addition to cost considerations, the timing of the learning sequences becomes more important. Finally, we would argue that there are differences between breakthrough and continuity oriented technologies in terms of the need to carry out a "full sequence" of learning steps.

Due to the structure of the knowledge and considerations of cost, learning in the German MagLev technology was conducted through a complete

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[5] See in particular Foray (2001) for an analysis of these cases.

sequence of steps. For instance, the propelling technology a set of rules concerning the infrastructure and control electronics. The necessity for learning to follow the full sequence is lessened in relation to Wheel/Rail systems since spill-overs from other similar projects can be expected. This was the situation that occurred in the late 1990s: before the French pendular system was developed, there had been several trials conducted in France (*e.g.*, Lyon–Modena) based on the Italian ETR460 pendular system (*cf.* Saubesty and Vernimmen 1999). In Germany, the various MagLev technologies did not benefit from cross-learning because the systems were at a very early stage of maturity and embodied few common characteristics.

This section has introduced some of the elements that can be used as the basis for an appraisal of the role of "doing" in learning processes. We argue that this is of particular significance in the switching time from pre-commercial exploitation to commercial exploitation. The arguments developed by Von Hippel and Tyre (1995) and Pisano (1996) suggest that doing plays a crucial role in the learning process involved in "breakthrough" technologies. But, the necessity for "pre-doing" learning should not be underestimated. First, evaluation of the various learning environments must account for the (direct or indirect) costs entailed. Further, in the context of high-speed train technologies, factors such as "acceptable risk" must be considered. More precisely, the possibility of "catastrophes" tends to reduce the decision makers' flexibility in determining the duration of the pre-doing learning process. Whether the development of ICTs will enhance the efficiency of the learning process substantially (for example, through the use of virtual prototyping and computer simulations) is an open question worthy of further investigation (see, *e.g.*, Nightingale 2000).

Doing and access to a representative learning environment are strongly correlated with the existence of a "lead user" (Von Hippel 1988). In this respect, the contexts within which the two alternative technologies were developed were different.

In the case of the ICE, the DB had a greater commitment after 1977 to the development of the technology. Under pressure from BMV, the DB participated directly in the design and experimentation phases of the ICE, mostly as a reaction to the development of the TGV in France. In this respect, the experimental platform (Rheine–Fehre section) and later the first commercialization on the Hannover–Würzburg and Mannheim–Stuttgart lines, were critical for the fine tuning of the technical and operational solutions. In addition, DB's support was essential in providing commercial credibility and increasing take-up by other users.

The Transrapid case stands in stark contrast. The project has never been able to attract or integrate a significant "lead user". The position of DB in relation to this project has always been ambiguous, probably because the MagLev technology was judged to be too "disruptive". Moreover, the Lufthansa airline company, which was involved in the process (especially in the latest phase), was unable to provide the necessary knowledge and support (in terms of infrastructure, for instance) to enable improvements and the fine tuning of the technology to user needs. Partially as a consequence of this, the Transrapid, up to the time of writing, has never been able to demonstrate its feasibility and economic viability, and thus has lacked credibility.

In this section, we have focused on the learning processes supporting the development of technologies. We consider that the "efficiency" of a learning process is closely related to the "correct" management of learning environments, which, in turn, is related to commercial exploitation.

However, such commercial success of a technology is also dependent on effective diffusion opportunities. This issue is particularly relevant to the Transrapid case: even though competition between the Transrapid and the ICE is officially precluded, the established ICE network is likely to have an effect on the diffusion opportunities for Transrapid, particularly because of the increasing returns to adoption that occur in network technologies (*cf.* Arthur 1989).

4.5.2 Network Competition

Guided ground transport systems comprise complementary elements, such as infrastructures, rolling stock, etc. In this context, the geographic diffusion of a particular technical system in part defines its economic value: a better diffused system enables the junction between more sites, which would be expected to increase demand. As a corollary to this, the economic value of any technical system depends on its ability to become integrated into established ones. The deciding factor is the compatibility between established and new systems (see, *e.g.*, Cohendet and Schenk 1999), a characteristic of systems that exhibit network effects: the "value" of a technology increases with the size of the associated network. The "associated network" can be a technology-specific network when there is incompatibility with existing technologies, or a shared network when there is compatibility with the existing technologies.

As we have seen, the solutions adopted for the ICE favoured continuity (and compatibility) with traditional Wheel/Rail systems. Thus, the high-speed network that was developed during the 1970s provided the base for the initial commercial exploitation of ICE, with specific parts being developed incrementally. The rationale for this approach was the low deployment costs and the speed of diffusion it allowed. Moreover, the compatibility enabled its speedy implementation on the high-traffic lines, and especially along the Köln–Rhein–Main corridor.

There are consequences in terms of the opportunities for diffusion of the Transrapid in Germany. For both economic and "political"[6] reasons, in the short run, the opportunities for diffusion of the Transrapid lie in connections where the ICE does not operate: the fall of the Berlin Wall produced some good prospects since at the time there were no high-speed connections between the former East and West Germany. A Hamburg–Berlin Transrapid project was launched in 1992, but was abandoned in 2000 after re-evaluation.

The ICE has the benefit of "first mover advantage" over the Transrapid, which considerably reduces the latter's scope for diffusion in Germany. However, although the incompatibility of the Transrapid with established systems is a drawback from a network effect standpoint, it does have some positive effects. For the ICE, compatibility generates incentives to exploit the existing network. In other words, there is little motivation for DB to develop a specific ICE network. Therefore, we would argue that the potential of ICE is not being fully exploited: heterogeneity in terms of network quality, high and low speed trains using the same tracks, and the constraints imposed by the frequency of stops, are all handicaps to higher transportation speeds. Such constraints would not apply to the Transrapid, since its incompatibility would necessitate development of a specific network[7].

Since the abandonment of the Hamburg–Berlin project, export has been seen as a credible alternative to national implementation of the Transrapid. China is constructing a 30 km Transrapid connection between Pudong airport and the Shanghai Lujiazui financial district, and this should become commercialy operational in 2004. Other projects in the United States and in the Netherlands have been positively evaluated.

The Chinese Transrapid project demonstrates a change to the initially perceived opportunities for MagLev technology: short distance connections (*e.g.*, airport–city connection) are now being given deeper consideration. Such a "re-encoding" is linked to a re-evaluation of the competitive advantage of MagLev: flexibility, space saving and ecological aspects (low

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[6] Several actors (such as Siemens, Adtrans and the DB) are engaged in both the Transrapid and the ICE.

[7] As an instance, the transportation time on the actual ICE Hanover-Frankfurt line (339 km) is over 2 hours, while the Transrapid Hamburg-Berlin connection (292 km) would take 1 hour.

energy consumption and minimal noise) and not just commercial speed are being classed as essentials.

Our analysis suggests that, in the short term, implementing the Transrapid was of particular importance since its commercial exploitation acts as a "technological display" and enables new technological learning. In the longer term, the successful introduction in China of the first Transrapid connection could open the way for its further exploitation, and once again, particularly in China where many high-speed connections are still needed.

4.6 Conclusion

The history of the German high-speed train offers rich opportunities for analyses. Observation of the development of "a-synchronic", but potentially competing technologies led to our focus on the interplay between learning and adoption processes. The main point that this chapter has tried to emphasize, is that the timetable of these projects, especially in terms of commercial exploitation, had an influence on the competition between these technologies.

On the one hand, delaying the commercial implementation of the Transrapid has prevented "real scale learning" from taking place and may lead to a learning gap between the MagLev and the Wheel/Rail technologies. On the other hand, the Wheel/Rail technology benefited from increased network advantage, which made the adoption of the MagLev even less likely. Excessive specialization between research oriented and implementation oriented institutions and difficulties in "relay transmission" makes the management of these aspects even more intricate.

Thus, designing policy recommendations in this context is a very complex business. The optimal decision sequence is determined by the value that public decision makers (and, by extension, society) attach to the preservation and the eventual exercise of options. This study could be helpful for anticipating the difficulties that might be encountered in innovation processes.

4.7 References

Arthur WB (1989) Competing technologies, increasing returns and lock-in by small historical events. Economic Journal 99: 116-131.

Bowe M, Lee DL (2004) Project evaluation in the presence of multiple embedded real options: evidence from the Taiwan high-speed rail project. Journal of Asian Economics 15: 71-98.

Büllingen F (1997) Die Genese der Magnetbahn Transrapid. Deutscher Universitäts Verlag, Wiesbaden.

Cohendet P, Llerena P (1989) Flexilibité, information et décision. Economica, Paris.

Cohendet P, Schenk E (1999) Irréversibilités, compatibilité et concurrence entre standards technologiques. In: Callon M et al. (eds.) Réseau et coordination. Economica, Paris: 65-109.

Cowan R (1991) Tortoises and hares: choice among technologies of unknown merit. Economic Journal 101: 801-814.

ECOSIP (1993) Pilotages de projet et entreprises: diversités et convergences. Economica, Paris.

Farrell J, Saloner G (1986) Installed base and compatibility:innovation, product preannouncements, and predation. American Economic Review 76: 940-955.

Foray D (2001) Choix technologiques dans les projets de ruptures technologiques. Rapport final pour le PREDIT. IMRI, Université Paris Dauphine.

Habermeier KF (1990) Product use and product improvement. Research Policy 19: 271-283.

HSB mbH. (1971a) Studie über ein Schnellverkehrsystem (Kurzbericht: Systemanalyse und Ergebnisse). Schriftreihe des Bundesministers für Verkehr.

HSB mbH. (1971b) Ein neuartiges Verkehrssystem für die Bundesrepublik Deutschland. Schriftreihe des Bundesministers für Verkehr.

Jänsch E, Keil J (1999) ICE und Transrapid: Konzeptionnelle Planungen für Elemente im HGV-Angebot der DB AG. Bahn Report 99, ETR Edition.

Kester C (1984) Today's options for tomorrow's growth. Harvard Business Review 62: 153-160.

March JG (1991) Exploration and exploitation in organizational learning. Organization Science 2: 71-87.

Münchschwander P (Ed.) (1989) Schienenschnellverkehr, vol. 1-4. R.v. Decker's Verlag, G. Schenck, Heidelberg.

MVP- Versuchs und Planungsgesellschaft für Magnetbahnsysteme mbH. (1988) Einsatzfelder neurer Schnellbahnsysteme, vol. 1-4.

Nightingale P (2000) Economies of scale in pharmaceutical experimentation. Industrial and Corporate Change 9: 315-359.

Pisano GP (1996) Learning-before-doing in the development of new process technologies. Research Policy 25: 1097-1119.

Rosenberg N (1982) Inside the black box: Technology and economics. Cambridge University Press, Cambridge.

Saubesty C, Vernimmen S (1999) Incrémentalisme et rupture technologique: étude de cas à la SNCF. IMRI, Université Paris Dauphine.

Von Hippel E (1988) The sources of innovation. Oxford University Press, Oxford.

Von Hippel E, Tyre M (1995) How 'learning by doing' is done: problem identification in novel process equipment. Research Policy 24: 1-12.