TECHNOLOGY DEVELOPMENT IN ROAD CONSTRUCTION

HOW GOVERNMENT ROLES AFFECT PROJECT PERFORMANCE

Jasper Caerteling

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DISSERTATION

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by

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Preface

In August 2002, when I had accepted the offer from André Dorée to become a PhD student, I could not have imagined the journey I have since taken. This journey turned out to be demanding in at least three ways. At first, three temporary contracts were necessary to keep me from applying for a job elsewhere. Receiving a letter confirming my temporary position followed a few days later by one that confirmed my dismissal was a strange sensation. However, André Dorée promised me all would turn out well, and he has not betrayed my trust.

During this uncertain period I wrote my PhD proposal together with André Dorée. Road construction was to be the field of interest, because of the radical changes in road construction at that time. The Netherlands Competition Authority had enforced a redistribution of the ownership of asphalt production plants. A Dutch Parliamentary Inquiry had uncovered a large-scale price fixing scheme in the Dutch road construction industry. The consequences of these events would surely be extensive.

By the end of 2003, when I finally got a position as a PhD student, the next challenge had already arisen. Managing my supervisors became one of the hardest but most instructive aspects of my PhD research. In 2004, I welcomed Joop Halman as my second supervisor. His knowledge about innovation management soon became an important complementary asset in developing the theoretical framework and research methodology. Especially in the beginning, the three of us had disagreements about the appropriate theoretical framework and how to tackle the research problem we had defined. Although these disputes were at times frustrating, they helped me gain confidence in my own judgments, and also to admit to wrong ones.

This brings me to my third challenge: the wonders of social science and innovation management literature. This road trip was exciting and enlightening. It has broadened my horizon and increased my understanding of corporate management, but I also encountered many road works and dead ends. Yet, I would not dare to call it time lost. Besides my supervisors, Michael Song has been very helpful in helping me understand the dos and don’ts in innovation management research. His comments and suggestions enabled me to improve the craft of conducting academic research and writing academic papers. Furthermore, he gave me the pleasure of being a guest at his house, while we prepared the collection of the survey data in the United States. A beacon during the data analysis was Hans van der Bij who has

helped me with the puzzling world of statistics. Without hesitation, he has spent many hours in helping me analyze my data.

Many people have made my journey worthwhile. My colleagues at the Department of Construction Management & Engineering have created an enjoyable and stimulating environment. I would like to thank André Dorée and Joop Halman, who familiarized me with the demands of the academic profession and taught me the necessary skills. I would like to express my appreciation to Michael Song who has supported my work and enabled it to ripen. I would also like to thank Hans van der Bij for all the help he provided. In addition, I would like to thank Stefan Kuhlmann for his useful comments on public technology procurement. Furthermore, I would like to thank my PhD student colleagues for their support and for the relaxing moments we spend together. A special thanks here to Albertus Laan, who has been very supportive, especially during the first two years.

I would like to thank the members of the graduation committee for their willingness to take part in this committee and allowing me to defend my dissertation.

I would also like to thank PSi*Bouw* that provided the financial means for this research project.

In understanding technology development in road construction, three people were very important. Berwich Sluer (BAM Wegen), Jos Heerkens (Heijmans Infrastructuur) and Arian de Bondt (Ooms Nederland Holding) have showed me the inner workings of large contractors. This dissertation could not have been written without their support.

Finally, I would like to thank my family who supported me and enabled me to broaden my horizons. I would like to address a special word of gratitude to my spouse, Marloes Bomer, who stood by me and made all those small and larger sacrifices to enable me to pursue my PhD.

Jasper Caerteling

's Hertogenbosch, May 2008

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Chapter 4: Caerteling, Jasper S., Halman, Johannes, I.M., Song, Michael and Dorée, Andre G. Technology development in road infrastructure: the relevance of government championing behaviour. Submitted for publication in *Journal of Construction Engineering and Management*.

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CHAPTER 1

Introduction

Research into technology development has mainly focused on consumer and business-to-business markets. This research has created a wealth of knowledge about management processes in firms that develop and produce technologies for these markets (e.g. Capon and Glazer, 1987; Das and Van de Ven, 2000; Pavitt et al., 1989; Zahra and Covin, 1993).

Despite the wide variety of industries investigated by management scholars, there has been relatively little research about technology development in the public sector. However, the public sector is a substantial part of the world economy. In the United States, federal government expenditures amount to about 18 percent of Gross Domestic Product (GDP) and are expected to rise to 27 percent by 2050 (Congressional Budget Office, 2002). In the European Union, total government expenditure has risen to above 40 percent of GDP (Schuknecht and Tanzi, 2005). Further, the US federal government accounts for 30 percent of total United States' R&D expenditure (NSF, 2006); while, in the European Union, national governments fund 35 percent of R&D spending (Eurostat, 2005).

This dissertation contributes to both the academic and the policy debates on technology development in the public sector. In the public sector, government has several roles in technology development. Government agencies can be financiers, regulators, buyers, or champions encouraging new technology (Morris and Hough, 1987). These roles often change during the development process and are performed by different agencies. Owing to the complexity of all these roles and the accompanying rules and regulations, we would expect these roles to affect technology development in the public sector. Furthermore, governments usually enforce a strict separation between policymakers and those that effect the policies drafted. This separation necessitates coalition building among policymaking and executive agencies at different levels of government in order to implement new technology (Ring and Perry, 1985). Moreover, regular elections and appointments of political leaders have a disruptive influence on operations (Rainey, Backoff and Levine, 1976). These characteristics are distinctly different from those found in consumer and business-to-business markets.

Government as a Buyer

Addressing technology development in the public sector necessarily draws attention to government as a buyer and user of new technology. As a buyer and user, government can create a market for new technology or challenge companies to develop new technologies. Demand-side policies, therefore, are a key aspect in technology policy. In the 1970s and 80s, the relevance of public technology procurement was explored. These studies reported positive long-term effects that outperformed R&D subsidies (Edler and Georghiou, 2007; Lichtenberg, 1988; Rothwell and Zegveld, 1981). Despite the strong case for public technology procurement, its significance has been downplayed, especially in the European Union (Edler and Georghiou, 2007). Given the underlying assumptions of the current European procurement policy, much effort is put into improving supply-side policies to support private R&D (e.g. Martin and Scott, 2000).

In the 1990s, the policy regarding a Single Market in the European Union has led to a revision of procurement policy. Existing procurement practices were associated with protectionism, favoritism, and the support of national champions, limiting the emergence of a single European market for government contracts (Edquist and Hommen, 2000). Therefore, the current European Procurement Directive emphasizes open tendering to facilitate competition.

This emphasis leads to a non-interactive, "arms-length" relationship in public procurement (Edquist and Hommen, 2000). Furthermore, it disregards the fact that public procurement can be an instrument of technology policy. The procurement of new technology can help to achieve social and economic goals and attract innovative firms to enter the market (Edquist and Hommen, 2000; Jacobsson and Bergek, 2004).

Although appropriate for the purchase of existing, standardized supplies, works, and services, an "arms-length" approach may be less well suited for technology procurement. New technology demands mutual adaptation and a thorough understanding of the user environment, in particular when the developed technology is novel or complex (Leonard, 1995; Tether, 2002).

In their review of public technology procurement, Edquist et al. (2000a) noted that the procuring agencies need flexibility to enable mutual adaptation in technology procurement. This relates to both the timing of demand and their technical and organizational competences. To select a competent supplier and delineate the requirements, the procuring agency needs to consider the timing of demand. Timing is relevant for several reasons. The first reason is to allow the development of a sophisticated supplier base. The development of the supplier base can be monitored by the procuring agency through collaboration with leading firms. Another option is to open up the market to leading foreign buyers and producers, forcing domestic suppliers to invest. Another reason for considering timing is choice in competing technologies; choosing too early can lead to a risky new technological trajectory. Therefore, public technology procurement in the early phases of technology development needs to support choice between multiple trajectories. In later stages of development, public technology procurement has to allow for adjustments to the state-of-the-art, once a specific trajectory is chosen.

Technical and organizational competences are also needed to carry out public technology procurement. The procuring agency must have the technical competence to understand the feasibility of technological developments. The organizational competence reflects capabilities to coordinate multiple actors on both the supply- and the demand-sides. Therefore, procuring agencies themselves have to be knowledgeable about new technologies, the associated risks, and the development process. A key example of mutual adaptation in public technology procurement is the rise of GSM mobile telephony in Sweden and the global dominance of that system. According to Arnold et al. (2008), Swedish Telecom had an important influence over key parts of the GSM standard, created a sophisticated supplier base (Ericsson), and initiated research projects to solve foreseen problems. As such, Swedish Telecom enabled the emergence of a telecommunications industry that to date maintains a leading position in mobile telephony.

Another feature of the public sector which inhibits public technology procurement is the inherent risk aversion of policy-makers. The likelihood of total failure of a new technology is often much higher than a decision maker in public service is willing to accept (Edquist et al., 2000b). They have the tendency to disregard the potential economic and social benefits of a new technology compared to off-the-shelf products and services. The consequence of this risk averse behavior is that the purchase decision is postponed until the private sector, or other countries, have developed the new technology. Then, the technology can be bought as a mature product. However, the economic and social benefits have materialized elsewhere (Edquist et al., 2000b).

In contrast, the US government has taken a more active stance towards demand-side policies. US government R&D contracts in defense and aerospace have had many commercial spin-offs, mainly in information technology, notably the Internet (James, 2004; Mowery, 1998). Furthermore, the US government spending on R&D is concentrated on university research and industry, rather than national government laboratories. The strong focus on basic scientific research, public technology procurement, and antitrust laws provides a spur to new high-technology firms (Mowery, 1998). Silicon Valley is a key example of this rise in high-technology firms. The use of public technology procurement has not been limited to the defense and aerospace industries. The US government has used public technology procurement in other fields. The US Department of Energy has, for example, used this type of procurement to encourage firms to develop equipment with reduced energy consumption (Ledbetter et al., 1999). Another trend in US public technology programs in the late 1980s and the 1990s was the support of civilian technology developments by the US Department of Defense in its military programs. These civilian technologies were considered important for both national security and civilian economic competitiveness (Mowery, 1998). Advances in life sciences, computing, and communications were spun-into defense applications. Such dual use of commercial and military technology development has also been noted in the European Union (e.g. Guichard, 2005). In parallel to the application of 'dual use' technology development projects, anti-trust laws were relaxed to allow collaboration during the pre-commercial stage (Mowery, 1998).

In Europe, the US approach to public technology procurement has gained attention. Following the Barcelona target to raise R&D expenditures to 3% of GDP, the European Union reconsidered public procurement as an instrument of technology policy (Edler et al., 2005). Edler and Georghiou (2007) provide a detailed overview of the reappraisal of public technology procurement. However, they find that, despite the increased attention, demand-side policies are not generally applied as an instrument of technology policy. They argue that the adoption of a systemic approach to innovation (a national system for innovation) has not led to demand-side policies, but a further differentiation of supply-side instruments.

To understand how public procurement can be used in technology development and diffusion, Edler et al. (2005) have developed a typology in which they differentiate between the type of procurement, the type of user, and the role of government in relation to the market. The typology is summarized in Table 1. They distinguish two types of procurement: general and strategic. General procurement refers to public procurement that uses innovation as a criterion in all tender assessments. Strategic procurement occurs when public demand encourages the development of specific technologies, products, or services and creates a market for this new technology. Strategic procurement relates to those sectors where government agencies are an important buyer and user, such as public utilities and defense.

Table 1 Typology of technology procurement (adapted from Edler et al., 2005)

Type of procurement	*General procurement* Innovation as a criterion in all tender assessments		*Strategic procurement* Demand for technologies that fulfill specific societal and economic needs
Type of user	*Direct*	*Cooperative*	*Catalytic*
Demand driver	Intrinsic needs of procuring agency	Shared needs, public and private users	Societal needs extrinsic to procuring agency
Role in relation to market	Market creation (development)	Market escalation (adaptation)	Market consolidation (standardization)

The type of user for new technology varies from public, public and private, to private. Differentiating between the type of user leads to three types of procurement: direct, cooperative, and catalytic. Direct procurement fulfils the need of a government agency. For example, the procurement of a waste water treatment plant to purify household waste water. Cooperative procurement occurs when both public and private users purchase a technology. In such cases, public demand can launch a market and stimulate private demand for the new technology. An example is the use of low energy heating and cooling in public buildings. Catalytic procurement is used for technologies that are mainly or exclusively used by private users. In these instances, the government is the initial buyer, but it does not buy the technology for its own, direct use. A good example is the US government's support to alternative energy sources in the late 1970s, 80s and 90s (Norberg-Bohm, 2000). The energy crisis of the 1970s encouraged several state-initiated technology programs for industrial and domestic energy provision.

The effects of the aforementioned types of procurement are related to three types of market conditions. The first is market creation. Public users demand a new technology and, through their demand, create a new market. Notably, many forms of information technology have originated from defense-related technology procurement. The second is market escalation. As an early adopter, government can spur technology development by enabling a technology to become commercially viable. The third is market consolidation. As a buyer, government can standardize technical requirements and performance criteria by coordinating and concentrating public demand. As such, government can create a critical mass for the acceptance of a technology.

This typology shows that public technology procurement can be a powerful instrument in effecting technology policy. Further, it highlights that this instrument can be used for needs that are both intrinsic and extrinsic to the government.

The preceding discussion about government as a buyer and user of new technology has clarified several aspects. First, demand-side policies, and the role of government as a buyer and user, have often been neglected despite government procurement contributing to a strong domestic market, overcoming market failures and improving public services (Edquist and Hommen, 2000; Porter, 1990). Furthermore, public technology procurement programs can have substantial commercial spin-offs (James, 2004; Mowery, 1998). Second, the potential of public technology procurement can only be fully exploited when policy-makers recognize that procuring new technology is different from buying off-the-shelf products. The current public procurement practice in the European Union favors an open tender - sealed bid procedure among all potential suppliers to maximize competition (Edquist and Hommen, 2000). This preference disregards the fact that, in procuring new technologies, interaction between buyers and suppliers is highly beneficial. The nature of public technology procurement requires a collaborative attitude to negotiate risks, share information and coordinate the public and private parties involved (Edquist et al., 2000a,b). Third, public technology procurement can contribute to the adoption and diffusion of new technology in both public and private markets. It can encourage new technology with economic and social benefits in both markets. Therefore, studying government roles in technology development in the public sector involves both supply- and demand-side policies (Edler and Georghiou, 2007). Furthermore, when examining government roles, the possible tensions between these roles need to be taken into account.

In the following section, we discuss several perspectives on government roles in technology development. These will help in understanding the various rationales for government intervention in technology development, and the roles through which these interventions are carried out.

Government's Roles in Technology Development

There are many perspectives that consider governmental roles in technology development. These perspectives include competition, property rights, market failure, and science and education. Depending on the perspective, and its emphasis on demand pull or technology push, some scholars have advocated a laissez-faire approach and others an active role in encouraging R&D investments and the development and diffusion of a new technology (e.g. Dosi, 1982; Freeman, 1995; Lundvall and Borras, 2005). In recent decades, several perspectives have highlighted the role of government in technical change and innovation. Porter's 1990 work on the competitive advantage of nations has become a milestone in technology policy (Davies and Ellis, 2001; Grant, 1991; Porter, 1990). Porter tried to bridge the gap between strategic management and international economics (Grant, 1991; Porter, 1990). Porter's framework gave governments a direction to follow in interventions in industry, involving demand conditions and factor conditions to push innovation and competitiveness. However, Porter discouraged interventionist policies and saw government as a pusher and challenger rather than a supporter of industry (Grant, 1991). Most notably, Porter's framework encouraged governments to stimulate early demand for innovative products, to focus on clustering industry, capital, and academic research, and to enforce antitrust regulations (Grant, 1991; Porter, 1990). However, the framework was biased towards the US economic model and many flaws were found in the reasoning and methodology used to devise the framework. For an overview of the criticisms of Porter's competitive advantage of nations see Davies and Ellis (2000). Given the numerous reservations, we will not discuss this framework in more detail.

Another perspective that emphasizes the role of government in technical change and innovation is the Triple Helix perspective. This perspective, developed by Leydesdorff and Etzkowitz (1996, 1998), stresses university-industry-government relationships. Based on the premise of the knowledge economy, it draws attention to science, university research, and knowledge transfer. The role of government is directed towards higher education and academic research, stimulating university-industry knowledge transfer and improving exchange media. Furthermore, this perspective highlights the continuous change or transition in university-industry-government relationships (Etzkowitz and Leydesdorff, 2001). That is, a technological trajectory or stabilized design is unlikely to occur. Instead, throughout the process of technical change, shifts and recombinations take place in institutions, market developments, and complementary technologies. These shifts and recombinations mean that a stable environment fails to emerge. Although this perspective discusses government interventions, its emphasis is on the transfer of academic research and it neglects several other government roles, such as those of buyer and champion. Given these gaps, we will not address this perspective in more detail.

In the remainder of this section, we will discuss three perspectives on technical change in more detail. These three have been influential in science, technology, and public procurement policy. The first perspective, the national system of innovation (Lundvall, 1992), has been adopted by the Organization for Economic Co-operation and Development (OECD). The OECD plays an important role in the economic and technology policies of many countries, including most members of the European Union, Japan, and the US. The second perspective, called the technological regime, has its roots in economics. It is based on the assumptions put forward by Nelson and Winter (1982) that technological change is an evolutionary process. The evolutionary mechanisms of selection, variation, and self-replication create technological paths. These paths, or trajectories, determine technological change in industries. The third perspective is referred to as large technical systems (Hughes, 1983). This perspective takes an historical view of technological developments. Regulations and government policy are seen as important drivers in advancing a technology. Below, we will discuss these three perspectives and, at the end of this section, we explain our choice of perspective as a guiding concept for the remainder of this dissertation.

National system of innovation

Lundvall (1988, 1992) can be seen as the founding father of the national system of innovation perspective (Freeman, 1995). The national system of innovation consists of five structural elements (Lundvall, 1992): (1) the internal organization of firms, (2) the interfirm relationship, (3) role of the public sector, (4) institutional set-up of the financial sector, and (5) the R&D intensity and R&D organization. These elements and their relationships interact in the production, diffusion and use of new, and economically useful, knowledge within the borders of a nation state (Lundvall, 1992). Essential to this perspective is learning and user-producer interaction (Lundvall, 1988). Innovation is an interactive process emanating from the relationships between firms, universities, users, and policy-makers. These relationships affect the use and accessibility of knowledge, and the information flows among the various parties. The national system of innovation perspective highlights the role of government in the process of innovation. As a knowledgeable user, and through institutionalized cooperation with industry and institutions, government can support interactive learning processes (Gregersen, 1992). Furthermore, as a matchmaker, government can create, revitalize, or disband user-producer relationships in order to adapt the national innovation system to new opportunities (Dalum et al., 1992). A good example of government's role in matchmaking is the Japanese Ministry of International Trade and Industry (MITI). Through a comprehensive policy of tax incentives, subsidies, consultations, and the building of infrastructures, it has encouraged the establishment of user-producer networks and the use of new technology. MITI's technology policy has been important in guiding the future direction of technical and social change in Japan

(Freeman, 1988). This systemic approach to technology by the Japanese government has enabled the widespread use of new technologies throughout various different industries in both high- and low-tech sectors (Lundvall and Borras, 2005). In contrast, the US and European countries have focused on distinct industries, with varying degrees of success.

In addition to the general reappraisal of the role of government in technology development, this perspective also emphasizes the demand-side policies of government (Edquist and Hommen, 1999). Government intervention in technology development has traditionally been mainly directed towards supply-side policies such as tax incentives, subsidies, and the funding of basic scientific research. These supply-side policies were designed to compensate for market failure and under-investment in R&D. However, public technology procurement can be a powerful incentive for new technological developments. US defense and aerospace innovations, for example, can generally be traced back to public procurement agencies such as DARPA and NASA.

The national system of innovation perspective emphasizes government's roles as buyer, user, and matchmaker in technology development. The systemic nature of this perspective shows the relevance of both supply- and demand-side policies. Technological change, learning, and innovation are seen as a process of user-producer interactions involving firms, users, and scientific research. Government plays a significant role in coordinating the interdependencies between these parties. The supply-side policies of government, including education, funding of basic research, intellectual property rights, tax incentives and subsidies, facilitate the innovation process between these actors. Further, public demand challenges firms to develop new technologies and can create a sophisticated market for new technologies.

The national system of innovation perspective is based on national boundaries. However, the basic assumptions of this system approach can also be applied to other geographical regions. In parallel with national systems of innovation, this has led to the study of regional systems of innovation (Asheim and Gertler, 2005). This approach focuses on the local production system and the socio-political infrastructure. Examples of regional systems of innovation include Silicon Valley in the US and the Baden-Württemberg region in Germany (Doloreux, 2002).

As an analytical instrument, this perspective has great value in comparing different countries or regions, and describing differences in innovative activities. However, this perspective does not allow for formal theorizing as the concept remains diffuse and this limits the explanatory power of this perspective (Edquist and Hommen, 1999). It is geared towards analyzing the differences between systems of innovation and their effects on innovation dynamics (Edquist et al., 2000a). Despite its limited explanatory power, the emphasis on user-producer interaction provides some guiding principles for policy instruments. First, government should facilitate linkages and the exchange of information between the interdependent actors in the innovation process. Here, supply-side policies are important in stimulating linkages and technology transfer. Second, government, as a buyer and user of technology, should use its buying power to initiate the development of new technologies. This enables the formation of new markets and helps to overcome fear of market failure.

Technological regimes

Related to the national system of innovation, the perspective of technological regimes is similarly primarily used to theorize about patterns in technical change. In the literature, one finds two research fields that use the term technological regime. Both fields build on the initial work of Nelson and Winter (1977, 1982). Nelson and Winter (1977) define a technological regime as a shared cognitive belief among technicians about feasible technologies. This shared belief creates a natural trajectory for the technological development of a specific technology. The first research field adopts an econometric approach to technological regimes and explains innovation patterns using four industry characteristics. This approach has been developed by Breschi, Malerba, and Orsenigo (Breschi et al., 2000; Malerba and Orsenigo, 1996, 1997). The second field takes a sociological approach to technological regimes and argues that scientists, policy-makers, users, and special-interest groups are all equally important in explaining technological trajectories (Bijker, 1995; Geels and Schot, 2007). In this approach, a technological regime is defined as "the complex of scientific knowledge, engineering practices, production process technologies, product characteristics, user practices, skills and procedures, and institutions and infrastructures that make up the totality of a technology." (Van den Ende and Kemp, 1999:835).

In more detail, in the econometric approach, a technological regime is defined as a particular combination of the following four factors (Breschi et al., 2000):

- *Technological opportunities*. These reflect the likelihood of innovating for any given amount of money invested in research. Promising opportunities provide substantial incentives to undertake innovative activities because the probability of successful innovation is high. Technological opportunities play a part in determining the frequency and variety of technological innovations. The frequency and variety of new opportunities differ across industries and, depending on the stage in the industry life-cycle, such opportunities may eventually disappear. Also the source of the opportunities varies. Research has shown that the sources range from major scientific breakthroughs and R&D to suppliers and users.

- *Appropriability conditions* reflect the possibility of appropriating returns from innovative activities. These conditions involve the effectiveness of the various means available to avoid imitation and knowledge spillovers, including secrecy, patenting, and lead time (Levin et al., 1987). Higher levels of appropriability are associated with higher investments in R&D.
- *Cumulativeness of technical advances* which reflects the reality that today's knowledge and innovative activities are the building blocks of tomorrow's technologies. Greater cumulativeness makes it more likely that firms will innovate along specific technological trajectories.
- The *properties of the knowledge base* reflect the specificity, tacitness, complexity, and independence of the knowledge underpinning innovative activities. A general distinction made is between the use of basic or applied science as the basis for technology development. To use basic science in technology development, firms need high levels of absorptive capacity to be able to incorporate it and apply it to commercial ends (Cohen and Levinthal, 1990). In contrast, applied science is directed more towards problem-solving, practical experience, and experiential learning. This knowledge is more accessible and easier to translate into new technology.

These four factors have been studied separately and together to explain differences in industry structures and patterns of technical change (Audretsch, 1995; Kusunoki et al., 1998; Levin et al., 1987; Malerba and Orsenigo, 1997; Park and Lee, 2006). Most studies that analyze technological regimes use aggregated data and patent databases to substantiate the theorizing about technological patterns and industry differences. Based on these factors, Malerba and Orsenigo (1997) made a classification of industries and their resulting innovation dynamics.

- Traditional sectors, such as shoes and textiles, have low opportunity, appropriability, and cumulativeness conditions. Therefore, knowledge should be easily transferable across firms and regions leading to many, geographically-dispersed innovators.
- In mechanical industries, they expect to see many innovators, geographically concentrated with local knowledge boundaries.

In these industries, the knowledge base has a high level of tacitness and specificity, and cumulativeness is also high, necessitating proximity. Furthermore, appropriability conditions are low, enabling many innovators to enter the market. Examples of these industries are machinery and industrial engineering.

- In modular and process industries, they anticipate high levels of cumulativeness and appropriability. Therefore, there will be few innovating firms. Owing to the systemic nature of the products and the organization of the value chain, outsourcing and component compatibility are important. Therefore, knowledge is partly tacit and partly codified. Consequently, innovating firms are geographically clustered and work together with local suppliers. These industries include the automobile, consumer electronics, and semiconductor industries.

These patterns are useful in explaining differences in industry structures, patenting behaviors and barriers to entry. From a policy perspective, the econometric approach to technological regimes offers a rationale for industry-specific technology policy. An understanding of industry characteristics helps in predicting the effectiveness of policy instruments. In traditional sectors, expanding the range of technologies that can be patented provides little incentive for R&D investment. In these sectors, strengthening the linkages between geographically-dispersed innovators seems likely to be more effective. In contrast, in modular and process industries, extending what can be patented can be effective in promoting R&D in emerging fields. The econometric approach offers no formal guidance on the role of demand, either public or private. Implicitly, however, demand for new technology is important in stimulating innovative entry and challenging established firms to develop new technologies.

The sociological approach on the other hand focuses on transitions in technology. These transitions are based on interactions between three levels: technological niches, the technological regime, and the socio-technical landscape. A technological niche is on the level of individual companies or research laboratories. The technological regime is the meso-level, and the socio-technical landscape reflects the macro-level of infrastructures, political institutions, and cultural patterns (Van den Ende and Kemp, 1999). Differences in timing and the nature of interactions among these levels explain the different transitional paths (Kemp et al., 1998; Geels and Schot, 2007). In this approach, the technological regime is part of a larger system and clarifies the stages of technical change. Technical change starts with a small network of actors at the niche level. When this network reaches a critical mass and actors are aligned, a dominant design can emerge. At the same time, developments at the level of the socio-technical landscape pressurize the technological regime, creating windows of opportunity. At this point, the new technology can enter mainstream markets (Geels and Schot, 2007). Although the sociological approach to technological regimes emphasizes the view that technical change is a co-evolutionary process of technological, social, and organizational change, it is reluctant to offer policy implications. This hesitancy is explained by arguing that the co-evolutionary process is a diffuse and complex one that cannot be reduced to linear models of innovation (Van den Ende and Kemp, 1999). Government should, therefore, try to bridge the gaps between technology actors (firms, universities, users), initiate societal debates about controversial technologies, and press for desirable technologies (Kemp et al. 1998; Van den Ende and Kemp, 1999).

Large technical systems

The perspective of large technical systems draws attention to the technical, economic, and political factors in such systems that direct technological developments in a certain direction. Large technical systems are essentially large systems of capital equipment, such as telecommunications, energy supply, and radio (Hughes, 1983; Davies, 1996). A large technical system is defined (Hughes, 1983; Davies, 1996) as follows:

- A system consisting of various components or subsystems that form different pieces of the system. Each component or subsystem performs a function that serves the entire system. These components can be physical, for example, transmitters, telephones, and switches in the telecommunications system, but also non-physical, such as operators, telecom regulators, and technical standards.
- A network or structure formed by the components. The interconnectivity of the components and subsystems create system-wide effects when individual components are changed. Interoperability of components is therefore central to the functioning of the entire system.
- A system with a need for efficient capacity utilization to mitigate the effects of the large fixed capital costs. For optimized performance and goal achievement some form of control is exercised to regulate the use of the system.

Hughes (1983) emphasizes the role of entrepreneurs, financers, users, government, and other actors in the development of large technical systems. According to Hughes, there are several phases of development in which different actors play a role. In the first phases, the inventor/entrepreneur is crucial and Hughes mentions Edison as a good example. The inventor/entrepreneur develops and introduces a new technology. As the system grows, managerial, financial, technical, and societal aspects need to be addressed, requiring different actors.

A central concept in the growth and diffusion of the system is momentum. Momentum stems from increasing returns from adoption, economies of scale, and the growing number of parties committed to the system. Momentum is maintained by removing components or subsystems that lag behind and impede the development of the entire system. Hughes (1983) describes these lagging components as "reverse salient".

A growing system increases the number of organizations involved. Financiers, regulators, users, firms, and government agencies all become part of the system, and share a commitment to prolong the system. The so-called system builder is a central actor that is technically, financially, or politically so powerful that it can strongly affect the development and diffusion process of the system (Jacobsson and Bergek, 2004). This system builder usually owns and operates the system, allocating system traffic, optimizing capacity utilization, and increasing performance. In the past, most large technical systems such as energy, telecommunications, and railways operated as natural monopolies. The system builder, often a government agency, regulated access to and use of the system. Further, large technical systems are intertwined with other systems since they form the infrastructure for all kinds of economic activity. The importance of large technical systems has warranted the involvement of governments in their control. Jacobsson and Bergek (2004) provide several justifications for the relevance of government intervention.

- First, the introduction of new technologies often involves societal motives, such as reduced environmental impact, improved accessibility, or availability. These benefits do not necessarily offer a direct benefit to the owner, investor, or operator of the system.
- Second, new technologies often have cost disadvantages compared to existing technologies necessitating some kind of incentive. In addition, existing technologies can be indirectly subsidized, because the costs of negative externalities are not internalized.
- Third, new technology often threatens established interests whose proponents attempt to block new technologies through lobbying and influencing public opinion and institutional frameworks.
- Fourth, government can play a role in forming markets for new technology through tax incentives, subsidies, or public

procurement. These "protected" markets can serve as steps toward economically viable mass markets. Furthermore, these "protected" markets offer opportunities to improve the technology, build a support infrastructure, or develop secondary innovations.

- Fifth, emerging technologies may require a shift in policy, a redirection of funds for basic science, or changes to regulatory frameworks. The latter includes standard-setting processes and the development of rules and regulations. Especially in large technical systems with positive network externalities, early standard-setting increases the likelihood of success and ensures compatibility (Gandal, 2002).

These reasons show how government affects technology development through both supply- and demand-side policies. Further, they show the relevance of a combination of policies to effect the development, introduction, and diffusion of a new technology. As with the national system of innovation perspective, this perspective lacks a theoretical grounding that allows for system optimization and explains causality. Despite this limitation, this perspective can be used to analyze system characteristics and understand technical change within a system. Another constraint is that the explanatory power of this perspective is limited to large technical systems, such as utilities. Although many public goods and services can be characterized as large technical systems, this does constrain the generalizability of any findings. Nevertheless, its origins in analyzing public utilities does help in comprehending how the diverse roles of government are interwoven into the process of technical change.

Perspectives on government's roles in technology development: a comparison

In the previous discussion about government as a buyer and user of new technology, we concluded that a realistic perspective had to incorporate both supply- and demand-side policies. Further, the role of government as a buyer and user in technology development needs to be taken into account. In addition, the interaction between buyers and suppliers is central to technology development. To ease the comparison between the three perspectives discussed above, we have identified two dimensions. The first dimension is technological, and refers to the view taken of technical change and buyer-supplier interaction. The second dimension is institutional, and relates to government as an actor in technology development and the different roles that are acknowledged. The comparison between the three perspectives is summarized in Table 2.

Table 2 Comparison of perspectives on government's role in technology development

	Technological dimension	*Institutional dimension*
National systems of innovation	User-producer interaction. Innovation as a process of collaboration and interactive learning. Understanding rather than optimization of the system.	Active role of government. Supply- and demand-side instruments coordinate user-producer linkages and innovative demand. Governmental roles are buyer/user, matchmaker and sponsor.
Technological regimes	Two approaches: Econometricians explain Schumpeter's patterns of innovative activities through four industry factors. Sociologists clarify shift in dominant technologies through co-evolutionary transition in technical, social and political dimensions.	Effect of government only indirectly observable. Supply-side instruments affect opportunities and appropriability, and stimulate knowledge transfer and adaptation. Governmental roles are catalyst and regulator.
Large technical systems	"Reverse salients" induce technical change in the system. Technical change is path dependent. System builder guides technical change.	Government intervention is extensive because most large technical systems are partially public goods. Government acts as system builder. Governmental roles are system builder, buyer, operator, sponsor and regulator.

Technological dimension

The national system of innovation perspective revolves around the user-producer interaction. The underlying assumptions are that technical change is a non-linear process and that users and producers are interdependent (Edquist and Hommen, 2000). Consequently, technical change is a process of collaboration and interactive learning among diverse actors. Further, institutions, such as laws, norms, and rules, play an important role in shaping the technological paths or trajectories along which technologies develop. As an analytical instrument, this perspective does not compare actual systems to an 'ideal' or 'optimum'. Rather, it tries to explain the outcomes of the system by analyzing the interactions among the actors and the institutional framework. In comparing national systems of innovation, it can clarify why a monopsony might work well under the conditions in nation A, but would be detrimental in nation B.

The econometric approach to the technological regime perspective explains technical change as a result of four factors that vary across industries. These factors describe the (dis)incentives for innovation in an industry's institutional and socioeconomic structure, and together have a substantial predictive power in explaining Schumpeterian patterns of innovation (Breschi et al., 2000). These innovation patterns are based on theoretical assumptions. Schumpeter Mark I refers to the role of entrepreneurial firms: innovative entry continuously disrupts the current ways of production, organization, and distribution, leading to so-called "creative destruction". Schumpeter Mark II is related to "creative accumulation": large, established firms, with their wealth of knowledge and R&D resources, create effective entry barriers to new entrepreneurs. The econometric approach is somewhat static and does not take buyer-supplier interactions into account. The sociological approach to technological regimes perceives technical change as transitions that arise through dynamic interactions between the technical, social, and political mechanisms. It tries to explain how regime shifts come about. Unlike the econometric approach, it does not derive causal relationships between industry characteristics and outcomes. This approach recognizes the importance of networks and coalition building at the firm level.

In the large technical system approach, the perspective on technical change highlights compatibility of and interoperability between the components of the system. These aspects induce path dependent and incremental technological developments (Markard and Truffer, 2006). Technical change is a result of "reverse salients" in existing components that impede the progress of the entire system. These lagging components of the system can be physical, such as analog switching in telecommunications (Davies, 1996), or non-physical, such as technical regulations in the construction industry (Nam and Tatum, 1988; Oster and Quigley, 1977). This perspective includes a historical account of technological development. It shows that the interactions between a growing number of committed parties are important in establishing large technical systems. Further, it emphasizes the role of the system builder who has the power to direct technical change within the system.

Institutional dimension

Given the emphasis on user-producer interaction, the national systems of innovation perspective includes a broad spectrum of relevant government interventions (Lundvall and Barros, 2005). These interventions relate to science policy (i.e. education, scientific research, property rights), technology policy (i.e., standard setting, funding of private R&D), and public technology procurement (i.e. demand for new technology). This perspective highlights the importance of building a support infrastructure for technical change, and also emphasizes the importance of government as buyer and user. Government intervention stretches from creating interfirm linkages and knowledge transfer to the procurement of new technologies. Its relevant roles are as buyer/user, matchmaker, and sponsor.

The econometric approach to technological regimes marginalizes the nation-specific institutional dimension. Malerba and Orsenigo (1996, 1997) have shown that industry patterns of technical change are consistent across countries. Government intervention is, therefore, only indirectly observable. Supply-side instruments such as education, basic research, and the funding of private R&D can affect technological opportunities. Furthermore, regulations, property rights, and law enforcement can influence the appropriability conditions in an industry. The role of government in the econometric approach seem limited to supply-side instruments. As a sponsor, it can effect technological opportunities and as a regulator it has an effect on the appropriability conditions. The sociological approach to technological regimes takes government policies and the regulatory framework into account. In this approach, science, education, and laws and regulations can facilitate or hinder the emergence of new technologies (Kemp et al., 1998). However, technical change is seen as a complex, co-evolutionary process that cannot be fully orchestrated. Therefore, government's primary role is that of a catalyst: influencing technical change to serve wider societal goals (Van den Ende and Kemp, 1999).

In reality, most large technical systems are large utilities. These systems are often considered as natural monopolies and, in the past, a centralized, vertically integrated organization was seen as the appropriate governance structure. Such an organization had the scale, the resources, and the authority to implement, operate, and control these systems nationwide. Therefore, most of these organizations were publicly owned or strictly regulated private monopolies. The downside of such a monopsonistic demand structure was that there were few pressures to innovate. Further, the political will to reduce the burden on taxpayers led to routine operation and cost minimization (Edquist and Hommen, 2000). Given that most large technical systems are to an extent public goods, governments usually have a substantial influence on technical change (Geyer and Davies, 2000; Jacobsson and Bergek, 2004; Markard and Truffer, 2006). This influence emerges through several roles, of which system builder is the most prominent.

Comparison

Given the stress placed on demand-side instruments and buyer-supplier interaction, the econometric approach to the technological regime perspective seems inappropriate as a guiding concept for this study. The sociological approach to technological regime focuses on regime shifts, and emphasizes the interactions between actors that interpret and negotiate technical change (Geels and Schot, 2007). The role of government is that of catalyst and process manager in directing the interpretation and negotiation of technical change towards socially desirable outcomes (Kemp et al., 1998). However, this approach lacks an understanding of government as a buyer, which again makes it inappropriate for this study. The remaining perspectives both highlight the significance of demand and of interaction in technology development. However, for our study, the large technical system perspective has certain advantages over the system of innovation perspective. First, the large technical system perspective concentrates on the technological system rather than on the national or regional system. Second, it recognizes the importance of government as a system builder when it comes to public goods, such as in defense, healthcare and nationalized or regulated public utilities, such as transportation and energy (Dalpé et al., 1992). Therefore, we will use the large technical system perspective as a guiding concept for this study.

Field of Study

In this dissertation, we concentrate on the development and implementation of new technology in road construction. We define the road construction industry as consisting of those firms and organizations that design, build, own, operate, and maintain road infrastructure. Road construction firms have to cope with significant government involvement in their development activities. First, in most countries, the government is the sole buyer of road infrastructure and, therefore, has substantial buying power. Second, as a regulator, governments have a high concern for public safety and usually the environment. Road construction involves a large degree of social responsibility. As a consequence, there are many construction-related regulations which encourage conservatism in design (Nam and Tatum, 1988; Oster and Quigley, 1977). Further, the government agencies themselves are bound by regulatory and procurement policies which therefore also play an important role in shaping the direction of technological change (Gann and Salter, 2000).

As a buyer, governments have predominantly used competitive bidding and method-based specification in procuring road infrastructure. Method-based specification is seen as restricting the opportunities for construction firms to implement new technologies.

However, in recent years, the attitude of governments towards construction firms has changed. In the United States, the Department of Transport has established the Research and Technology Coordinating Committee to encourage innovation and the transfer of federally-funded technology to the private sector. This committee includes representation from the Federal Highway Administration. The Federal Highway Administration acknowledges that existing procurement procedures in road construction are flawed because they provide little opportunity for private investment in new technology (Carlson, 2006). In Europe, reports on rethinking construction have had a substantial impact on policies towards procurement and innovation in several European countries, including the Netherlands, the United Kingdom, and Sweden (Atkin, 1999 and 2002; Egan, 1998). Based on these reports about the deficiencies in construction approaches, governments have made changes in their procurement policies. One significant change is the integration of design and construction. Governments expect these changes to reduce costs and improve overall performance. Further, using the knowledge of the construction firms in the design stage, and not just in the construction phase, should broaden the scope of the technological solutions offered.

Besides these general changes in procurement policy, the US and Dutch governments are both reducing their technical staff and outsourcing not only design but also other tasks and responsibilities (FHWA, 2001). The US and Dutch governments have shifted their focus from project management towards program management. This change has had several consequences. First, governments have introduced new types of contract in which firms have greater responsibilities, including for design and maintenance, and more opportunities to optimize the production method to fit their design. Further, since these contracts use performance specifications rather than method-based specifications, firms are required to achieve and maintain a specified service level throughout the lifetime of the road infrastructure.

Second, governments have initiated innovation programs to facilitate and stimulate technology development in road construction firms. These programs provide an opportunity for experimentation and demonstration. In addition, governments can indicate their future needs through such programs and encourage firms to develop new technologies to fulfill these needs. Examples are the Roads to the Future program in the Netherlands, and the Corporate Master Plan for Research and Deployment of Technology and Innovation of the Federal Highway Administration in the United States (2003).

Third, the growing need for road infrastructure, together with the trend within governments to privatize public services, challenges road construction firms to develop business models for the financing and exploitation of road infrastructure. In recent years, contractual arrangements that combine public and private funding to design, build, and exploit road infrastructure have multiplied. Well-known examples are the Private Finance Initiative, Build Own Operate and Transfer schemes and Public Private Partnerships. All of these arrangements involve some form of risk and benefit sharing.

One consequence is that technology development activities have to incorporate performance measurement systems to evaluate whether the required service levels are met throughout the technology's lifetime. Further, the innovation programs offer opportunities to experiment and demonstrate new technology. Influencing these programs, and the way government expresses its future needs, can increase one's success. In addition, business models and collaborative arrangements to finance and exploit road infrastructure are becoming part of technology development activities.

As such, road construction is an interesting field of study. In this industry, government plays several roles in technology development, ranging form buyer and system builder to sponsor and regulator. Further, governments have developed several technology procurement instruments to stimulate technology development and diffusion.

Definitions

Following the OECD (2007), we define the public sector as the general government sector and all public corporations including the central bank. Public corporations are legal entities that are owned or controlled by the government and that produce goods or services for sale in the market at economically significant prices. All corporations are members of the non-financial corporations sector or the financial corporations sector.

According to Edquist and Hommen (2000), public technology procurement is an order placed by a public agency for a product or system which does not exist at the time, but which could probably be developed within a reasonable period. To fulfill the demands of the procuring agency, additional or new technological development activities will be required. The main difference between private and public technology procurement is that public technology procurement must satisfy societal needs that are unlikely to be met by the market.

In this study, we will use the perspective of large technical systems as a guiding concept to examine technology development in road infrastructure. Road infrastructure is a large technical system (Mom, 2005) and is defined as a system consisting of physical components such as roads, bridges, tunnels, and traffic controlling equipment, and non-physical components, such as traffic laws and regulations. In this dissertation, we concentrate on the highway network which consists of roads, signaling equipment, bridges, and tunnels. In this network, the operator/owner tries to optimize capacity utilization through regulations and dynamic route information. Further, the highways network has the characteristics of an impure or partially public good: the benefits of the highways network are excludable through toll booths, but its consumption to an extent lacks any rival. That is, the consumption of the highways network by one individual only partially detracts from the consumption opportunities available to others (Cornes and Sandler, 1996).

Objectives of this Research

This research aims to enrich our understanding of technology development processes within the public sector, and the significance of government roles in the development and adoption of new technology. Within this overall aim, the research objectives include:

- Identifying the interdependencies among the diverse roles of government in technology development and commercialization.
- Developing an analytical model to assess the impact of these government roles.
- Increasing understanding of technology development processes within road construction firms.

Based on the research findings, we will develop managerial and policy recommendations to improve the development and adoption of technology in the public sector, and especially in road infrastructure. A better understanding of technology development in this industry can help road construction firms respond to changing customer demands and increase their innovative performance. Furthermore, our results will help government understand its diverse roles, and indicate which roles are most crucial in the development and diffusion of technology.

Research Questions

The research objectives lead to the following research questions:

1. What are the relevant government roles, and how do they affect technology development projects?
2. What are the relevant dimensions of firms' strategic behavior and how do they affect technology development projects?

3. How important are the various government roles in the performance of technology development projects?

To answer these questions, we have followed the steps shown in Figure 1.

STEP 1 Exploratory research	
• Literature review, including technology policy, new product development and strategic management literature • Development of case study protocol	

STEP 2 Case study research	Dissertation
Government roles in technology development • Develop insights in the relationships between government roles • Compare findings across firms • Develop a model to analyze and predict effect of government roles on technology development projects **Strategic management of technology projects** • Develop insights in the strategic management in road construction firms • Compare findings across firms • Develop a model to analyze effect of different strategic orientations at the project level	Analysis of technology development processes in three firms with different corporate strategies **Chapter 2** • Analytical model and propositions about the effect of government roles on technology development projects **Chapter 3** • Analytical framework to examine the effect of a road construction firm's strategic orientation on technology development projects

STEP 3 Survey research	Dissertation
Test of insights and model about the effect of government roles and a firm's strategic orientation on technology development projects in road construction and manufacturing and pharmaceutical firms	**Chapter 4** • Test of the effect of government as a buyer and champion and a firm's strategic orientation on technology development projects in road construction **Chapter 5** • Impact of government as a sponsor and champion on technology development projects in a sample of road construction, manufacturing and pharmaceutical firms

STEP 4 Reflection and conclusion	Dissertation
• Discussion of research findings • Implications for literature, management and policy • Comparison of US and Dutch situation	**Chapter 6** • Main findings and contributions • Differences and similarities in findings • Conclusions about the effect of government roles and a firm's strategic orientation on technology development projects **Appendix 1A** • Comparison of US and Dutch survey sample

Figure 1 Steps in the research and relationships with dissertation

As the first step, we conducted exploratory research to determine the relevant factors in government roles and firm behavior regarding technology development. For the government roles, we consulted literature on technology policy and public management. To assess the relevant factors in firm behavior we studied literature on new product development, project-based firms, and strategic management. We have developed two conceptual models: one concerning government roles and one concerning firm behavior.

The second step was to carry out a multiple case study involving three road construction firms. During the case study period, we confronted the insights gleaned from the literature with empirical findings about technology development in road construction. This step involved both governmental roles in technology development as well as the firm's strategic behavior. The case study allowed us to refine the literature-based conceptual models and include additional factors not covered in the literature. In the case study, we focused on technology development at the project level. In most road construction, and other project-based, firms there is an overlap between construction, or business, projects and technology development activities. In most construction projects there is some degree of technical problem-solving that will result in an incremental improvement in existing technologies (Dulaimi et al., 2002; Slaughter, 1993 and 2000). However, this type of technology development is not relevant to our research, our focus is on new technology that is developed in distinct projects.

As the third step, we conducted a large-scale survey to quantitatively test the conceptual models developed in the multiple case study. The multiple case study was conducted at Dutch road construction firms. However, only about 29 Dutch road construction firms work for the central government and this sample was too small to fully test our case study findings statistically. Therefore, we also conducted a survey in the United States' heavy and highway construction industries. To assess whether the Dutch and American firms differ in terms of the effects of government roles, we compared the means and standard deviations of both samples. The results of this comparison are discussed in Appendix 1A.

To extend the generalizability of our findings, we carried out a second survey using the same questionnaire with a sample of manufacturing and pharmaceutical firms. Manufacturing and pharmaceutical firms are considered to be less dependent on the public sector. This allowed us to examine whether government influence in markets they dominate is different from that in consumer and business-to-business markets.

To conclude, we have reflected on our findings in Step 4 of the research. Here, we discuss our research questions and draw inferences from theory, management, and policy perspectives.

Outline

Chapters 2 to 5 of this dissertation consist of one previously published article and three working papers. We have chosen to include these four articles as chapters of this dissertation for several reasons. First, in the academic profession, performance is measured in terms of scientific output, i.e. journal articles. Writing and publishing articles is therefore an important craft of the academic profession. Further, the process of peer review in publishing improves the quality of work and is instructive in dealing with review comments. Second, the fact that publishable articles can be written based on the findings of this research demonstrates its academic relevance. In addition, the articles provide a concise summary of the research conducted. As such, writing a thesis based on a collection of articles was a deliberate choice. The downside of this approach is that the review process of scientific journals can be lengthy, especially in the social sciences. Therefore, a dissertation based on three or four published articles can be difficult to achieve within the time constraints of a PhD research project. Further, the resulting thesis becomes a collection of stories rather than a monograph. We fully accept there are the drawbacks in producing a thesis based on articles, but we believe the advantages outweigh the limitations.

The first research question is discussed in Chapter 2 where we present the findings of an in-depth case study into three technology development projects. In this article, we assessed the combined effect of the various government roles on these technology development projects. We referred to literature on technology policy, large technical systems, and technological regimes. This literature provides the relevant dimensions for the conceptual model developed in the article. The model is refined with the case study findings. On the basis of the refined model, we derived propositions describing the relevant relationships between government behavior and technology development projects. The results indicated that technical, human, and financial support in facilitating the emergence of a market is important for a new technology. These findings answer the first research question on the effect of government behavior on technology development projects.

In Chapter 3, we address the second research question and turn to the effect of a firm's strategic behavior on technology development projects. In this paper, we used strategic management and technology management literature. Based on this literature, we argued that project-based firms will use a range of diverse strategic orientations at the project level. A second expectation was that these firms will have created conditions to deal with different strategic orientations. We compared three road construction firms with different business strategies to explore these theoretical assumptions. Findings suggest that project-based firms are likely to use various strategic orientations at the project level. Further, the extensive use of external sources of technology and the lack of a coherent strategy impede the development of routines for the efficient execution of similar projects, thereby limiting the opportunities for "economies of repetition". Although the road construction firms studied were familiar with multi-project planning in their business projects to efficiently allocate resources, they lacked program management techniques. The firms studied could benefit from program management in their technology development projects.

Chapters 4 and 5 concentrate on the third research question. Chapter 4 assesses whether it is government roles or firm behavior that is more important in explaining the performance of technology development projects. For this, we conducted a large scale survey in the United States heavy and highway construction industries. The 115 respondents confirmed that the government demonstrating championing behavior was a key factor in the performance of technology development projects.

In Chapter 5 we expand our horizon and include manufacturing and pharmaceutical firms, producing goods such as electrical equipment and semiconductors, drugs and medicines. For these types of firm, government support is probably less important, because these firms are less dependent on the government as a buyer of new technology. Counter to our expectations, industry differences are not significant. Although a firm's strategic behavior is here the most important factor in performance, government championship is still a significant factor in explaining the performance of technology development projects in these industries.

Finally, in Chapter 6, we discuss our findings and reflect upon the theoretical implications of this dissertation. We end the chapter with suggestions for research, for management , and for policy.

CHAPTER 2

Technology Commercialization in Road Infrastructure: How Government Affects the Variation and Appropriability of Technology

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Abstract

Successful technology commercialization is important for business profitability, and government's policies can help or hinder firms' success. As a regulator, government affects standard setting and the nature and scope of property rights. As a sponsor, government can empower technology commercialization by its financial support of new technology. As a first user, government can significantly enhance the chances of successful technology commercialization. And as a buyer, government accounts for a substantial part of the world economy.

Previous research on government's roles in technology commercialization mainly addressed the effects of specific roles. However, there is little understanding about the combined impact of these roles on technology commercialization. This article develops a conceptual model to analyze the combined effect of these roles on technology development projects. This model is based on a review of the literature on large technical systems, technological regimes and technology policy that enabled us to study government's diverse roles in technology commercialization.

To refine the conceptual model, we conducted an in-depth analysis of three technology development projects. The empirical findings are drawn from road infrastructure. In that sector, government is the dominant customer and first user of most new technologies. Therefore, government has to create a market for those technologies and strongly affects their viability.

This research has produced several major results. First, the developed model is the first to conceptualize the relevant relationships between the various roles of government in technology commercialization. Second, this study has shown that government's behavior as a regulator and sponsor conflicts with its preferences as a buyer and user. Consequently, the support of and demand for new technology is inconsistent and uncoordinated, leaving firms with significant uncertainties in assessing market opportunities. Third, the dominant position of government as a buyer in road infrastructure weakens the effectiveness of intellectual property rights. Fourth, existing studies on technology for partially public goods are mainly historical accounts and only a few are empirical studies on innovation processes. This study provides an in-depth analysis of the development and commercialization of technology for partially public goods.

This article concludes with policy implications and suggestions for future research. An important policy implication is that government could improve technology commercialization by either stimulating the

commercialization of various competing technologies or developing various competing products based on the same technology. A central issue for future research is how firms can involve government in its diverse roles in technology commercialization. Most of the existing research on customer involvement deals with consumer and business-to-business markets. A better understanding of government involvement could help firms to overcome the impediments they face in dealing with government.

Introduction

Successful technology commercialization and entrepreneurship are important for firm survival (Zahra and Nielsen, 2002). According to Ziamou (2002), a new technology is defined as a new 'capability' that can be used in a variety of products. The ultimate value of that technology lies in the applications in which it gets incorporated. Technology commercialization, then, is the design, manufacturing and marketing of products with the developed technology or the transfer of technology through licensing or other collaborative activities (Kollmer and Dowling, 2004).

Government affects the conditions for successful technology commercialization in a number of ways. First, government may intervene in technology commercialization by regulating the allocation of resources and defining the nature and scope of property rights (Ring et al., 2005). Second, government's official standard-setting organizations affect market competition, particularly in the sector encompassing information, communications and entertainment (Shapiro, 2000). Third, government is a large sponsor of technology commercialization through their financial support for R&D and new businesses (e.g., Lerner, 1999). As a result, government's policies can help or hinder firms engaged in technology commercialization.

While the importance of the influence of government on technology commercialization is recognized, most studies only focus on government's behavior in the private sector. Although the private sector is the largest sector of the economy in most countries, government expenditure is often also substantial. In the United States, government consumption expenditures alone compose more than 15 percent of GDP (BEA, 2006). The public sector in the European Union even accounts for more than 20 percent of GDP (Eurostat, 2005). Furthermore, defense, health care and infrastructure are important drivers of technological progress, often with spin-offs benefiting the private sector. This study addresses government procurement of new technology.

Why is this research important?

There are several reasons for this research. First, government is a first user of 25 percent of innovations (Dalpé et al., 1992). Second, government as a customer often has significant buyer power (Dalpé et al., 1992), which affects market price and reduces seller profitability (Lustgarten, 1975). Third, government is both a promoter of R&D for public goods and a buyer of new technology. Therefore, during commercialization, government must simultaneously support technology development and create new markets (Norberg-Bohm, 2000). However, previous research on the role of government in technology development focused on macro-level analysis and failed to address the impact on firm or project level (Dalpé et al., 1992; Greer and Liao, 1986). Furthermore, most studies have been limited to the effect of regulations or funding on technology commercialization (Lerner, 1999; Ring et al., 2005; Shapiro, 2000). Yet, government has more roles in technology commercialization than regulator and sponsor.

This study's main contribution is to consider the different government roles and analyze their combined effect on technology commercialization. Based on a distinction between supply- and demand-oriented policies, this article will develop a model to explain how government affects technology commercialization of partially public goods. According to Dalpé et al. (1992), partially public goods include public administrations (e.g., defense and legislature), health and educational institutions under public control and nationalized or regulated public utilities, such as transportation, communication and the production and distribution of energy.

The second contribution is an in-depth analysis of the development and commercialization of technology for partially public goods. Existing studies on technology for partially public goods are mainly historical accounts, and only a few are empirical studies on innovation processes (e.g., Geyer and Davies, 2000). Three in-depth case studies of technology commercialization in road infrastructure are examined. In that sector, government is the largest customer and first user of most technologies. Therefore, government has to create a market for most new technologies and strongly affects the viability of new businesses in this industry. Conversely, government does not itself develop new technologies in road infrastructure. Firms develop and commercialize new technologies and government, as a customer, depends on these firms. To avoid the emergence of monopolies and a dependence on a single supplier, government may stimulate the development and commercialization of competing technologies.

This article follows this outline. In the next section, we review the factors in government behavior that direct technology commercialization. After that, we introduce the research methodology and discuss the cases. Based on the cross-case analysis and discussion of findings, a model for understanding technology commercialization of partially public goods will be developed. From this model, we offer propositions for future research. This article concludes with the contributions to the literature, research limitations and policy implications.

Theoretical Background

Research on large technical infrastructures, such as road infrastructure and energy supply, has shown that these infrastructures have specific characteristics that have to be taken into account (Davies, 1996; Geyer and Davies, 2000). Furthermore, research on technology commercialization has shown that social, economic and political factors have to be considered when studying technology commercialization (Das and Van de Ven, 2000). To account for those characteristics and factors, the model will draw on elements of the concepts of large technical systems (Hughes, 1983) and technological regimes (Van den Ende and Kemp, 1999).

Large technical systems

Partially public goods and services such as defense systems, road infrastructure and health care, show similarities in their structure and innovation dynamics. These goods are characterized by a capital-intensive infrastructure, a broad range of technical components and the involvement of a variety of actors and institutions (Markard and Truffer, 2006). In the literature, the concept of large technical systems has emerged to explain the process of innovation in these types of goods and services (Davies, 1996; Hughes, 1983). The concept of large technical systems focuses on technical, economic and political factors as the forces that direct innovative activity (Davies, 1996).

Large technical systems are "those complex and heterogeneous systems of physical structures and complex organizational routines that (1) are materially integrated, or 'coupled' over large spans of space and time, quite irrespective of their particular cultural, political, economic and corporate make-up, and (2) support or sustain the functioning of very large numbers of other technical systems, whose organizations they thereby link" (Joerges, 1988: 24). A key characteristic of large technical systems is the process of technical standard setting. This process guarantees that a set of standards and organizational practices co-evolve with the system to ensure the compatibility and interoperability of its numerous components (Markard and Truffer, 2006). A second key characteristic of large technical systems is the high degree of interdependence between their components. As a consequence, a change in one component may improve one part of the system, while negatively affecting other parts (Geyer and Davies, 2000). Third, all large technical systems have high-fixed costs of capital investments. Therefore, some form of control to secure efficient capacity utilization is a major determinant of system performance (Nightingale et al., 2003).

Road infrastructure as a large technical system

Road infrastructure consists of physical components such as roads, bridges and traffic monitoring equipment. These components form a network that hierarchically links roads of various classes (Mom, 2005) and that is controlled through signs, regulations and dynamic route information to optimize traffic flow. Important operational goals in road infrastructure are the improvement of the capacity utilization, safety and reducing the environmental side effects of car traffic. These goals are the drivers of many improvements in road infrastructure, such as dynamic route information systems and quiet pavements.

Road infrastructure as a large technical system has four distinct characteristics that distinguish it from other large technical systems. First, road infrastructure is superimposed on an existing road network. Contrary to railroads and telecommunications, road infrastructure was and is dependent on an existing hierarchical network whose individual roads had often benefited from prior technical improvements (Mom, 2005). Second, traffic flows have a nonsystemic character. This typically creates control problems owing to the asynchronical changes between diverse operating agencies, diverse users, or between operators and users (Joerges, 1988). Third, road infrastructure has a huge physical impact on the landscape. Consequently, changes to and growth of road infrastructure often requires extensive government procedures involving politics and citizen participation. Fourth, road infrastructure is controlled and owned by government.

These characteristics have several implications for understanding technology commercialization in road infrastructure. First, government has to create a market for new technology and technology commercialization is subjected to competitive bidding. Second, technologies that increase capacity utilization and the control of traffic flows are important. Third, government support for new technologies is prone to extensive administrative rules and procedures. Taken together, these characteristics induce incremental and path-dependent innovation.

Technological regimes

Complementary to research on large technical systems, economic literature has provided explanations for path-dependent innovations (Davies, 1996; Markard and Truffer, 2006). In that literature, technological regimes direct the variation in new technologies (Malerba and Orsenigo, 1997).

Van den Ende and Kemp (1999:835) define a technological regime as "the complex of scientific knowledge, engineering practices, production process technologies, product characteristics, user practices, skills and procedures, and institutions and infrastructures that make up the totality of a technology." The technological regime reinforces the established consumption patterns and principles for the solution of techno-economic problems (Markard and Truffer, 2006). As such, the technological regime guides the direction of technological change and the adoption and diffusion of new technologies.

Besides variation in new technologies, a technological regime also affects the appropriability conditions (Shane, 2001). These refer to the ability firms have to exploit new technology. The conditions that govern a firm's ability to profit from a technology are the nature of the technology and the efficacy of legal instruments (Teece, 1986). Legal instruments, such as trade secrets and intellectual property rights, are intended to prevent copying. In most industries, firms consider secrecy, lead time and complementary skills as more important than patents (Cohen, 2005).

The literature on technological regimes has two relevant implications for technology commercialization. Both supply and demand factors determine the rate and direction of innovation. In addition, the appropriability conditions affect the opportunities for exploiting new technologies. However, these dimensions vary from sector to sector (Malerba and Orsenigo, 1997), and therefore, have to be adapted to the sector studied.

How government directs the variation and appropriability of technology

In this subsection, literature and existing empirical studies on technology policy are used to adapt the dimensions of technological regimes to road infrastructure. Analogous to the dimensions in technological regimes, this literature distinguishes supply- and demand-oriented policies to direct the rate and direction of innovation and conditions to appropriate returns (Moon and Bretschneider, 1997; Rothwell and Zegveld, 1981).

Supply-oriented policies

Supply-oriented policies are the provision of funding, technical assistance and human resources (Moon and Bretschneider, 1997). In the literature, two important motives are presented for government funding of private R&D. First, the social returns of R&D are much greater than the private returns to the firms because of knowledge spillovers (Lerner, 1999). Second, public funding can compensate for the market failure of profit-maximizing firms, because it funds projects that otherwise would not be undertaken (Hall, 2002; Klette et al., 2000). Lerner (1999) has shown that the U.S. funding program for small- and medium-sized enterprises had a substantial effect on employment and sales growth of the funded firms.

Analogous to the role of product champion in the NPD literature, Morris and Hough (1987) argue that governments can act as a champion. We define government championship as a supply-oriented policy to provide technical assistance, political support and human resources to firms engaged in technology commercialization. Government championship can create favorable demand conditions and help in obtaining planning approvals.

Morris and Hough studied nine major technology projects, including the Concorde, in which governments acted as champions. In these projects, government absorbed part of the financial risks, integrated various regulatory authorities and generated political support. Particularly, in projects that do not have an obvious initial beneficiary, a government's championship is vital. A well-known example of government championship is the rise of Silicon Valley. The close collaboration between government, Stanford University and entrepreneurial firms on state-of-the-art defense systems was crucial for the region's emergence (Bresnahan et al., 2001). Other renowned examples of government championship are the Concorde and governmental support for the U.S. semiconductor industry in the 1980s (Klette et al., 2000). However, there is also a downside to government championship. Political and social motives or prestige might enter into the decision-making process. Governments can be committed to a certain course of action, even if success is not likely. In contrast, withdrawal of government championship can be a direct cause of failure, as was the case in the first Channel Tunnel project (Morris and Hough, 1987).

Demand-oriented policies

Demand-oriented policies are carried out through the public procurement of new technologies (Moon and Bretschneider, 1997) and have a direct effect on their variation and selection. Improving public goods and services, cost-reduction and the changing needs of society are a few of the factors that induce governments to adopt new technologies (Bingham, 1978; Rothwell and Zegveld, 1981). In mainly or exclusively public markets, such as defense and transport infrastructure, government procurement can dominate the adoption and diffusion of technology. In the defense industry, the government has complete control over the size and timing of demand and whether there will be a market for a specific technology (Greer and Liao, 1986). In addition, innovation-oriented procurement policies can provide an opportunity for experimentation and demonstration of new technology (Rothwell and Zegveld, 1981; Seaden and Manseau, 2001). Providing this opportunity can include technical support for prototype development or technical assistance during the phase of final adjustments (Dalpé et al., 1992). In this respect, procurement and championship are interrelated and can complement each other.

Appropriability conditions

As Teece (1986) states, the opportunities to achieve returns differ with the efficacy of legal instruments and the nature of the technology. Governments can affect the efficacy of legal instruments in several ways. First, laws and regulation define what can be protected with intellectual property rights (IPRs). For example, the Bayh-Dole Act and the Technology Transfer Act have extended the eligibility of who can patent and what can be patented considerably (Cohen, 2005). Second, the standard-setting behavior of government can affect the appropriability conditions. Government regulation can impose a technology standard on an industry. That standard will self-evidently dominate other technology options in an industry (Schilling, 1998) and limit the viability of other technologies. In large technical systems, such as telecommunications, the need to ensure compatibility in technology often warrants government intervention (Shapiro, 2000; Schilling, 1998). Third, government can indirectly promote new technologies by providing tax incentives. During the 1970s and 1980s, the U.S. government stimulated the demand for alternative energy systems through tax incentives. This created a spur of products in solar, wind and other energy fields (Radosevich and Kassicieh, 1993).

Besides these three factors, the appropriability conditions are affected by the decisions about size and timing of demand. As a major customer for a new technology, government has a vested interest in promoting the conditions for long-term implementation success (Morris and Hough, 1987). Yet, promoting these conditions is a great challenge for government. First, elections and political appointments have a disruptive influence on operations (Ring and Perry, 1985). Second, governments' roles are dispersed across different organizations and offices at national, regional and even local levels. Therefore, there is a danger that governments promote diverse and possibly even conflicting regulations (Ring et al., 2005). In addition, policy making and policy implementation are usually separated to prevent the arbitrary exercise of power. Thus, developing and implementing new technology require coalition building among policy making and executive agencies at different levels of government (Ring and Perry, 1985). Third, technology commercialization is influenced by administrative decision-making processes that are regulated by procedures imposed by legislation, court decisions and often subjected to public pressures (Ring and Perry, 1985). These processes cannot easily be adjusted to the uncertainties in technology commercialization.

Conceptual model

The discussion of the separate roles of government in literature provides us with the relevant dimensions to study the combined effect of those roles on technology commercialization in road infrastructure. Figure 2 shows the conceptual model based on this discussion. This model will allow us to explain how government affects technology commercialization of partially public goods, such as road infrastructure.

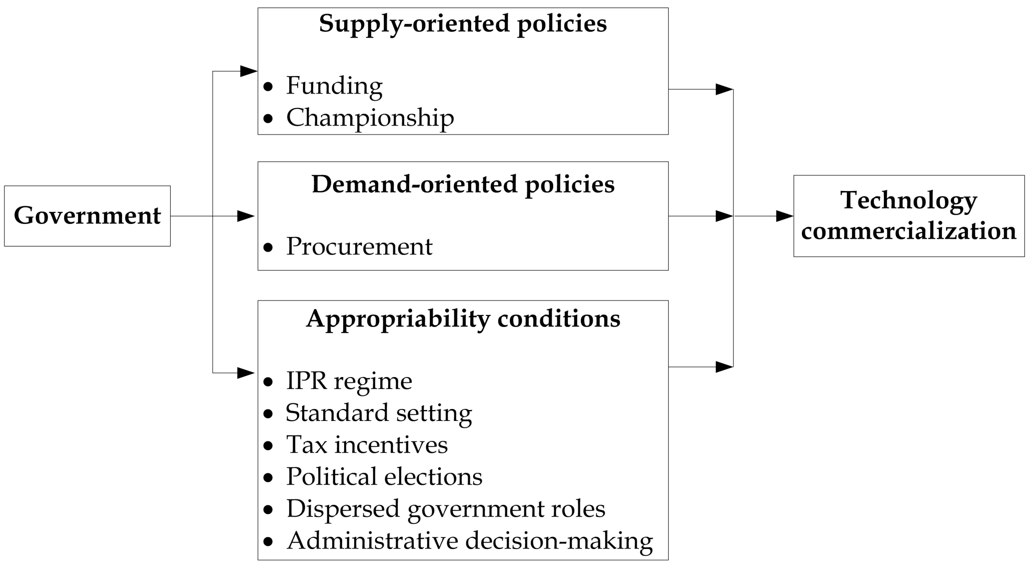

Figure 2 Conceptual model of government roles in technology commercialization

The case studies will help us to develop insights in the relationships between the dimensions of the model to assess their combined effect on technology commercialization. The empirical findings of the case studies will refine the conceptual model. Propositions are developed to describe the relevant relationships between the dimensions in the model.

Research Methodology

This research is a multiple case study to gain insight into the effects of governments on technology commercialization. Case studies are well suited for understanding the "how and why" of phenomena in their natural settings (Yin, 2003). Furthermore, case studies are most suitable when the object under study is difficult to quantify, as in this case. The multiple case study design is used for literal replication (Yin, 2003). Yin considers two to three cases as adequate for literal replication.

To study the technological regime of road infrastructure, technology projects had to conform to the following characteristics. First, technology projects had to be distinguished from construction projects. Second, the main customer of the developed technology had to be central government. Third, the technology had to be new to the market. The first characteristic would make an application for government funding and support more likely as the technology project cannot be financed directly by a construction project. The second characteristic would allow us to study the effect of government procurement and the third characteristic would allow us to examine the appropriability conditions. The three in-depth case studies are Dutch road infrastructure technology projects. The Dutch road infrastructure is known for its innovative solutions, such as the advances in the use of recycled materials (Holtz and Eigmhy, 2000) and the dominance of the Dutch government in technology commercialization (Seaden and Manseau, 2001). The three cases were conducted within an established firm. The unit of analysis is the individual technology project. The technology sources considered are those regarded as important in the literature (e.g., Brown and Eisenhardt, 1995). Both internal and external technology sources are examined (Zahra and Nielsen, 2002). The internal sources include senior management and the R&D department. External sources include suppliers, customers, competitors or other organizations, such as universities and research institutes.

Data collection

Data collection consists of several sources. Table 3 gives an overview of the data sources for each case. Interviews were held with all project team members, the relevant senior managers of the firms involved in the projects and the relevant government officials – including six experts from the Dutch Highways Authority. During the interviews, interviewees answered questions concerning the development process (e.g., project team, planning of work) and how government and contextual uncertainties (e.g., market and technological) interfered with the process and how they both anticipated and reacted to events. In total, 38 interviews of 34 people were conducted, varying in length from 50 to 150 minutes. The average interview took about 90 minutes. Before the interview, a questionnaire was sent to the interviewee for him or her to prepare for the interview. Semistructured interviews were used to probe deeper into the “how and why” of their perceptions of the factors that affected the technology development process. To avoid excluding findings, the respondent was asked to add any events that he or she found relevant for the project outcome. For each interviewee, these topics were adapted to his or her specific role in the technology development project and his or her contextual setting. During the interviews, notes were made and then used to type the interview transcripts. Unless the interviewee objected, the interview was recorded and the recordings were used to supplement the interview transcripts. Furthermore, interviewees were asked to provide documents or other written or electronic material to illustrate or complement their statements. Each interview transcript was sent by e-mail to the relevant interviewee for remarks and consent.

Table 3 Sources of evidence in case studies

	Sources of evidence	*Details*
Case 1	Interviews	13 interviews with project team members, government officials, senior R&D and managers, including site visit to the Thermal Conversion Unit
	Documentation	Agendas, minutes, reports, policy articles, professional articles and newspaper articles
Case 2	Interviews	16 interviews with project team members, government officials, senior R&D and managers
	Documentation	Agendas, minutes, reports, contractual arrangements, design specifications, tender documents, letters, policy articles, newspaper articles and newsletters
Case 3	Interviews	3 interviews with project team members and senior R&D managers
	Documentation	Agendas, minutes and professional articles
	Direct observation	Observations during project meetings

One project started just before this research began. This offered an opportunity to attend project meetings. During those meetings, actual decision making about the development process and which uncertainties and unexpected events to dealt with were observed. This additional information was discussed with the senior R&D managers to see whether the observations were typical for this project. If they were not, these findings were included.

Following Hult et al. (2004), several projects within one firm were studied to avoid the potentially confounding effects of variation in company practices. The projects studied were carried out by Heijmans Infrastructure, a division of Heijmans which is a large contractor with more than 9,000 employees and a turnover of more than 2 billion euros. The Heijmans Infrastructure division is responsible for about a quarter of annual turnover. Heijmans is one of the five largest construction firms in the Netherlands.

Operationalization

Appendix 2A shows the topics discussed with the interviewees. The references included show that those topics are embedded in the relevant literature. The topics list is part of the research protocol to allow a structured examination of the cases and to compare findings (Yin, 2003). In this protocol the commercialization process is related to the dimensions described in this article.

Data analysis methodology

Following Eisenhardt (1989) and Brown and Eisenhardt (1997), data analysis consisted of building individual case descriptions and then making a comparison across the cases to reflect on the conceptual model. As a first step, all transcribed responses were grouped by events. Next, secondary sources relating to the projects were reviewed. From this, a case description for each project was written.

To reconstruct developments over time, the case description was written in chronological order. The individual case descriptions were discussed with senior R&D managers at Heijmans Infrastructure to achieve realistic descriptions of the developments. Once the individual case descriptions were complete, a cross-case analysis was conducted. Following Eisenhardt (1989), different categorizations were used to find similarities and differences across the cases. The events were grouped in a partially ordered matrix (Miles and Huberman, 1994).

This matrix specified the internal process conditions (e.g., project team composition and planning of work), project performance, government behavior and contextual conditions (market and technological uncertainty). Table 4 shows a part of such a matrix. In an iterative process of going back and forth from the literature to the findings, several partially ordered matrices were created. These matrices helped to refine the conceptual insights and the relations between the dimensions in the conceptual model.

Table 4 Partially-ordered matrix for data analysis

	Case 1	*Case 2*	*Case 3*
Project team composition	R&D and production departments Three competitors	R&D, production and marketing departments Supplier	R&D, engineering and production departments
Planning of work	Little predevelopment planning Fast upscaling	Extensive predevelopment planning directed by supplier Many design iterations	Little predevelopment planning Quickly jumping to technicalities
Senior Management Support	Negotiations with government officials about price and environmental regulations Approved business concepts	Met twice a year Set clear financial objectives	Gave high priority, but hardly monitored progress and performance
R&D cooperation	Joint venture with three competitors Contractual arrangement with supplier Supplier lacked resources and know-how for development of Thermal Conversion Unit Customer involved as single buyer/user and regulator	Contractual arrangement with supplier Preferred buyer-supplier relation Cooperation with customer as main buyer/user Customer sets performance requirements in preliminary technical standards	Cooperation with customer to allow for joint agreement on design specifications and performance measures

Cases

In this section, the three cases will be discussed and analyzed on the basis of the dimensions in Figure 1. This section concludes with a cross-case analysis of the three cases. Table 5 describes the three cases studied.

Case Analysis

Supply-oriented policies

In both Case 1 and Case 2, Heijmans Infrastructure applied for a subsidy from the Ministry of Economic Affairs, which subsidized up to 50 percent of labor and capital costs. The subsidies were granted on the basis of general policy goals that were of secondary importance to the projects. In Case 1, the subsidy was granted because the technology, the Thermal Conversion Unit, would save energy in the production of new asphalt. This energy-saving characteristic was, however, a side effect. As one of the respondents clarified, energy costs are only a few percent of the total exploitation costs. Reduction in energy consumption would hardly affect the total exploitation costs. Furthermore, the interviews made clear that government's direct question to develop a technology for coal tar removal was the primary incentive to start the project, and not the opportunity of government funding.

Table 5 Case descriptions

Case 1. Thermal Conversion Unit	*Case 2. Dynamic Road Marking*	*Case 3. Re-use of scrap material*
The project goal was to develop a technology for the removal of coal tar from tar-containing asphalt. In 1992, the Dutch Ministry of Transport and Ministry of the Environment urged Heijmans Infrastructure and three other road contractors to start a joint venture to develop technology for environmentally friendly re-use of tar-containing asphalt. The Ministry of Transport was involved (price-performance and regulations) in the development of this technology. Heijmans Infrastructure involved the competitors to obtain government support and spread investments and risks. The project team consisted of R&D engineers from the road contractors and the supplier.	This project started in 1998 as a contest issued by the Dutch Highways Authority. This Authority asked firms to offer technical solutions for Dynamic Road Marking (DRM). DRM could be used to replace existing road marking and would allow the Dutch Highways Authority to change the number of lanes on a roadway by switching lights on or off. Heijmans Infrastructure formed an alliance with a large electronics firm. This electronics firm would develop the dynamic marker and Heijmans Infrastructure would develop tools to install them. The electronics firm would act as supplier. The Dutch Highways Authority was involved as potential customer and regulator.	In this project, Heijmans Infrastructure looked for ways to increase the re-use of scrap material in asphalt production. Large amounts of scrap material were temporarily stored at asphalt production plants, creating high storage costs and the need for additional storage capacity. In November 2004, Heijmans Infrastructure initiated this project to improve the re-use of scrap material from renovated roads.

Table 5 Case descriptions continued

Case 1. Thermal Conversion Unit	*Case 2. Dynamic Road Marking*	*Case 3. Re-use of scrap material*
The supplier was involved to design and manufacture the technology. Senior management controlled the budget and regularly met with government officials to discuss regulatory constraints. Government determined the size and timing of the market for the thermal conversion of tar-containing asphalt. The commercialization strategy of the road contractors was licensing and the implementation of a Thermal Conversion Unit in their asphalt plants. The supplier would manufacture these units. Technical difficulties included the design parameters of a large scale Unit and the installation of this Unit in existing asphalt plants. From 2000 onwards, the contractors tried to make the large scale demo Unit operational, but failed to do so. National bodies representing regional and local governments were involved, since most of the tar-containing asphalt was used in local roads. In 2001, central government made thermal processing of tar-containing asphalt mandatory.	The project team consisted of R&D engineers from Heijmans Infrastructure and its supplier. In addition, the supplier involved its marketing department. Senior management assessed progress and the size and timing of the market half yearly. The commercialization strategy was to develop, manufacture and sell own products. Technical difficulties were the traffic load on the dynamic marker, attaching the markers to the asphalt road and brightness of the markers during daytime. In 1999, 2002 and 2004, the Dutch Highways Authority carried out pilot projects to test DRM. During this period, the application and technical specifications of DRM changed. Technical uncertainties made the Dutch Highways Authority hesitant to apply DRM. Heijmans Infrastructure and its supplier waited for large scale application before developing and manufacturing a finalized product. In May 2005, Heijmans Infrastructure and its supplier ceased the project.	The project team consisted of R&D engineers and production engineers. Senior management gave this project high priority and assigned a senior R&D manager, but failed to give clearly defined project goals and monitor the project. The commercialization strategy was to develop, manufacture and apply these new mixtures in own business projects. Technical difficulties were the adjustments to the asphalt plant to control for the increase in scrap material (larger variation in material composition and effect on production temperature). The Dutch Highways Authority was involved to negotiate the design parameters for the new mixtures. The new mixtures would be stiffer than existing mixtures. The consequences had to be measured and monitored in laboratories and large scale simulations before the Dutch Highways Authority would approve the application of the new mixtures.

In Case 2, the subsidy was granted by the Ministry of Economic Affairs based on the collaboration between Heijmans Infrastructure and an electronics firm, entailing cross-industry knowledge transfer. Again, this subsidy was applied for after Heijmans Infrastructure started the project. Also, the respondent responsible for the application stated that the time-consuming procedures were hardly compensated by the subsidy. In Case 3, Heijmans Infrastructure did not apply for a subsidy. During the interviews it became clear that subsidies would not compensate the cost of writing the application and managing the paperwork.

The champion role in Case 1 included technical and human support in testing and developing a prototype. The Ministry of Transport provided 50ktons of tar-containing asphalt for testing. Furthermore, the Ministry of Transport made agreements to allow cleaned tar-containing asphalt to be re-used in new asphalt. The respondents made clear that for Heijmans Infrastructure to invest in developing a prototype, these government guarantees were very important. Without those guarantees, Heijmans Infrastructure would be unable to refine the technology and generate sales.

Furthermore, the Ministry of Transport coordinated the various government bodies and persuaded regional and local governments to support thermal conversion of tar-containing asphalt. In addition, the Ministry of the Environment paid one-off monetary compensation to the regional and local governments for the increased costs of processing tar-containing asphalt. In Case 2, the Dutch Highways Authority provided test locations to firms for dynamic road marking, which was an important precondition for success. In addition, the Dutch Highways Authority presented two preliminary standards for dynamic road marking to encourage firms to proceed with this technology. However, from 2000 to 2002, policy changes led to a different, smaller-scale application for dynamic road marking with simplified specifications. The firms involved in developing dynamic markers did not receive periodic notice of government policy changes and revised specifications. Consequently, firms lacked the information on the smaller-scale application to reassess their business cases. During the interviews, respondents commented on the lack of communication and the unexpected changes made by government. In their opinion the nature of the technology necessitated close cooperation with government as customer and user. Now they were forced to make costly redesigns. In Case 3, government did not play a champion role as increasing the re-use of scrap material was not a government priority. In this case, respondents indicated that Heijmans Infrastructure chose to informally consult the Dutch Highways Authority. A formal approach would attract too much attention from competitors.

Demand-oriented policies

Government initiated the commercialization of new technology in Case 1 and Case 2. Yet, government used different means to articulate its objectives. In Case 1, government contacted Heijmans Infrastructure directly and urged Heijmans Infrastructure to develop a technology.

Furthermore, government insisted that Heijmans Infrastructure would involve three competitors to share costs and risks and to ensure the nationwide processing of tar-containing asphalt. Respondents stated that government is unlikely to support just one or two firms. In Case 2, the Dutch Highways Authority organized a contest for dynamic road marking in which no specific technologies were specified. Everyone could participate and a reward would be paid to the winner. Furthermore, the Dutch Highways Authority organized three pilot projects for firms to demonstrate and test their dynamic markers. In Case 3, Heijmans Infrastructure initiated the commercialization of new asphalt mixtures. To test and refine its new asphalt mixtures, Heijmans Infrastructure was permitted to use these mixtures if two conditions were met. First, the performance of the mixture in lab tests had to be at least equivalent to those of standard mixtures. Second, the mixture used in the construction project had to be the same as the mixture tested in the lab. Variations in the raw materials and during production would not be permitted.

Appropriability conditions

In Case 1, Heijmans Infrastructure had patented the use of a Thermal Conversion Unit operating as a furnace in an asphalt production plant. Central government demanded a free license of that technology, if Heijmans Infrastructure were to attain a dominant position in the market. As respondents indicated, they depended on government to create a market and therefore had to accept those conditions. In contrast, in the second case the Dutch Highways Authority had no objections to a patent if the Dutch Highways Authority would receive the right to use the technology for the consecutive pilot projects. In Case 3, Heijmans Infrastructure thought its idea was best protected through secrecy. Patenting would lead to exposure of the idea, which would create the opportunity for competitors to imitate the idea.

Standard setting shows similarities between Case 1 and Case 2. In Case 1, central government made thermal conversion mandatory, but took nine years to reach agreement among different government bodies. Many parties were involved in the decision-making process: the Ministry of Transport, the Ministry of the Environment and the national bodies representing all the regional and local governments. The regional and local governments were involved because they had to pay most of the cost. While improving labor and environmental conditions were important objectives, regional and local governments were subjected to budgetary constraints. Therefore, regional and local governments were forced to make a trade-off between road maintenance and improving labor and environmental conditions. Similarly, the Dutch Highways Authority was reluctant to impose a standard for dynamic road marking, because of differences of opinion within the Authority. Some people wanted to follow existing rules on marking and others wanted new rules based on dynamic markers with lights in the road surface. Furthermore, as the customer, the Dutch Highways Authority scrutinized cost, reliability and maintainability aspects early in the process before there was any clarity about the application and the production costs of dynamic markers. For example, the Dutch Highways Authority pressed Heijmans Infrastructure and its partner to estimate the price of a commercial road marker. Yet, respondents stated that the changes in specifications meant that they were unable to estimate a price, as production costs changed with the changes in specifications. In 2000, a first preliminary standard was published by the Dutch Highways Authority, but by 2006, the Dutch Highways Authority still had no firm specifications for dynamic road marking.

In contrast, in the third case, the Dutch Highways Authority only provided rules concerning test procedures and mathematical models representing the behavior of asphalt mixtures, leaving firms to develop their own standard within the boundaries of the provided test procedures and mathematical models.

Although elections were held and political appointments made during two of the cases, this did not affect technology commercialization in these cases. However, administrative decision-making procedures had several effects on the implementation of the new technologies. First, these decision-making procedures are time-consuming because these procedures involve many government offices and procedures require series of tests in both lab and on test strips to assess long-term performance. For example, in the second case decision making on dynamic road marking progressed slowly because there were differing opinions within the Dutch Highways Authority regarding road infrastructure and traffic management that influenced decisions. In addition, the necessity for a flexible road infrastructure was still under political debate.

Second, the government offices involved represent different and often conflicting interests. The interviews with government officials made clear that effecting policy is difficult. In Case 1, for instance, the termination of temporary storages was not effected. The shortage of processing capacity would increase the cost of road maintenance, and the budgets of the regional and local governments were not increased to reflect that.

Third, the decision-making procedures are not flexible and cannot adapt to the uncertainties within a technology commercialization process. For example in Case 1, the Thermal Conversion Unit was not yet operational and no alternative thermal processing technique was available. To cope with this situation, central government allowed temporary storage of tar-containing asphalt for up to three years. In this way, central government created a low-cost alternative to thermal conversion. Consequently, prices for processing tar-containing asphalt dropped, which was an unintended outcome.

The next section will highlight the similarities and idiosyncrasies in the cases.

Cross-Case Analysis

Table 6 summarizes the main results of the cases. First, funding of the technology projects had a positive effect on the net costs of the projects, although the objectives on which the funding was granted were of secondary importance to the projects. A drawback of public funding is the potential exposure of ideas to competitors.

Second, in all cases, Heijmans Infrastructure depended on government for test locations and test procedures. Allowing firms to test and refine their technologies on existing infrastructure is an important stimulus for firms to engage in technology projects. Furthermore, Case 2 demonstrated that championship can be combined with procurement to encourage investments in new technology. Also, in all three cases government tried to be "technology-blind" to avoid favoring certain firms or technologies.

Third, procurement policies were used to achieve certain socioeconomic goals. In Case 1, government wanted to improve labor and environmental conditions. In Case 2, government sought technologies to increase capacity utilization. These goals were subjected to policy changes and changing priorities. In addition, the demand for new technologies was affected by the separation between policy makers and policy implementers. The objectives of policy makers were not always aligned with the interests and considerations of policy implementers. Furthermore, government focused on low-cost technologies as public funds have to be spent efficiently.

Table 6 Cross-case analysis

	Funding	*Championship*	*Procurement*	*Appropriability conditions*
Case 1. Thermal Conversion Unit	Funding 50 % of investment reduced costs; funding based on energy saving, which was of secondary importance	Ministry of Transport provided 50ktons of tar-containing asphalt for testing Ministry of Transport allowed use of cleaned tar-containing asphalt in new asphalt Ministry of Transport integrated the diverse government bodies and persuaded them to support the technology Ministry of the Environment paid one-off monetary compensation to regional and local governments	No formal tender procedure meant that Heijmans Infrastructure did not have to compete with others to favor its technology Government urged Heijmans Infrastructure to collaborate with competitors that reduced Heijmans Infrastructure's ability to achieve a competitive advantage over its rivals	To prevent a monopoly government demanded a free license Implementation progressed slowly owing to budget constraints of regional and local governments and their conflicting interests Temporary storage of tar-containing asphalt created a less expensive and easier solution for tar-containing asphalt
Case 2. Dynamic Road Marking	Funding 50% of labor costs reduced costs; funding based on cross-industry collaboration, which was of secondary importance	Dutch Highways Authority provided test locations to firms for Dynamic Road Marking, which was an important precondition for success To encourage firms to develop a dynamic marker, Dutch Highways Authority presented preliminary standards	Contest in a public tender to encourage commercialization of Dynamic Road Marking 3 pilot projects and a test location offered firms the opportunity to test and refine their technology	Disagreement within Dutch Highways Authority slowed down the standard setting and created uncertainty about application and specifications of Dynamic Road Marking There were differences of opinion within Dutch Highways Authority about specifications and necessity of flexible roads

Table 6 Cross-case analysis continued

	Funding	*Championship*	*Procurement*	*Appropriability conditions*
Case 2. Dynamic Road Marking				Dutch Highways Authority as client scrutinized cost, reliability and maintainability aspects when clarity about application and costs of Dynamic Road Marking were lacking
Case 3. Re-use of scrap material	Heijmans Infrastructure did not apply for funding	No championship; re-use of scrap material was not a government priority	Under strict conditions experimenting with new asphalt mixtures was permitted	Dutch Highways Authority has rules, procedures and mathematical models of asphalt mixtures to facilitate standard setting and testing Test procedures take long time
Effect	Positive by reducing cost; not an incentive to start project	Positive by creating encouraging framework	Positive effect in offering opportunities; negative in allowing competitive advantage	Negative in standard setting and in allowing firms to effect its Intellectual Property Rights Administrative decision making has negative effect on progress

Fourth, the appropriability conditions seem to be weakened by government behavior. Government was reluctant to impose a standard that would favor Heijmans Infrastructure's technologies. Furthermore, the strong bargaining position of government reduced the effectiveness of patents, preventing Heijmans Infrastructure from reaching an exclusive position. Also, the necessity of coalition building within and among the different levels of government affected the chance of success. Changing policies and conflicting interests affected the level of demand and the performance requirements. Consequently, government had no robust strategies to encourage and implement new technologies. In all three cases, government did not offer any tax incentives to the firms.

Besides these similarities, all cases have there idiosyncrasies. Case 1 is a technology that differs significantly from the knowledge base and technologies developed in road infrastructure. This led to an underestimation of the technological challenges and increased the dependence on the supplier.

Case 2 is exceptional in its cooperation between a construction firm and a large electronics firm. This is apparent in the differing objectives and the way they dealt with the development and commercialization process. The electronics firm made an elaborate business case, patented the basic principles and formed a cross-functional team to develop the dynamic marker. Heijmans Infrastructure considered this as just another technology project and did not have a formalized development process.

Case 3 seems a straightforward example of most incremental technology projects of construction firms. However, the project team consisted of all senior R&D staff. This negatively influenced the progress, because senior staff could not dedicate enough time to this project.

In the next section, these findings will be used to develop an improved model for studying technology commercialization of partially public goods.

Discussion

In the previous sections, both the literature and the findings from three technology projects in road infrastructure were reviewed. Based on this review, five variables are linked to technology commercialization of partially public goods. These links are shown in Figure 3.

The links show that far more aspects affect technology commercialization for those goods than procurement alone. This section proceeds with propositions to describe the relationships between the variables and technology commercialization and include possible control variables.

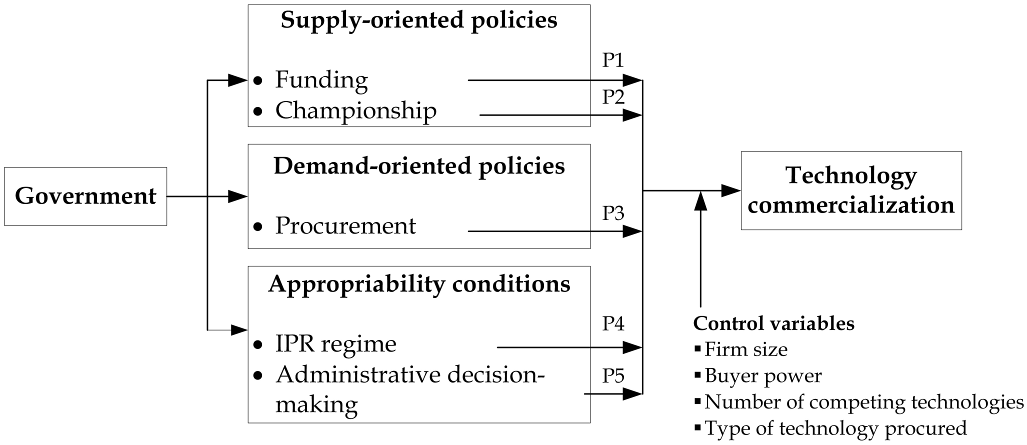

Figure 3 Improved model of government roles in technology commercialization

Several studies have found a positive relation between government funding of private R&D and technology commercialization (Hall, 2002; Lerner, 1999). However, doubts about the methodology of empirical studies remain (Klette et al., 2000). In the cases, R&D funding was less important as the firms applied for subsidies for projects that had already started. Far more important for the willingness to invest were the government incentives and 'guarantees' to create a market. The absence of a market of a certain size led firms to cancel their projects. Therefore, R&D sponsorship was not a primary incentive for those projects studied. At the same time, the firm studied was a large corporation and Hall (2002) found that large corporations are less dependent on government R&D funding.

P1: Government funding of private R&D is not a key driver for technology commercialization, but contributes by reducing the net costs.

Government championship is a powerful instrument to encourage firms to invest in specific technologies. Many empirical studies show the positive impact of innovation programs initiated by governments on industries such as biotechnology, semiconductors and energy systems (Morris and Hough, 1987; Radosevich and Kassicieh, 1993). However, it is difficult to prove that government championship necessarily induces greater innovation (Grubb and Ulph, 2002). The cases show that political support and likelihood of a new market are important preconditions for investing in new technology. Bresnahan et al. (2001) have also argued that suitable demand and markets are important drivers. Two of the cases show that government used championship to offer technical assistance and generate political support to create a market. Without this supportive attitude, these projects would not have been undertaken. However, these projects also show that unclear policy objectives and changes directly affect the viability of new technology. In all three cases, firms depended on government support to test and refine their technologies.

P2: Technical support and the creation of a new market are positively associated with technology commercialization.

Several studies have focused on the impact of procurement policies on technology commercialization (Dalpé et al., 1992; Norberg-Bohm, 2000). According to these studies, procurement policies can have a positive effect on technology commercialization if two conditions are met. First, government customers must have a certain technological capacity to contribute to a firm's technology. Second, a market of a certain size is necessary as an incentive for firms to invest. However, procurement policies can restrict governments in adopting new technologies because factors other than technology and quality are important in procurement decisions (Dalpé et al., 1992). Procurement policies are used to achieve socially desirable outcomes, demonstrate or initiate new technologies and encourage their dissemination to other users (Seaden and Manseau, 2001). The findings confirm that procurement is used to attain socially desirable results. Improving environmental conditions and reducing traffic congestion and waste are essentially the drivers for the cases studied. However, these objectives can be achieved through various means and do not exclude existing, low-cost technologies. Government was not interested in the highest quality or best technology. Furthermore, in two of the cases, government changed its performance requirements and policies, which negatively affected the size and attractiveness of the market. Consequently, firms were unable to offer a competitive technology and regain their investments.

P3: Procurement policies are negatively associated with technology commercialization.

IPRs are considered by many scholars and policy makers as an important incentive for firms to develop technology. IPRs facilitate knowledge transfer and increase firms' efforts and investments (Radosevich and Kassicieh, 1993). Although the benefits of IPRs are increasingly disputed by both scholars and the business community (Cohen, 2005), Shane (2001) showed that the effectiveness of patents is an important variable in the exploitation of technology. However, the effectiveness of patents varies widely across technologies and depends on the appropriability regime within an industry. The cases show that government is reluctant to adopt patented technology as it does not want to be dependent on one or a few suppliers. Furthermore, competitive bidding and competition policies constrain governments in using patented technology, as governments are not allowed to favor specific firms. In two of the cases, government is the initiator and single buyer of the project and could, therefore, impose the conditions for the exploitation of the technology.

P4: The dominant position of government as a buyer makes IPRs less effective in exploiting new technology.

Although government encourages firms to invest in new technologies, the final goal and application of a technology can change unexpectedly. Consequently, firms are left with technologies that have lost value because they cannot easily be put to other uses. Morris and Hough (1987) have shown that government behavior is not embedded in robust strategies and profitability criteria. This can result in inconsistency and project cancellation without serious study of the opportunities lost. Furthermore, the research shows that the dispersed roles in government and the separation between policy makers and policy implementers hamper technology implementation. The officials that deal with technology are separated from those that set the rules and regulations and those, in turn, are separated from the ones that make the actual procurement decisions. Consequently, reaching agreement with technical officials or policy makers on the conditions for new technologies does not necessarily lead to implementation. This creates uncertainty about the timing and size of demand and slows down the implementation of new technology. This is consistent with earlier research (e.g., Ring et al., 2005; Ring and Perry, 1985).

P5: Dispersed roles and the separation of policy and execution within government have a negative effect on the size and timing of demand.

The empirical findings are based on road infrastructure. A large scale study has to control for possible industry effects. Furthermore, a large firm was studied. As mentioned earlier, a large firm is less dependent on government R&D funding. Therefore, firm size should be controlled for. In addition, the empirical study showed that government has considerable buyer power. Including buyer power, type of technology and number of competing technologies seem relevant. These factors have also shown to be important influences on technology commercialization in other studies (Zahra and Nielsen, 2002; Lustgarten, 1975; Porter, 1980). These factors are included in the model as control variables.

Contribution, Implications and Limitations

Major research results

This study has produced the following major research results. First, this study yields a model to analyze the combined effects of government roles in technology commercialization. This model conceptualizes the relevant relationships between the supply-oriented and demand-oriented policies of government. Furthermore, this model focuses on the project level and extends existing findings on industry level.

The second major result is the inconsistency in government championship on the one hand and procurement policy on the other. Championship promotes technology champions, while procurement policy cannot favor one firm over the other. Therefore, government championship as a policy fails to create a market for new technology.

The third major result is the uncoordinated implementation of the separate supply-oriented and demand-oriented policies. Consequently, firms face additional uncertainties in assessing market opportunities and the potential of new technologies.

The fourth major result is the finding that the dominant position of government in road infrastructure and the persistence of competitive bidding weaken the effectiveness of IPRs to capture the profits of new technology. Therefore, investing in patent positions does not provide a competitive advantage.

The conceptual model provides a richer understanding of the factors that firms engaged in technology commercialization in road infrastructure have to take into account to be successful. Furthermore, given the similarities between road infrastructure and other partially public goods, it is likely that the applicability of the model extends to technology development projects for partially public goods. In addition, the dimensions of the conceptual model seem to be relevant for existing models on technology development in consumer and business-to-business industries. Yet, future research has to show the impact of these dimensions on technology commercialization compared to factors that have already been described in literature.

Theoretical and policy implications

The findings support the results of other empirical studies on innovation processes in large technical systems (Geyer and Davies, 2000; Markard and Truffer, 2006) and of historical accounts on these systems (Davies, 1996; Jacobsson and Bergek, 2004). The strong position of government allows it to select technical standards and reduce the uncertainties that arise when standards emerge through competition. Furthermore, government's financial support of technologies is an important driver of technology commercialization. However, subsidies on existing technologies can create entry barriers for new technologies (Jacobsson and Bergek, 2004). Rosenberg's (1994) analysis of alternative energy sources highlights the important role of government's energy policy. In the United States, government championed nuclear energy by sponsoring R&D and transfer of research or information to firms. Yet, this study has extended the role of government in technology commercialization in large technical systems. In road infrastructure, government does not only affect technology commercialization through technology programs and standards, but it actually creates a market for new technology. Government is the owner and system builder of road infrastructure. In previous studies on large technical systems, this role of government in innovation processes has had little attention. Although Jacobsson and Bergek (2004) emphasize the importance of market creation, they neglect the importance of government in stimulating and creating a market. Also, privatization of large technical systems as energy supply and telecommunications is likely to increase the diversity of competing technologies and decrease government intervention (Markard and Truffer, 2006). Government is no longer the system builder in these large technical systems, although government regulation is still important to ensure minimum service and safety standards (Jacobsson and Bergek, 2004).

The focus on the public sector has also enriched the literature on technological regimes. This study combined existing studies on supply- and demand-oriented policies to explain how government behavior affects the variation and selection of technology. In addition, the strong bargaining position of the government weakens the appropriability conditions of firms in road infrastructure. In many studies in the private sector, customer involvement is an important factor for product success (Brown and Eisenhardt, 1995). The strong position of the customer in road infrastructure is somehow different. Government cannot favor specific technology and has to be "technology-blind." Also, government's priorities are a result of a compromise between multiple and competing objectives. This makes government hesitant to commit itself to a specific course of action. Therefore, government cannot guarantee to create a market of a certain size for a specific technology.

Furthermore, government can impose technical standards, making early involvement important to influence standard setting. Also, the often risk averse nature of government and the uncertainties in administrative decision making are incentives for firms to involve their customers.

The cases and literature studied also lead to several policy implications. First, as other studies have shown, government funding of private R&D does not automatically overcome under investment in socially desirable technologies. The cases show that stimulating those technologies through the funding of private R&D can be improved. One suggestion is to strengthen the link between these funding programs and government procurement. The strongest incentive for firms to develop socially desirable technologies is the emergence of a market for those technologies. However, the cases show that government procurement is biased toward cost-based criteria. The use of socially desirable technologies could be enhanced when procurement criteria reward those technologies. As a result, firms will be encouraged to develop and commercialize these technologies. Second, government's attitude toward IPRs in the cases was hesitant. In part, this attitude is explained by the fact that government procurement presupposes the presence of multiple suppliers of the same technology. IPRs are used to prevent the spillover effect and copying of technology. To deal with IPRs, government should either stimulate the commercialization of various competing technologies or the development of various competing products based on the same technology.

Limitations and future research directions

This study has several limitations. First, although the findings are based on an extensive literature review and three case studies, to generalize the findings, additional empirical data is needed. Future research could focus on testing the propositions in a large-scale study. The model combines supply- and demand-oriented policies to study the impact of government behavior on technology commercialization of partially public goods. This study has extended previous research that focused on either supply- or demand-oriented policies. However, a second limitation is that one market, namely that for road infrastructure, is considered. Future research could extend the model to other markets and use cross-national data to account for differences in institutional structure. Furthermore, the three cases are based on technology commercialization by just one firm in the Dutch infrastructure. Future research could incorporate other firms so as to account for organizational differences and firm size. Third, this article argued that customer involvement in road infrastructure is different from consumer and business-to-business markets. Yet, most strategies for customer involvement are based on those markets. Future research could extend existing strategies for the involvement of government as a customer in technology commercialization. This could help firms to overcome the impediments they face in dealing with government as a buyer. In addition, future research could account for the buyer power of government in the public sector. In the cases studied, the firm faced a monopsony, which weakened its bargaining position. Finally, the possible interaction effects between the independent variables were not addressed. However, the findings do suggest that there are possible interaction effects between procurement and championship. Future research could explore those possibilities.

Addressing the limitations described above would be an important contribution, from the academic, managerial and policy points of view. This research has started on the road to addressing these remaining questions by laying a useful foundation for expanding the investigation in large-scale studies and to other industries. This will broaden the knowledge about technology commercialization in the public sector.

Conclusion

Governments can have a substantial effect on technology commercialization and account for a significant part of the world economy. However, most empirical research is limited to studies about public funding and the effectiveness of IPR regimes (e.g., Lerner, 1999; Shane, 2001). In part, future research can build on these existing empirical studies to construct measurements. Yet, the links between the independent variables procurement policies and government championship and technology commercialization as the dependent variable are mainly indicative and still lack empirical results. This study offers a first step to examine these links. Furthermore, considering these links also allows researchers to evaluate and test possible interaction effects among these variables.

The model provides a richer understanding of how government behavior can direct technology commercialization of partially public goods. It clarifies the complexity of the diverse policies and roles of government in technology commercialization. These diverse policies affect the lead time and appropriability conditions of new technology. In addition, the proposed model contributes to the understanding of the interdependencies between technology policy and other policies related to the procurement of new technology. This understanding helps policy makers in policy formation and has implications for firms engaged in technology commercialization.

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Appendix 2A

Topics

Respondent name (organization)
Date, time
Location

- Role of respondent in the project
- Project objectives
  - Expected outcome in terms of duration, investment and technical specifications (Shenhar et al., 2001)
- Involvement of parties
  - Supplier, customer, research institutes or other (Brown and Eisenhardt, 1995)
- Project team and cooperation
  - Type of arrangement, division of tasks and risks (Gulati and Singh, 1998)
  - Project team composition: cross-functional; technical disciplines; skills (Brown and Eisenhardt, 1995)
  - Planning of work (Song and Montoya-Weiss, 1998)
  - Legal instruments or other measures to protect technology (Teece, 1986; Cohen, 2005)
- Technological uncertainties (Brown and Eisenhardt, 1995; Gupta and Wilemon, 1990)
  - Changes technical design
  - Quality and reliability of the new technology
  - Compatibility of new technology with existing product components
  - Time to acquire new technology
  - Other uncertainties
- Market uncertainties (Porter, 1980)
  - Supplier concentration
  - Significant costs to switch supplier
  - Buyer concentration
  - Large buyer volume
  - Low switching costs for buyer
  - Substitutes
  - Asset specificity of resources
  - Market growth potential

  - Number of competitors
  - Other uncertainties
- Effect of government organizations on the project
  - Progress and/or cost
  - Technical specifications
  - Technical assistance (Dalpé et al., 1992)
  - Size and timing of demand, emergence of market (Greer and Liao, 1986)
  - Other effects
- Lessons learned from the project for future projects

CHAPTER 3

Strategy Implementation in Project-Based Firms: an Empirical Analysis of three Road Construction Firms

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Under review at

Organization Studies

Abstract

Although the attention to project-based firms is currently growing, the strategic management literature has largely neglected these firms. In this study, we developed and applied a framework to analyze strategy implementation in project-based firms.

The value of the framework was demonstrated in a multiple case study of three road construction firms. Results suggest that project-based firms are likely to use various strategic orientations at the project level. Furthermore, the extensive use of external sources of technology and the lack of a coherent strategy impedes the development of routines for efficient execution of similar projects, thereby, limiting the opportunities for "economies of repetition". Although multi-project planning is used in the business projects to efficiently allocate resources, program management is underdeveloped. The firms studied could benefit from program management techniques to manage their technology projects.

Introduction

Studies of business strategies and innovation management have diverged in two types of firms: manufacturing and service firms (e.g. Brown and Eisenhardt, 1995; Cooper and Kleinschmidt, 1987; Olson et al., 2005; De Brentani and Ragot, 1996). Both of these types of firms have distinct features that impact business strategy and technology development (e.g. De Brentani, 2001; Van Gunsteren, 1987; Zeithaml et al., 1985). Manufacturing firms develop, manufacture and sell *products* to either consumers or business-to-business markets. Service firms on the other hand provide *performances* instead of products. The main differences between products and services, is that services are intangible and production and consumption is inseparable (Zeithaml et al., 1985). These differences affect the sources of competitive advantage and the importance of success factors in technology development (e.g. Bharadwaj et al., 1993; De Brentani, 2001). The focus on these two extremes has drawn attention away from firms that produce hybrids, a combination of custom-designed products and related services.

Most project-based firms, such as construction firms, offer a combination of products and related services (Blindenbach-Driessen and Van den Ende, 2006). In project-based firms, projects are the main mechanism to organize business processes (Hobday, 2000). As each project has its own objectives and specific customer or product/service, a project can be considered a temporary organization with its own strategic targets. Although the attention to project-based firms is growing, the implementation of business strategies at the project level has largely been unexplored (Prescott and Smith, 1987).

In this study, we will address this gap in the literature and examine business strategy implementation in project-based firms. Business strategy implementation refers to the relative emphasis on information about customers, competitors, innovation and cost management in their marketing and development activities (Baker and Sinkula, 2005; Olson et al., 2005). We concentrate on how project-based firms manage the combination of diverse strategic targets at the project level.

Based on literature about strategic management and project-based firms, we will develop a framework to analyze business strategy implementation at the project level. We will examine eight technology development projects within three project-based firms.

In this study, we focus on a specific project-based industry, road infrastructure. There are several reasons why we address this sector. First, government has a substantial role as a buyer and first user of new technology in road infrastructure (Dalpé et al., 1992; Caerteling et al., 2008). The unified way of buying in the public sector and the buyer power of government are likely to affect the implementation of a firm's corporate strategy (Christensen and Bower, 1996; Edquist and Hommen, 2000). Second, most studies on project-based firms concentrate on so-called complex products and systems industries, such as aircrafts, telecom and weapon systems (e.g. Brady and Davies, 2000; Brusoni and Prencipe, 2001; Davies and Brady, 2000; Hobday, 1998, 2000). Although important, these studies neglect other, more traditional project-based firms, such as road infrastructure. Third, road infrastructure is an important sector both in terms of GDP and employment (ERF, 2007).

This paper has the following outline. In section 2, we review the relevant literature on strategic management and project-based firms and develop a framework to analyze our cases. In the following section, we discuss the methodology used and, in section 4, we describe the projects studied within our three firms. In the fifth section, we discuss our findings. We conclude this paper with managerial and research implications.

Theoretical Background

Strategic management literature argues that a firm's performance depends on how well business strategy is implemented in its business activities, specifically its marketing and development activities (Walker and Ruekert, 1987; Olson et al., 2005). The effectiveness of a business strategy depends on the way information about customers, competitors, innovation and cost management is acquired and used (Baker and Sinkula, 2005; Olson et al., 2005; Porter, 1980). There are four behavioral orientations that function at the operational level: customer orientation, competitor orientation, innovation orientation and internal/cost orientation.

A customer orientation involves a thorough understanding of the user environment (Olson et al., 2005). This entails the will to tailor and shape products and services to the exact definition of individual customers. Customer orientation requires ample time to make sure the customer receives precisely what it wants (Treacy and Wiersema, 1993). Competitor orientation means having an understanding of the short-term strengths and weaknesses and long-term capabilities and strategies of key competitors and potential competitors. An innovation orientation entails having the will to acquire a substantial technological background and to use it in the development of radical new technologies (Gatignon and Xuereb, 1997). In contrast, an internal/cost orientation pursues efficiency in primary activities and support activities, such as logistics, operations and administrative functions. It is aimed at reducing transaction costs (Treacy and Wiersema, 1993).

Olson et al. (2005) have shown which strategic orientations at the operational level complement the business strategy at the corporate or business unit level. A match between business strategy and strategic orientations is necessary to ensure that the firm can take advantage of established capabilities and resources (Mintzberg and McHugh, 1985) and sustain its competitive advantage (Olson et al., 2005; Day and Wensley, 1988). The basis for Olson et al.'s study is the hybrid model of Walker and Ruekert (1987) that combines Porter (1980) and Miles and Snow (1978). According to this model the relevant dimensions in business strategies are: (1) the targeted market, (2) the basis for competing and (3) the intended intensity of product-market change (Olson et al., 2005; Walker and Ruekert, 1987). This leads to three archetypes: prospectors, low-cost defenders and differentiated defenders. Prospectors continuously seek to exploit new technologies and market opportunities. Low-cost defenders try to acquire a stable market share in terms of customers and sales by being cost leaders. Differentiated defenders try to seal off their share of the market through features that are considered unique by the customer.

According to Olson et al. (2005), low-cost defenders benefit from an internal/cost orientation and a competitor orientation, although the latter relationship was not significant. Differentiated defenders have to emphasize a customer orientation, while other orientations are less relevant. A prospector firm has to combine an innovation and a customer orientation to ensure high performance.

A premise of strategic management literature is that acquiring information about customers, competitors, innovation and cost management should be comprehensive and ongoing (Prescott and Smith, 1987). This information guides the strategic decisions in developing, producing and selling the products and services. Therefore, a functional department at the business unit level is necessary to collect and coordinate such information in a systematic manner. In multi-product firms this functional department is the marketing department. In contrast, managers in project-based firms are confronted with strategic decisions regarding a specific project and customer. While a comprehensive, ongoing approach is valuable for mass-produced goods and services, its usefulness for specific projects may be limited (Prescott and Smith, 1987).

The study of Olson et al. (2005), as most studies in strategic management, was conducted with a large sample of manufacturing and service firms. In this paper, we concentrate on project-based firms. Project-based firms organize all their business processes around projects (Hobday, 2000). As argued by Precott and Smith (1987), this is likely to have an effect on business strategy implementation. In the remainder of this section, we discuss project-based firms and how their characteristics affect business strategy implementation.

Project-based firms

Project-based firms can be characterized as organizations which have projects as their primary units for production organization, innovation, and competition (Hobday, 2000). Examples of project-based firms are the construction, film, airplane and semi-conductor industry (DeFillippi and Arthur, 1998; Hobday, 1998). Organizing the business processes around projects has several major consequences for the organization. First, the primary business mechanism for coordinating and integrating all the main businesses of the firm, such as engineering, marketing, personnel, finance, and production, is the project (Hobday, 2000; Keegan and Turner, 2002). Their business processes are designed to produce specific outputs for a single customer or product. The design and production process is customized and engineered after customer order. In contrast, in manufacturing firms product design and production is engineered prior to customer order, to achieve economies of scale and meet the needs of mass markets (Hobday, 2000). Second, in multi-product firms, the functional division of tasks promotes the efficient production of mass-produced goods. The functional managers allocate resources and coordinate business processes. In project-based firms, project managers often have equal or more status than functional managers in directing and coordinating personnel, finance and resources (Davies and Hobday, 2005; Hobday, 2000). This facilitates optimization at the project level, because projects compete for limited resources, thereby, limiting the optimized use of corporate capabilities. Third, the knowledge, capabilities, and resources of the firm are built up through the execution of projects. Project execution promotes the circulation of people from project to project and thereby cross-functional learning and knowledge transfer. However, there are little formal incentives for cross-project learning, information sharing and optimizing the use of established capabilities and resources across projects, because at the end of the project people are often assigned to a different type of project (Davies and Hobday, 2005). This complicates the transfer of relevant knowledge and capabilities from one project to the next (Prencipe and Tell, 2001; Winch, 1998). Furthermore, in most projects, these firms hire subcontractors or self-employed specialists to do (a part of) the job (DeFillippi and Arthur, 1998; Jones et al., 1997). Project-based firms, therefore, face complications in accumulating knowledge and using tacit knowledge, because they operate with a highly mobile workforce. Fourth, the customer usually has direct involvement in production and innovation processes (Hobday, 2000). In most project-based firms, customers specify the product concept and, sometimes, the production. The customer, often user or owner/operator, is directly involved as the project will tend to be critical to its business functioning, performance and profitability (Davies and Hobday, 2005). Direct customer involvement and the customized nature of the product/service create high levels of demand uncertainty and interdependence (Eccles, 1981; Jones et al., 1997). Consequently, each project has its own strategic targets geared to one specific product/service and customer rather than multiple related products (Davies and Hobday, 2005).

The characteristics of project-based firms diverge from the characteristics of the multi-product firm on which most strategic management literature is based. The multi-product firm is designed for mass production along functional lines to achieve economies of scale and scope (Hobday, 2000). In most strategic management literature the marketing department is, therefore, seen as the centre of strategy implementation. In project-based firms strategy implementation is likely to occur at the project level rather than at the business unit level.

Strategic management in project-based firms

In most studies on strategic management in project-based firms the resource-based view has been dominant (Davies and Hobday, 2005). The resource-based view argues that firms create competitive advantage through the possession of non-imitable resources (Penrose, 1959; Richardson, 1972; Wernerfelt, 1984). These resources are either tangible assets or human resources. Over time, firms develop and accumulate these non-imitable resources which form the technology and market base. A strong base enables a firm to adapt to the environment and diversify its operations. Projects are considered a flexible and efficient way of exploiting a firm's resources in existing and new technology and market bases. However, most of these studies focus on the corporate or business unit level. There is little empirical data on strategic management at the project level (Davies and Hobday, 2005).

The characteristics of a project-based firm suggest that the project level is the primary level in these firms. Strategies are organized around projects (Hobday, 2000). The project manager rather than the functional manager decides on resource allocation, based on the needs of its project. Furthermore, projects are temporary organizations with their own strategic objectives (Hobday, 2000). These temporary organizations can span different legal entities and customer involvement is usually high. These aspects are hardly recognized in the strategic management literature. Olson et al. (2005) have analyzed which strategic orientations at the operational level complement the business strategy. Their operational level is the central marketing department. Yet, most intelligence systems are designed to provide a broad, general understanding of a business's market, related markets and specific competitors (Prescott and Smith, 1987). In project-based firms, this general understanding will not suffice at the project level. The customized nature of production and varying composition of the project organization creates strong incentives for a project level approach. According to Prescott and Smith (1987) there are four main advantages in a project level approach. First, a project level approach is more focused, driven by the specific information requirements of the project and thereby more manageable. Second, the number and types of competitors typically differs across projects. Therefore, relative competitive strengths and weaknesses can be better assessed at the project level. Third, data collection is tailored towards the specific information requirements, increasing efficiency and lowering the cost-per-unit of useful information. Fourth, the results can be immediately integrated into strategy implementation.

These advantages have led Prescott and Smith (1987) to develop a framework for project-based competitive analysis. We follow Prescott and Smith and extend their framework to include customer, innovation and internal/cost orientations.

Conceptual framework

Prescott and Smith's (1989) framework consists of four interrelated steps: (1) project definition, (2) determination of project constraints, (3) implementation of analysis tasks, and (4) project recommendations.

Project definition refers to articulation of project objectives and how they secure or improve a firm's competitive position. The project objectives guide the collection of market, competitive, technological and cost information.

A clear understanding of time, financial, organizational, informational and legal constraints assists the project team members in determining a realistic approach to the project. Identifying constraints can help to recognize restrictions on actions and the information that can be collected. Furthermore, it helps to interpret the results of the information analysis.

Implementation of analysis tasks relates to different stages. Precott and Smith (1987) concentrate on competitors and define the following stages: identification of relevant competitors, critical success factors, information sources, analysis of competitors with respect to critical success factors, integration with other primary and secondary data.

Based on the results of the analysis tasks project recommendations are provided. These are action-driven and directed at achieving the stated objectives.

The steps are summarized in Table 7. Based on Olson et al.'s (2005) operationalization of customer, innovation and internal/cost orientation, we extend Prescott and Smith's (1989) framework to incorporate these dimensions. We excluded steps 2, determination of project constraints, and 4, project recommendations, because these steps are similar for competitor, customer, innovation and internal/cost orientations.

We will draw on this framework to analyze the coordination and integration of different strategic targets at the project level in road construction firms.

Road construction as a project-based industry

In this paper, we focus on one type of project-based firm, road construction firms. The road construction industry has several characteristics that need to be considered to assess the generalizability of this study. Road infrastructure, like energy supply and telecommunications, can be considered a large technical system. Large technical systems are "those complex and heterogeneous systems of physical structures and complex organizational routines that (1) are materially integrated, or 'coupled' over large spans of space and time, quite irrespective of their particular cultural, political, economic and corporate make-up, and (2) support or sustain the functioning of very large numbers of other technical systems, whose organizations they thereby link" (Joerges, 1988: 24). A key characteristic of large technical systems is the process of technical standard setting. This process guarantees that a set of standards and organizational practices co-evolve with the system to ensure the compatibility and interoperability of its numerous components (Markard and Truffer, 2006). A second key characteristic of large technical systems is the high degree of interdependence between their components. As a consequence, a change in one component may improve one part of the system, while negatively affecting other parts (Geyer and Davies, 2000). Third, all large technical systems have high-fixed costs of capital investments. Therefore, some form of control to secure efficient capacity utilization is a major determinant of system performance (Nightingale et al., 2003).

In most large technical systems there is a system builder that strongly affects the system to ensure aforementioned characteristics are addressed (Hughes, 1983). In most countries, the government as the owner of the road infrastructure performs the role of system builder. Therefore, the government largely determines the specifications of road infrastructure and future needs. Furthermore, the government has a public responsibility regarding the safety and accessibility of road infrastructure. This warrants extensive regulations about design to ensure safety, accessibility and compatibility (Nam and Tatum, 1988).

Table 7 Conceptual framework of strategy implementation at the project level[a]

Step	Competitor orientation	Customer orientation	Innovation orientation	Internal/cost orientation
Project definition	Understanding how competitors may influence the success of a given project.	Understanding what features of this technology customers perceive as unique.	Understanding how new technology may extend market opportunities and customer base.	Understanding how the project reduces operational costs.
	Identify those competitors relevant to the project.	Identify those customers relevant to the project.	Identify state-of-the-art developments relevant to the project.	Identify those cost drivers relevant to the project.
Analysis tasks	How can competitors and other stakeholders affect the project implementation?	How can targeted customers or other stakeholders affect project success?	Who are the relevant actors in the value chain?	How does this project improve our margins or our relative cost position?
	Are the benefits of this project directly observable for competitors?	What is the potential for follow-on contracts? How does this project adhere to future developments in customers' markets?	What are the uncertainties in technological and market development s and support infrastructure?	How does this project leverage our economies of scale and scope? How does this project increase the effectiveness of our business processes?
	What are the strength and weakness profiles of relevant competitors relative to the project success factors?	What are the strength and weakness profiles of this project relative to the features customers value most?	What are the strength and weakness profiles of relevant competing technologies relative to project success factors?	What are the strength and weakness profiles of this project relative to project success factors?

[a] This framework is based on the following literature: Prescott and Smith, 1987; Olson et al., 2005

The role of government as a system builder has several consequences for the strategic orientations of road construction firms. As the government articulates future needs, firms can be reactive in understanding customer needs. Government as a customer states in detail what it needs and performs its own assessment of economic and socio-cultural trends. Furthermore, government as a system builder has a considerable knowledge about the factors in the user environment that affect the success of new technologies. In addition, government as a system builder monitors technological developments in the industry and tries to keep pace with the forefront of technology. Consequently, government is a knowledgeable customer that signals to firms which technologies it considers valuable.

Methodology

We used a multiple case study design for theoretical replication (Yin, 2003). The research uses an embedded design (i.e. multiple levels of analysis) that includes an analysis of the technology projects and an analysis at the firm level. The projects studied are described in Table 8.

Sample

The case study involves three construction firms. There are several reasons why we considered road construction firms. First, road construction firms are key examples of project-based firms. Second, besides the provision of the physical product, infrastructure provision increasingly involves services such as design, financing, operating and maintenance (Ivory et al., 2003). The three firms were chosen based on the business strategies stated in their annual report. The firms were selected to match the three archetypes as defined by Walker and Ruekert (1987).

Firm 1, BAM Roads, is a division of the BAM Group which is the largest Dutch contractor with a turnover of over 7 billion euros and 30,000 employees. The BAM Roads division has a turnover of about 500 million euros (650 million USD) and employs about 1,750 people. BAM Roads' business strategy focuses on defending and consolidating existing market share and profitability ratios and seems risk averse. We anticipate that BAM Roads is a low-cost defender which puts emphasis on operational excellence and costs reduction.

Firm 2, Heijmans Infrastructure, is a division of Heijmans, which is a large contractor with a turnover of over 2 billion euros and over 9,000 employees. The Heijmans Infrastructure division is responsible for about a third of annual turnover. Heijmans is one of the five largest construction firms in the Netherlands and has the ambition of becoming a one-stop shop for their customers offering all services from early planning to exploitation and maintenance. Heijmans wants to span the whole value chain. Following this business strategy, we expect Heijmans to be a differentiated defender emphasizing customer value to increase profitability.

Firm 3, Ooms Nederland Holding, is a medium-sized construction firm. It has a turnover of about 150 million euros and employs 500 people. It is a family-owned enterprise and the owner values new technology. We expect Ooms Nederland Holding to be a prospector, operating in specific niche markets to translate its technological advantages into profitable business propositions.

Table 8 Brief project descriptions

	Projects		
BAM Wegen	Kjellbase: modified stone mastic asphalt with high void ratio and thick bitumen film; advantages are increased stability and durability.	Drainway: modified asphalt binder with sand as filler and high void ratio; used to repair holes in porous asphalt.	Away with Noise: a new quiet pavement design which consists of a concrete honeycomb layer filled with rock wool, an open concrete slab to redistribute the force and a porous asphalt layer on top.
Heijmans Infrastructure	Torbed: technology based on heating or pasteurization of food and spices; redeveloped to incinerate tar from tar-containing asphalt mineral.	Dynamic Road Marking: consists of light emitting road marking units that can delimit a lane or access road by turning the lights on or off.	Re-use of scrap material: development of new asphalt mixtures with higher percentages of re-used asphalt scrap material.
Ooms Nederland Holding	Sealoflex: polymer modified bitumen for heavily loaded asphalt pavements.	Road Energy Systems: system that uses asphalt road as a low temperature energy source to heat or cool buildings.	

Data sources

We used several data sources: (1) quantitative and qualitative data from open and semi-structured interviews, (2) archival data, including company websites, business publications, contractual arrangements, design specifications, newspaper articles and newsletters and (3) a workshop with senior management and R&D managers from each firm to discuss the findings of the projects studied.

We conducted about 61 interviews over a two year period. The interviews varied from 50 to 150 minutes, with an average interview taking about 90 minutes.

Before, the interview, a questionnaire was sent out to the interviewee for him or her to prepare for the interview. During the interviews, notes were made and these notes were later used to type out the interview transcripts. To avoid excluding findings, we asked the respondent to add any events that he or she found relevant for the project outcome in addition to the range of topics asked. The topics were adapted to each interviewee's specific role in the technology development project and to their contextual settings.

Unless the interviewee objected, the interview was recorded and the recordings were used to supplement the interview transcripts. Furthermore, interviewees were also asked to provide documents or other written or electronic material to illustrate or complement their statements. In each interview, we noted the interviewee's name, date, place and the duration of the interview. Each interview transcript was finally sent by e-mail to the relevant interviewee for their remarks and consent.

We spoke to all the project team members and the relevant senior managers of the firms involved in the projects. The individual case descriptions were discussed with senior R&D managers so that realistic descriptions of the developments could be achieved.

All the projects are studied retrospectively. We asked the senior R&D managers which projects they found to be representative of their technology development activities. We chose the technology projects as the primary unit of analysis, because this allows us to link the intended strategy of the firm with the implementation of the strategy. The characteristics of the projects are summarized in Table 7.

Operationalization

In this study we focus on four main constructs: customer orientation, competitor orientation, innovation orientation and internal/cost orientation. We adapted the measures used by Olson et al. (2005) for customer, competitor and internal/cost orientation. Customer orientation was measured in terms of (a) close collaboration with lead users, (b) actively seeking additional and unarticulated customer needs and (c) signaling new development in customers' markets. Competitor orientation was measured as: (a) regular assessment of key competitors' strengths and weaknesses, (b) rapid response to competitive actions, (c) sharing of information concerning competitors throughout the organization and (d) identifying areas where competitors succeeded or failed. Internal/cost orientation was measured through: (a) promoting economies of scale or scope, (b) constant concern for reduction of operating costs and (c) monitoring of effectiveness of key business processes.

The measurements for innovation orientation are derived from Gatignon and Xuereb (1997) and Narver et al. (2004). They entail: (a) products are at the state-of-the-art, (b) sophisticated technologies are used in product development and (c) first on the market with new technology. Interviewees were asked to clarify how they acquired and used information of customers, competitors, costs and innovation in the projects studied.

Data analysis

The data analysis was done in several steps following Eisenhardt (1989) and Brown and Eisenhardt (1997). First, we built individual case descriptions of the transcripts and archival data, then we grouped all the transcribed responses by events, and finally, secondary sources relating to the projects were reviewed as well. Using this information, a case description of each project was written. To reconstruct developments over time, the case description was written in chronological order. Each individual description is about 30 pages in length.

Second, when the individual case descriptions were completed, a within-firm, cross-case analysis was conducted to look for patterns in the observed behaviour. Following Eisenhardt (1989), different categorizations were used to find similarities and differences across the projects. Then, we did a cross-firm analysis to examine similarities and differences across firms to see if there were any distinguishable ways of managing and commercializing technology. For the cross-case and cross-firm analysis we used the methods described by Miles and Huberman (1994), such as partially-ordered matrices.

Case Analysis

In the following subsection we show the results of the cross-case analysis within each firm. We discuss the observed behavior regarding the source of competitive advantage, the targeted market and the intended product-market change. The analysis of the individual projects is shown in Table 9. In the cases, we will address how project-based firms acquire and use information about customers, competitors, innovation and cost management to meet the strategic targets of their projects.

Based on their annual report we have expectations about which information the firm is likely to emphasize in project definition and analysis. The annual report states the intended strategy of the firm and we assess whether the actual behavior in terms of project definition and analysis corresponds with this intended strategy.

BAM Roads

BAM Roads, based on its business strategy, has been typified as a low-cost defender. In the set of strategic orientations, competitor and internal/cost orientations are anticipated to be dominant. Therefore, we expect BAM Roads to emphasize competitor analysis and the improvement of operational processes.

Project definition

Within BAM Roads we studied three technology projects. In the *Kjellbase* project, BAM Roads was approached by a customer to develop new asphalt based on a coarse-grained mixture. The customer believed that the Kjellbase mixture would be superior to existing products. The new coarse-grained mixture could be applied in base layers in roads with high traffic loads, creating a new product for highly durable base layers. Existing road mixtures suffered from rutting and this problem would increase in the years to come. BAM Roads was willing to invest in the development, because it was allowed to pave a road segment with this new mixture. In identifying relevant customers, BAM Roads focused on this single customer. The opportunity to pave a road segment without competitive bidding offered sufficient slack to be able to develop the new mixture.

In the case of *Drainway*, BAM Roads decided to expand its business to green areas. In identifying relevant state-of-the-art technologies, it chose a porous epoxy-sand pavement, based on a German technology. The technology was used successfully in Germany. However, in the Netherlands, this application failed because of premature cracking and high costs. BAM Roads, faced with the idea of being stuck with a useless technology, thought of a new application. This new application was inspired by a problem with porous asphalt, namely, raveling. This caused premature maintenance and the only solution available at that time was to cut out the raveled asphalt and pave new surface layers. Applying a thin layer of an epoxy-mineral mixture on top of the fretted asphalt would reduce maintenance costs and hardly disturb traffic, which would be valuable to the customer and create a niche market with little rivals.

Away with Noise started in response to a design competition held by the Dutch Highways Agency. In this competition, the Highways Agency asked for a technology that would substantially improve noise reduction compared to the existing silent pavements. As the Highways Agency was the most important customer of BAM Roads, it felt obliged to develop a technology to meet these new requirements. During the initial tests, it became clear that the new pavement performed extremely well at lower speeds. Therefore, municipalities could be an additional market, but BAM Roads focused on the Highways Agency and decided to neglect the applicability in municipalities.

Table 9 Analysis of individual projects

		Observed behavior
Projects	*Project definition*	*Analysis tasks*
Kjellbase	Focus on specific customer and the feature -improved durability- that this customer valued.	Several actions to facilitate adoption: - Mixture design was declassified. - Examples of contract specifications were made available to customers. Adheres to future customer's demand for more durable roads.
Drainway	Permeable epoxy-sand technology would create a new market for the repair of porous asphalt. Unique compared to other slurries.	Application for porous asphalt had to be approved after extensive testing by Highway Agency. Strengths compared to existing technologies: - Reduced maintenance costs for customer - Reduced construction time means less nuisance for motorists. Failed to track market development.
Away with Noise	Focus on Highways Agency, although the high level of noise reduction at lower speeds offered the opportunity to expand to municipal roads.	Failed to assess the potential for follow-on contracts. As a new potential market segment emerged, this opportunity was not taken. Project success was made dependent upon decisions of Highways Agency.
Torbed	Customer required the development of a technology that would remove tar from tar-containing asphalt and could be applied on a large scale.	Analysis of how stakeholders can affect success: - Roads owners with tar-containing road surfaces had to be compelled to offer tar-containing asphalt. - Opportunities for re-use of cleaned minerals had to be ensured. - User would have to adapt its asphalt production plant to process tar-containing asphalt - Market for thermal processing of tar-containing asphalt had to be created through regulation.

Analysis tasks

For the production of *Kjellbase*, cellulose fibers had to be added to ensure the mineral and bitumous binder would mix. BAM Roads cooperated with a large supplier of cellulose fibers. After Kjellbase was developed and tested, the customer wanted to have the specification of the mixture for future contract specifications. As such, the customer would not depend on a single supplier for Kjellbase.

Table 9 Analysis of individual projects continued

		Observed behavior
Projects	*Project definition*	*Analysis tasks*
Dynamic Road Marking	Heijmans Infrastructure tried to understand what features were valuable to customer. Supplier focused on how dynamic markers could extend its market base.	Uncertain whether light is legally allowed as road marking Lights would increase flexibility, but are more vulnerable. Visibility under all light conditions is costly. Switch board of dynamic road marking had to be incorporated in existing dynamic route information and monitoring system. Increased maintenance costs. Partially substitute existing road marking products.
Re-use of scrap material	Increase of scrap material in base layers would reduce storage costs.	Increased economies of scope; how to apply scrap material in more products. Dependence on customer to use an increased amount of scrap material in different projects. Adjustment of production facilities to increased amount of scrap material. No clear picture of actual storage costs.
Sealoflex	Understanding of polymer modification to improve durability of asphalt pavements.	Existing pavements distort under repetitive stress and are vulnerable to ultraviolet sunlight. Polymer modified bitumen extends market to airports, ports, industrial areas and roads that use concrete pavements.
Road Energy Systems	Understanding of low temperature heating to use asphalt collector as energy supply in buildings. Number of asphalt pavements is huge potential for energy supply.	Existing low temperature heating systems lack a regenerator that can produce cold and heat. Extends market to durable and environmental friendly energy supply.

Although this would weaken the competitive position of BAM Roads, it was confident about its knowledge and skill advantages over rivals. The mixture specification on its own was no guarantee for a well-produced and applied mixture. In assessing the potential for follow-on contracts, BAM Roads agreed to this condition. It expected that declassifying the mixture specification would increase the diffusion and adoption of the mixture. Furthermore, BAM Roads expanded its range of relevant customers and sent the mixture specification to all road administrators who were interested. The mixture specification included an example of how the mixture could be specified in a standardized contract. As such, BAM Roads pursued an active strategy to facilitate the adoption of its technology.

When identifying relevant actors in the value chain for *Drainway,* BAM Roads realized it had to cooperate with a competitor to realize a sufficient scale and persuade its customers to apply the technology. Therefore, it used an existing joint venture with a competitor to introduce the new technology in the Netherlands. Furthermore, the new application meant that a thorough understanding of the technological background of epoxy as a binder had to be achieved. This understanding was necessary to assess uncertainties in technological and market developments. BAM Roads tested five different epoxies in the lab before applying it to a test section. The epoxy-mineral mixture had to be slightly elastic to match the behavior of asphalt surfaces. The R&D manager stated that the chosen epoxy performed well, but absorbed water, an unknown phenomenon. Because of this problem the joint venture switched to a bitumous binder, but these technological problems caused a significant delay in the market launch and consequently, a competitor was able to introduce a similar product two years before BAM Roads.

For *Away with Noise*, BAM Roads consulted an engineering firm which specialized in noise and vibration research. Furthermore, it contacted a concrete manufacturer when the design was chosen. The new design achieved a noise reduction of eight decibels, three decibels more than existing technologies. Moreover, this reduction was achieved at 50 km per hour and higher, whereas existing technologies perform best at only 70 to 80 km per hour. After the first test project, BAM Roads had no clear plans about how to reach the stage of prototype development and market launch. BAM Roads expected the Highways Agency to support the development and market launch of this technology. Although BAM Roads had made a detailed technical plan for the first test project, it lacked a business model that assessed relevant market segments, opportunities for exploitation and the profit potential. The expectation was that the Highways Agency would create a market for the new generation of silent pavements. But the Highways Agency had no resources to support the development and considered the technology of Away with Noise as being too radical; the risk of failure was thus too high. Subsequently, BAM Roads stopped the development of this promising technology as the targeted customer was unwilling to purchase it.

BAM Roads failed to make a plan to acquire follow-on contracts and assess other market segments. It made itself dependent upon the decisions of the Highways Agency.

Summary

We expected BAM Roads to emphasize the improvement of operational processes and to analyze the strengths and weaknesses of relevant competitors. Counter to this expectation, the projects studied showed a focus on customer requirements and opportunities to diverge into new markets.

The divergence between intended and actual strategic behavior seemed a consequence of the strong relationship between technology and business projects. In two of the projects studied, BAM Roads could incur most of the development costs through the execution of a project without competitive bidding or the rewards in the design competition. In addition, the R&D department of BAM Roads had considerable autonomy. The R&D department of BAM Roads had a fixed budget for improving products and operations. As long as the investments could be covered with this budget, the head of the department could invest in new technology. Consequently, the head of the department could work relatively autonomously, thereby, deciding in which direction to expand the technology base.

Furthermore, this autonomy provides the freedom to outsource R&D and spread risks and costs. BAM Roads outsourced part of its R&D to compensate the lack of capabilities needed to develop new products and expand to new markets. In the Drainway project, BAM Roads spread its risks and costs through an existing joint venture with a competitor. In the Kjellbase project, BAM Roads worked with a supplier of cellulose fibers and a specialized engineering firm.

Although BAM Roads was able to create the necessary conditions for expanding its technology base, it failed at expanding and consolidating its market base. The introduction of the new products was not the anticipated success. In the Drainway project, BAM Roads focused predominantly on technical problem-solving. It failed to make an assessment of relevant competing technologies and how Drainway affected business processes. The high cost of epoxy as a binder would have rapidly eroded the competitive advantage of Drainway, when alternatives emerged. Furthermore, the application of an epoxy binder on a large scale would impose stringent conditions for production control to ensure product quality.

Although most of the projects started as a customer order, the customer was hardly involved in the development process. In the Kjellbase and Away with Noise projects, BAM Roads consulted its targeted customer, but failed to assess the factors in the user environment that could affect success nor did it assess the potential for follow-on contracts. BAM Roads had limited capabilities in positioning its new products as unique, restraining the success of the technologies studied. Consequently, these products were not a commercial success. Finally, it depended on external technical sources for technology development.

Heijmans Infrastructure

Following the business strategy in its annual report, we anticipated Heijmans Infrastructure to be a differentiated defender. Therefore, we expected Heijmans Infrastructure to emphasize future demand, unique selling points and the potential for follow-on contracts in its technology projects.

Project definition

In the *Torbed* project, Heijmans Infrastructure was asked by the Highways Agency and the Ministry of the Environment to develop a processing technology for tar-containing asphalt. The government wanted the complete removal of tar from road construction materials. It was willing to create a market for the processing of tar-containing asphalt, if Heijmans Infrastructure would develop a technology together with its main competitors. The government had to avoid creating a natural monopolist and in this way Heijmans Infrastructure could also spread its costs and risks over its partners. Although national government initiated the demand for this technology, the main customers would be regional and local road agencies. These agencies would be compelled to process tar-containing asphalt by law. As such, a regulated market of a considerable size would be created.

Dynamic Road Marking was developed as a response to a design competition held by the Highways Agency. This competition challenged firms to develop a technology that would temporarily increase the capacity of existing road infrastructure. A more efficient use of infrastructure could lessen traffic jams. Thus, this project is a response to an expressed customer need that also entailed the development of a new technology. Heijmans Infrastructure saw the Dutch Highways Agency as the single customer for this technology. Applications on a local scale or on an international scale were not considered. Heijmans Infrastructure focused on the Dutch home market and highways.

The *Re-use of scrap material* project was started to reduce the storage costs of scrap material and to avoid any additional investment in storage facilities. This project had to increase competitive advantage through the use of scrap material in a variety of base layers. The main driver of this project was to reduce operational costs and increase the effectiveness of business processes.

Analysis tasks

Heijmans Infrastructure started the *Torbed* project in 1992 with the use of existing technology based on chemical extraction with toluene. It planned to build a processing plant. But, chemical extraction had some drawbacks: its high costs and the residual waste of the extraction fluid. For the government these drawbacks were unacceptable. In 1998, Heijmans Infrastructure changed to a new technology which had been developed for heating or the pasteurization of food and spices. Heijmans Infrastructure experimented with this so-called Torbed reactor to remove tar from roofing material. This new technology had not been used in the cleaning of minerals and Heijmans Infrastructure would be the first to adapt the technology to this application. For the technical development, Heijmans Infrastructure depended on one supplier, a small firm, which was the only licensee of the Torbed technology in the Netherlands at the time. But, the supplier was found to have insufficient financial resources to participate in a long-term technology development project. Furthermore, the intended users of the new technology, the asphalt production plants were hesitant to buy a Torbed for two reasons. First, the reactor was technically complex creating a liability in asphalt production. Second, the processing of tar-containing asphalt meant that asphalt plants had to adhere to new regulatory requirements. In addition, Heijmans Infrastructure had to make arrangements with the government about who had to supply tar-containing asphalt and allow the re-use of cleaned mineral in new hot asphalt. Heijmans Infrastructure concentrated on the latter to reduce the uncertainties about market development and support infrastructure. However, Heijmans Infrastructure forgot other relevant actors in the value chain, such as the asphalt production plants that were the actual customers. Therefore, it had an incomplete picture of the stakeholders that affected project success.

In the *Dynamic Road Marking* project, respondents indicated that the idea of lights replacing conventional marking popped up as an ideal solution. By turning lights on or off motorists could see three or two lanes. Heijmans Infrastructure had no expertise on lighting equipment and set up a collaborative R&D arrangement with a large electronics firm. Heijmans Infrastructure and its supplier won the design competition and were allowed to make a demonstration project. In the subsequent development stage, Heijmans Infrastructure and its supplier were to transform the first prototype into a commercial prototype that could resist traffic loads. In this technical development stage, Heijmans Infrastructure was to develop the machinery and technology to install the marker in the asphalt road and the electronics firm would develop the marker including the electronic support systems (power supply, control panel). The supplier saw dynamic marking as an opportunity to expand its market base, whereas Heijmans Infrastructure perceived dynamic marking as a niche within conventional marking. As it turned out, the electronics firm took the lead as it was far more experienced in development projects. Consequently, the strategic targets of Heijmans Infrastructure and its supplier diverged. Where the supplier focused on state-of-the-art technology and uncertainties in technological developments, Heijmans Infrastructure concentrated on the requirements of the Highways Agency. The electronics firm made an extensive business case with international ambitions, whereas Heijmans Infrastructure focused on the Dutch home market and the Highways Agency.

In the *Re-use of scrap material* project two options were identified to reduce storage costs. First, Heijmans Infrastructure could negotiate an exemption for each awarded method-based contract that restricted the use of scrap material. Second, Heijmans Infrastructure could use more scrap material in performance-based contracts that do not prescribe the type of base layer. However, in both situations the application of higher levels of scrap material had to be allowed by the customer. In the first case, the customer had to give a formal approval. In the second case, Heijmans Infrastructure had to convince the customer of the equal performance of the mixture with higher levels of scrap material. Furthermore, Heijmans Infrastructure had to adjust its production facilities to cope with the increased levels of re-used scrap material. Despite the incremental nature of this technology, the necessary adjustments to production facilities were expensive. In addition, the lack of information about the actual increase in scrap material and the effect on storage costs made it difficult to assess the impact on operational costs. Therefore, the benefits of this technology project were unclear. Some of the respondents suggested that the high sense of urgency was created by the production plants without a proper assessment of actual costs and the fluctuations in scrap material. This seems to be supported by the fact that after six months production plants reported a shortage of scrap material.

Summary

We anticipated Heijmans Infrastructure to concentrate on future developments in its customers' markets and the features its customers value most. In two of the three cases, Heijmans Infrastructure reacted to specific needs of the customer. In both the *Torbed* and *Dynamic Road Marking* project, Heijmans Infrastructure focused on the requirements that were valued most, the complete removal of tar and a temporary increase in road capacity. To meet these requirements, Heijmans Infrastructure first thought of conventional technology. In the Torbed project, it had experience in using toluene as a solvent. In the Dynamic Road Marking project, the use of different colors of conventional marking was the first idea. The conventional technologies were abandoned for more sophisticated technologies. However, Heijmans Infrastructure was unfamiliar with these new technologies and depended on suppliers to develop the technology. The outcomes of the Torbed and Dynamic Road Marking project showed that Heijmans Infrastructure had insufficient experience in technology analysis tasks. It concentrated on the customer and related stakeholders, but lacked the capabilities to assess the technological uncertainties and the necessary support infrastructure. Therefore, Heijmans Infrastructure misinterpreted the technical feasibility of these projects. Owing to the underestimated technical problems in both the Torbed and Dynamic Road Marking project it failed to convince the user/customer of the unique features of this technology.

In third project of Heijmans Infrastructure, the focus was on operational costs. However, the R&D department lacked the information to assess the relevant cost drivers and develop cost-effective options. Instead, it tried to extend the use of scrap material in existing products. The effect of these options on business processes seemed to increase overall operational costs rather than reduce costs.

The analysis shows that Heijmans Infrastructure understood customer needs and how customers use its products and services. However, to meet these customer needs it had to expand its technology base. For this, Heijmans Infrastructure depended on suppliers. These suppliers were more knowledgeable and, therefore, became leading in the project. Heijmans Infrastructure was not capable to understand the technological uncertainties and assess the strengths and weaknesses of competing technologies.

Ooms Nederland Holding

Ooms Nederland Holding is a medium-sized firm focused on innovative niche markets. The owner values technology development and actively seeks to acquire new knowledge and develop really new technologies. Therefore, we expected Ooms Nederland Holding to pursue new market opportunities and identify state-of-the-art technologies.

Project definition

The main advantage of *Sealoflex* is that it extends the life of asphalt pavements by 30 percent compared to existing binders which is extremely important to airports and other privately operated facilities that compete on availability. Sealoflex extended the market of Ooms Nederland Holding to airports. Yet, contractors and public road administrators were less enthusiastic about polymer modification. Existing regulations and contract specifications did not appreciate the increased performance of polymer modification. Moreover, polymer modification is more expensive than existing asphalt binders and difficult to mix with the raw material during production.

In the *Road Energy Systems* project, Ooms Nederland Holding used an asphalt collector as source of energy for cooling and heating buildings. This technology could save up to 50 % in energy consumption with the accompanying reduction in CO_2 emission. This was also a new market for Ooms Nederland Holding.

Analysis tasks

In both projects, Ooms Nederland Holding acquired the knowledge itself through extensive R&D activities. Sealoflex and Road Energy Systems are projects in which Ooms Nederland Holding acquired a considerable insight into the technology by making computer models to simulate the technologies' behavior in different circumstances. Based on this knowledge, Ooms Nederland Holding could rapidly improve the technology using lab tests and optimize the design for in-situ tests. In the Sealoflex case, the understanding of polymer modification allowed Ooms Nederland Holding to differentiate between high and medium performing binders to serve different market segments. The development of Sealoflex also meant that Ooms Nederland Holding became a supplier. In the Netherlands, Sealoflex is sold through an external sales office. In other countries, Ooms Nederland Holding has licensees that produce and sell Sealoflex.

In the *Road Energy Systems* project, Ooms Nederland Holding developed an asphalt road that included a grid with piping. The grid performed as structural element in the asphalt road. A finite element model was used to predict the effect of traffic load and optimize the design. For knowledge and resources regarding low temperature heating systems, Ooms Nederland Holding needed the help of a specialized engineering firm and a fitter. Their knowledge was necessary to connect the asphalt collector to the buildings and aquifers in which hot and cold water is stored. After the first two projects, the specialized engineering firm abandoned Road Energy Systems as the market opportunities were unsatisfactory.

Understanding the technology is not enough for project success. Ooms Nederland Holding also had to gain insight into the market for sustainable energy systems. The main advantage of an asphalt collector is that it can deliver both cold and heat, while most competing systems cannot and deplete the cold or heat aquifer. However, the market for durable energy is complex and a Road Energy System required large investments in hardware. Respondents indicated that every customer asked two questions: "who is going to pay?" and "who will exploit Road Energy Systems?" The smaller size of Ooms Nederland Holding restricted its financial resources and thereby the scale of the projects they could build. After six projects, Ooms Nederland Holding realized that it did not have to do everything on its own and made arrangements with an energy provider and a corporate investor to help exploit Road Energy Systems.

Summary

The projects of Ooms Nederland Holding, confirmed that it is a prospector firm in which the innovation orientation is dominant at the project level. The studied projects resulted from the will to acquire a thorough technological background of the technologies. Ooms Nederland Holding used various means to understand the basic mechanisms of the technology and the ways to manipulate them. As a result, it knew how to differentiate the technology to match different performance levels. However, the analysis of the two projects suggests that the capabilities to translate the technology in a valuable product/service for the customer are underdeveloped. In both cases, Ooms Nederland Holding applied a trail-and-error approach in promoting the features of the technology. In both projects, it emphasized features that were not considered relevant or unique by the targeted customers. During the market launch and first projects, Ooms Nederland Holding understood it had to stress different features and address other departments within the targeted customers.

In the Sealoflex case, Ooms Nederland Holding cooperated with an external sales office to overcome these problems. The external sales office functioned as the marketing and sales department that Ooms Nederland Holding did not have. As such, it used the external sales office to gather an understanding of the customer needs and the factors in the user environment that affect project success. In the Road Energy Systems project, Ooms Nederland Holding realized along the way that despite its technological background, it lacked the resources and knowledge to span the whole value chain. Again, it needed others, such as a sales office and a corporate investor to understand the factors in the user environment that affect success and how to deal with them.

Cross-case Analysis

The cross-case analysis of the projects studied serves two goals. First, we examine the strategic orientations in the projects. Second, we assess whether the intended and actual strategic orientations match. Table 10 provides an overview of the effect of the difference between the intended and actual strategic orientations at the project level.

Table 10 Implications of various strategic orientations at project level

	Business unit level	*Project level*	*Consequences*
BAM Roads	Internal/Cost orientation	Strong customer involvement affects strategic orientation at project level, resulting in customer orientation.	- Limited capabilities in assessing user environment. - Limited understanding of market potential. - Dependence on external technology sources.
Heijmans Infrastructure	Customer orientation	Strong customer involvement resulted in a reactive customer orientation.	- Limited capabilities in assessing market and technological uncertainties; - Limited capabilities in discovering additional customer needs and anticipating developments in the user environment.
Ooms Nederland Holding	Innovation orientation	Limited customer involvement resulted in an innovation orientation that lacked an understanding of the strengths and weaknesses of relevant competing technologies.	- Limited capabilities in conducting a market and competitor analysis; - Limited understanding of the value chain.

Project definition

In both defender firms, project definition seems to be led by the opportunities of short term gain. In four of the six projects studied within these firms, the opportunity to acquire a project or divest a large portion of the development costs led them to start the project. Consequently, the strategic targets of the customer rather than the firm's business strategy affected the definition of relevant objectives, constraints and resources.

This behavior had several consequences. First, this dependence on the strategic targets of the customer led to reactive behavior at the defender firms. Whereas Ooms Nederland Holding actively sought new market opportunities, BAM Roads and Heijmans Infrastructure waited for a customer order to develop a new technology.

Second, BAM Roads and Heijmans Infrastructure depended on suppliers to develop the technology. Their lack of competence in assessing uncertainties in technological and market development and the support infrastructure caused technical problems and delays. In the case of Heijmans Infrastructure, the suppliers even took the lead in the technology projects. This complicated the project definition in terms of specifying relevant market, competitive, technological and cost information.

Analysis tasks

The projects studied suggest that Ooms Nederland Holding and Heijmans Infrastructure stayed close to their expected strategic orientation. Ooms Nederland Holding emphasized an innovation orientation and Heijmans Infrastructure a customer orientation. Consequently, the corresponding analysis tasks were present in these firms. Ooms Nederland Holding had capabilities in understanding how new technology could extend its market opportunities and customer base. Furthermore, they had personnel competent of identifying state-of-the-art developments and develop new technologies in-house. Likewise, Heijmans Infrastructure had developed capabilities in understanding relevant features and how customers can affect project success.

However, these firms lacked some capabilities in their respective orientations. Ooms Nederland Holding faced difficulties in identifying the relevant actors in the value chain and the interdependencies among these actors. Furthermore, it assessed the strengths and weaknesses of relevant competing technologies, but had an incomplete picture of the project success factors.

Heijmans Infrastructure had trouble in assessing the influence of other stakeholders besides the customer. Furthermore, its reactive behavior limited its competence in anticipating future developments in its customers' markets.

In contrast, BAM Roads applied a customer and innovation orientation in the technology development projects studied that mirrored the expected internal/cost and competitor orientations. The projects studied showed the pitfalls of a divergence between an intended and an actual strategic orientation. BAM Roads had limited capabilities in assessing the potential for follow-on contracts. Based on the opportunity to recover the costs in a single project and within the R&D department's budget, a project was started.

Furthermore, BAM Roads seemed to have insufficient understanding of how customer or stakeholders could affect project success. In the Kjellbase and Away with Noise projects, BAM Roads made itself dependent on a single customer and made no assessment of other relevant customers and market segments. In addition, BAM Roads depended on external technology sources.

Main findings

In the projects studied the strategic objectives of the individual projects seem leading in the strategic orientation chosen. The corporate strategy is hardly considered in developing and positioning a new technology. Furthermore, the focus on individual projects complicates the positioning of technologies vis-à-vis future developments.

Another main finding is the dependence of the firms studied on external technology and market intelligence. All three firms needed others to assess market opportunities or develop new technologies. This highlights the importance of coordination and integration capabilities for project success.

Discussion, Implications and Future Research

In road infrastructure, government as the main customer has a substantial influence on technology development. As mentioned earlier, government has a public responsibility regarding the safety and accessibility of road infrastructure. This warrants extensive regulations about design to ensure safety, accessibility and compatibility (Nam and Tatum, 1988). Furthermore, it monitors technological developments in the industry and tries to keep pace with the forefront of technology. As expected this strong position of government as the main customer, has made firms reactive in understanding customer needs. Notably, BAM Roads and Heijmans Infrastructure as the defender firms were reactive in their technology development activities. They perceived technology projects as one-offs and had little incentives to direct their technology development activities.

However, in recent years government tries to involve suppliers in design and operational tasks. Increasingly, the delivery of infrastructure and other large capital goods includes financing, operating and maintaining a performance level over the capital good's lifetime (Ivory et al., 2003). Consequently, the time horizon of the temporary project organizations shifts. Therefore, contractors are less depended on erratic demand and can employ more long-term business models to operate the capital goods they produce.

Ooms Nederland Holding can be seen as a road construction firm that could thrive under these new conditions. The increased freedom in contract specification will allow it to employ new technology ahead of competition and to grasp new market opportunities. Therefore, the change in contract specification seems a necessary condition for firms to expand their focus from a single project to several related projects. This is consistent with existing literature on strategic management in project-based firms (e.g. Davies and Hobday, 2005). To increase efficiency and use projects in achieving a firm's strategic objectives, Davies and Brady (2000) have argued that project-based firms at best achieve "economies of repetition". In carrying out similar projects at higher levels of efficiency rather than considering each project as a one-off, firms can try to repeat solutions developed in earlier bids or projects, creating new business. Davies and Hobday (2005) indicate that when similar bids and projects are repeated, recognizable patterns of organizational behavior occur. Besides standardizing repeatable organizational routines, project-based firms can also benefit from the recombination of capabilities, routines and components developed in previous projects. Analogous to the modularization of mass-produced goods and the use of product platforms, project-based firms can combine various standardized elements to serve unique customer needs.

According Davies and Hobday (2005), systems integration capabilities are important in creating "economies of repetition". These capabilities allow a project-based firm to integrate diverse disciplines, partners and knowledge in a project to achieve specific strategic objectives. Our case study findings showed that the firms were dependent on suppliers or other actors in the value chain. All firms collaborated with external parties to complement their own capabilities. Both Heijmans Infrastructure and BAM Roads collaborated with others to extend their technology base to meet the requirements of their existing customers. Ooms Nederland Holding cooperated with others to market and sell its new technologies. Systems integration supposes that the firms that integrates and coordinates, is knowledgeable about the core technology (Davies and Brady, 2000). Our cases indicate that the use of external parties can impede the accumulation of knowledge about project execution and the development of routines for systems integration.

Beyond the project level, Davies and Hobday (2005) suggest that senior management integrates project activities through program management techniques. However, in the firms studied we did not encounter program management techniques for technology development projects. The R&D departments within BAM Roads and Heijmans Infrastructure seemed to be organized to support the primary business processes, such as bidding and project execution. Most of their technology projects, therefore, emanate from the short-term needs of business projects. In part, this can be explained by the fact that a product is developed after customer order (Davies and Hobday, 2005). The design and/or production process of the product is engineered to the specific needs of the customer. In contrast, multi-product firms' design and production processes are developed and engineered prior to large-scale production.

This suggests that program management techniques become feasible when project-based firms have sufficient opportunities to employ new technology in several, future business projects. When this condition is met, investing in program management techniques could bridge the gap between the project and corporate level, as put forward by Davies and Hobday (2005). Building on the new product development literature, program management could act as a focusing device in linking corporate technology objectives to a firm's markets, products and technologies. It helps to assess the strategic value of a project and the potential to use a technology in different products and services. As such, it helps to choose among different projects and allocate resources (Cooper et al., 1999; Tikkanen et al., 2007).

Taken together, the project-based firms studied seem to choose their strategic orientation in technology development projects based on the specific needs of the project with little consideration of the business strategy. On the one hand, this can be explained by the way their customers specify their needs. Government is a knowledgeable customer that determines the agenda of relevant needs and technologies. This has made firms reactive in their technology development activities. On the other hand, program management techniques that can align project and corporate objectives are lacking in these firms. Although the firms studied use multi-project planning in the allocation of resources for their business projects, program management needs to be developed. Therefore, these firms lack this competence to strategically guide their technology development projects. However, the increase in the use of performance specification and the bundling of services in infrastructure allow for a cross-project perspective in developing and exploiting new technologies. This will positively affect the usefulness of program management techniques.

Theoretical and managerial implications

This study has enriched the literature on strategic management in project-based firms. Previous studies on strategic management in project-based firms have mainly focused on the resource-based view and the corporate level. In this study, we examine strategy implementation at the project level. We have used the strategic orientations described by Olson et al. (2005) to examine strategy implementation at the project level. Contrary to multi-product firms, project-based firms lack a functional marketing department that can coordinate and integrate the simultaneous use of various strategic orientations. Our results suggest that project-based firms choose their strategic orientation based on the specific needs of individual projects. This is consistent with earlier theorizing about the project-based firm (Hobday, 2000; Tikkanen et al., 2007). This implies that business strategy implementation in project-based firms needs other mechanisms to integrate and coordinate the simultaneous use of various strategic orientations. Several scholars suggest that program management is a central mechanism (e.g. Davies and Hobday, 2005; Tikkanen et al., 2007). Furthermore, senior management in project-based firms has to perform the coordinating and integrating tasks that are carried out by the functional marketing department in multi-product firms (Davies and Hobday, 2005).

Another implication is that the results suggest that project-based firms do not necessarily have sufficient understanding of customer needs to anticipate future needs in technology development activities. Blindenbach-Driessen and Van den Ende (2006) argue that project-based firms have a well-developed understanding of their customers' needs, because they work closely with customers in business projects. Our case studies indicate that the project-based firms studied are reactive and face difficulties in repeating solutions to create new business. Furthermore, external sources of technology such as suppliers and engineering firms are necessary to complement the capabilities of the road construction firm. These complementary capabilities relate to both the technology base as well as the capabilities to diversify into new markets. The observed lack of capabilities in anticipating future needs is not surprising. It can be attributed to the dominance of method-based specification in construction. In road construction, the government as an owner and operator has largely determined the specifications of road design. Consequently, construction firms can be reactive in understanding customer requirements. Therefore, these firms have little incentives for cross-project learning to recombine developed capabilities, routines and components in new projects and new lines of business. However, changing customer needs in the provision of large infrastructure will ask for additional skills such as performance measurement and life-cycle costing, and managing change and listening to customers (Davies and Hobday, 2005; Ivory et al., 2003).

Limitations and future research

This study has shown that there is still a great need for research on strategy implementation in project-based firms. This paper suggests that the strong customer involvement in defining the scope of technology development projects affects (a) the technologies and capabilities that these firms develop and (b) the competitive strategies that they use. Although this study focused on a key example of project-based firms, a limitation is that we only considered road construction. This industry differs in market and technological characteristics from other project-based industries such as shipbuilding and aircraft industries. Road construction firms are probably more reactive in their technology development activities than other project-based firms. Future research could incorporate other project-based industries to see whether those differences affect strategy implementation.

Furthermore, we used the framework of Olson et al. (2005) to examine strategy implementation at the project level. As argued this framework is more suitable to apply at this level than the resource-based view, although the latter has been dominant in studying strategic management in project-based firms. Future research could compare the various strategic frameworks proposed in the literature to assess their relevance for project-based firms. Our findings suggest that this comparison should incorporate a distinction between business unit, program and project level. This will increase our understanding of the complex interdependencies between these levels in project-based firms.

In addition, the findings of this study are based on a literature review and three case studies but, to generalize these findings, additional empirical data is needed. Future research could develop hypotheses based on our framework and test them in a large-scale study.

Conclusion

Project-based firms have had little attention in strategic management literature. Yet, the organizational differences between manufacturing and project-based firms are likely to have implications for strategy implementation. Our analysis of three project-based firms indicates that there is a mismatch between the intended business strategy and the actual observed strategic behavior at the project level. Furthermore, our findings suggest that there are insufficient incentives to replicate solutions from previous bids and projects into the next, limiting the opportunities for new lines of business. Also, the extensive use of external sources of technology impedes the accumulation of knowledge and the development of routines for efficient execution of similar projects, thereby, limiting the opportunities for "economies of repetition".

Our framework provides a richer understanding of strategy implementation in project-based firms and how firms struggle to manage the use of different strategic orientations at the project level.

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CHAPTER 4

Technology Development in Road Infrastructure: the Relevance of Government Championing Behavior

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Abstract

Low-technology industries are largely neglected in technology management literature. Yet, recent studies show the crucial importance of innovation in low-technology industries. In this study, we analyze technology development projects in a specific low-technology industry, road infrastructure. Based on the business strategy literature and literature on technology policy, we test the relevance of firms' strategies and government behaviour in low-technology industries.

Our empirical findings stress the value of government championing behaviour and show that this behaviour is more important than innovative procurement policies. The results even suggest that government championship is more important than a firm's strategic orientation.

Introduction

Most research on technology development has focused on high-technology industries, such as the biotechnology, semi-conductors and electronics industries. Yet, low- and medium-technology industries represent over 80 % of GDP and account for more than 55 % of total business R&D expenditures (European Economic and Social Committee, 2005). Despite the importance of low and medium-technology industries, these have been neglected in technology development literature. However, these technology industries have a considerable impact on both high-tech industries and the economy as a whole (Bender, 2006). Process innovations in these sectors are a key driver for sustainable economic growth and industry survival. Furthermore, low and medium-technology industries are important as suppliers to high-tech industries, therefore advancements in low and medium-tech industries are a necessity for developments in high-tech industries to be made. Low and medium-technology sectors account for more than 85% of value added (Von Tunzelmann and Acha, 2005), thereby, the vast majority of economic activity and employment (Bender, 2006).

This study focuses on technology development within a low-technology industry, road infrastructure. We consider road infrastructure, because road infrastructure is an important sector both in terms of GDP and employment (ERF, 2007). Furthermore, a well-established transportation infrastructure is seen as an important precondition for economic growth (Démurger, 2001). Finally, government has an important role as a buyer and first user of new technology in road infrastructure (Dalpé et al., 1992; Caerteling et al., 2008).

This paper contributes to the literature on technology development in two ways. First, we focus on the effect of government behavior on technology development. Although many studies emphasize the importance of government support in technology development and diffusion (Adams, 2005; Morris and Hough, 1987; Rosenberg, 1994), previous research on the role of government in technology development has focused on macro-level analysis (Dalpé et al., 1992; Greer and Liao, 1986). A systematic, empirical investigation at project level is lacking. Furthermore, most studies have been limited to the effect of regulations or funding on technology development (Lerner, 1999; Ring et al., 2005; Shapiro, 2000), yet government buys a significant part of new technology in low-technology industries (Dalpé et al., 1992).

Second, we focus on strategic orientation. Most research on technology development has concentrated on high-technology industries. Little knowledge has been gained about the strategies that firms in low-tech industries use to develop and commercialize new technology.

Therefore, we incorporated the firm's strategic orientation in assessing the performance of technology development projects (Baker and Sinkula, 2005; Gatignon and Xuereb, 1997; Han et al., 1998; Narver et al., 2004).

This research is designed to fill the aforementioned gaps. Based on a literature review and prior case studies we built and tested a theoretical model to answer the following research questions:

- How important is government behavior with regard to the performance of technology development projects in low-tech industries?
- What type of strategic orientation leads to the higher performance of technology development projects in low-tech industries?

In this study, the term 'technology' refers to the physical artifact as well as the proprietary design knowledge or 'capability' that can be used in different applications (Das and Van de Ven, 2000). In mature industries, most technologies are incremental improvements of existing products and processes (Christensen and Bower, 1996). Product technology refers to the design knowledge incorporated in a product. Process technology embodies the design knowledge required to manufacture a finished product (Capon and Glazer, 1987).

We define road infrastructure as a large technical system consisting of physical components such as roads, bridges and traffic monitoring equipment. Analogous to other large technical systems, such as telecommunications and railways, these components form a structured network (Hughes, 1983; Geyer and Davies, 2000). In road infrastructure this network hierarchically links roads of various classes (Mom, 2005). Furthermore, all large technical systems have a control component for system performance and efficiency (Geyer and Davies, 2000). Road infrastructure is controlled by the use of signs, regulations and dynamic route information which are organized to optimize traffic flow.

This paper has the following outline. In section 2, we develop a conceptual framework and research hypotheses. In section 3, we discuss the methodology used and in section 4, we will describe the results. In the final section, we will discuss our findings and conclude our paper with managerial and policy implications.

Theory and Research Hypotheses

In this section, we develop a conceptual framework and hypotheses to explain the performance of technology development projects in road infrastructure. Our conceptual framework is shown in Figure 4. Recent studies show that low-technology industries are relevant sources of innovative activities and vital for growth and employment (Bender, 2006; Von Tunzelmann and Acha, 2005). Although innovation research has primarily focused on high-tech industries and major technological advancements, these are not necessarily the economically or socially most important (Fagerberg, 2004). More relevant are so-called user-producer innovations that occur throughout low-, medium- and high-tech industries. In road infrastructure, like in other large technical systems, user-producer innovations are common, because the interoperability and compatibility of new technology is vital for its successful adoption (Hughes, 1983; Geyer and Davies, 2000; Markard and Truffer, 2006). In large technical systems, two dimensions are important in addressing technology development. The first dimension refers to the system builder. This actor is financially, politically or technically so powerful that it can direct technological change in the system (Jacobsson and Bergek, 2004). In road infrastructure, government performs this role of system builder. Government as an owner, operator and regulator is the key actor in the system's design and operation. Therefore, we include government behavior in our conceptual framework. The second dimension is the nature of technical change. In large technical systems, technological advancements occur along technological paths (Markard and Truffer, 2006). This path dependent nature has to ensure the interoperability and compatibility. As such, technology development is a process of improvement, incremental innovation and differentiation rather than radical change. Therefore, the relevant business strategies refer to operational efficiency and differentiation. These strategies are incorporated in our framework.

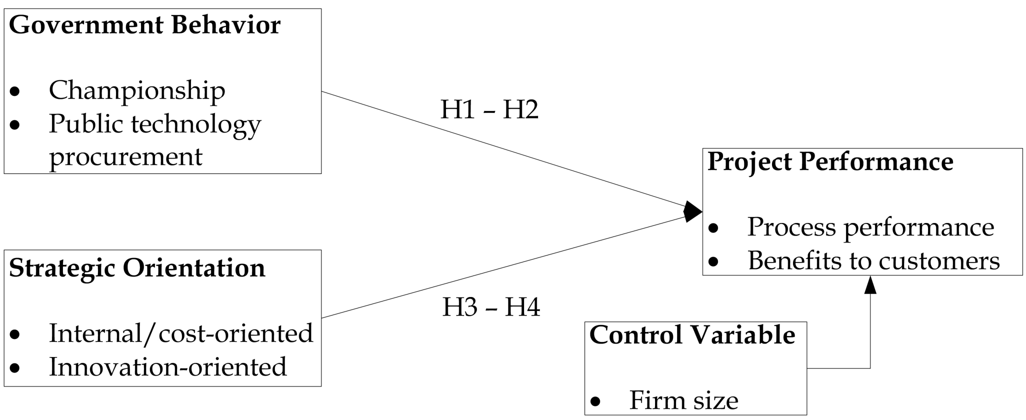

Figure 4 Conceptual framework with hypothesized relationships between the variables

In the remainder of this section, we will discuss these two dimensions of our conceptual framework and develop our hypotheses. To assess the impact of those two dimensions on performance, we define project performance at the end of this section. In the last part of this section, we also discuss why we add firm size as a relevant control variable.

Government behavior

Previous studies on government behavior and technology development have been mainly limited to the role of government as a regulator and sponsor (Lerner, 1999; Ring et al., 2005; Shapiro, 2000). Government as a regulator provides the conditions for competition (Dobbin and Dowd, 1997) and affects the development and commercialization of new technologies (Nelson, 1995; Norberg-Bohm, 2000). Government as a sponsor has concentrated on funding of basic research and private R&D, based on technology-push (Von Tunzelmann and Acha, 2005). The rationale for these instruments is that the social benefits of R&D are greater than the private returns. Therefore, regulation and funding is necessary to prevent underinvestment in technology development (Klette et al., 2000; Wallsten, 2000).

However, in low-tech industries, such as road infrastructure, stimulating diffusion and demand pull are often more important mechanisms than technology push (Jacobsson and Bergek, 2004; Von Tunzelmann and Acha, 2005). Championing behavior can be an important instrument to encourage demand and diffusion. Analogous to the championing behavior in NPD literature, the government can act as a champion too (Morris and Hough, 1987). Championing behavior is an important way of stimulating the development of specific technologies. Championing behavior is defined as making a decisive contribution to any innovation by actively and enthusiastically promoting its progress through the critical development stages (Howell and Shea, 2001). Examples of championing behavior are - the support for alternative energy sources, the semi-conductor industry and the rise of Silicon Valley (Adams, 2005; Mowery, 1998; Rosenberg, 1994). In large technical systems, the relevance of championing behavior increases when government is the system builder or when there is no obvious beneficiary of the new technology (Morris and Hough, 1987). As a system builder, government is the primary actor to champion new developments. When government is not the system builder, the partially non-rival nature of large technical systems requires a champion to encourage investments (Jacobsson and Bergek, 2004).

Championing behavior has a positive effect on technology development. This behavior can accelerate development projects by speeding up approvals and by involving key decision-makers (Morris and Hough, 1987). This behavior can also accelerate the first commercial application of a new technology, because it actively promotes the technology's advantages among targeted users. In addition, this behavior can knock down regulatory barriers that block the development or application of the new technology. These arguments suggest:

H1: Government championing behavior has a positive effect on the performance of technology development projects.

Closely related to champion behavior is procurement policy, as public technology procurement can be used to create demand pull. Dalpé et al. (1992) have shown that government buys a substantial part of the new technology developed in manufacturing industries, including low and medium-technology sectors. In low and medium-technology industries, firms concentrate on solving their main customers' needs and their product range is tailored towards a few large customers (Slater and Mohr, 2006). Therefore, their main customers, including government, strongly affect their technology development activities and commercial success (Christensen and Bower, 1996; Norberg-Bohm, 2000).

Furthermore, public technology procurement can be a powerful instrument to direct technological developments in an industry (Rothwell and Zegveld, 1981). As a buyer government has several ways of affecting technology development. First, government as owner and user can provide opportunities for experimentation and the demonstration of new technology (Rothwell and Zegveld, 1981; Saeden and Manseau, 2001). Providing these opportunities can include offering technical support for prototype development or technical assistance during the final test stage (Dalpé et al., 1992). Even when government is not the targeted user, experimentation can show the advantages of the new technology. This facilitates the diffusion process. Furthermore, experimentation and technical support can accelerate design iterations, thereby, improving quality and reducing development time (Eisenhardt and Tabrizi, 1995). Second, government methods of awarding contracts have an effect on technology development. The most common method is competitive bidding. Research in the defense industry has shown that competitive contracting for new technologies induces greater private R&D investment than non-competitive R&D contracting (Lichtenberg, 1988). This suggests that public technology procurement has a positive effect on the private R&D resources spend. An increase in resources is likely to improve the performance in terms of adherence to quality, time and budget constraints (Gatignon and Xuereb, 1997). Furthermore, demand specification affects the technologies that can be used. Method-based specifications specify in detail how the supplier should provide the technology and which components or materials to use. Performance specifications describe how the finished technology should perform over time without specifying how it should achieve the performance objectives. Performance specifications offer more opportunities for improvement and the development of technologies with significant benefits to customers.

H2: Public technology procurement has a positive effect on the performance of technology development projects.

Strategic orientation

The management literature argues that a firm's performance depends on how well business strategy is implemented in its strategic orientation (Walker and Ruekert, 1987; Olson et al., 2005). The most dominant frameworks on business strategy are Porter's typology and the Miles and Snow typology (Olson et al., 2005). Porter's typology differentiates between the cost and the perceived benefits for customers and whether the strategy is used in a particular market or on industry-wide basis (Porter, 1980). Porter's typology is based on observed competitive actions, whereas the typology of Miles and Snow (1978) focuses on the firm's projected strategy (Walker and Ruekert, 1987). The primary dimension of Miles and Snow's typology is the intended rate of product-market change (Olson et al., 2005). Most research on the implementation of business strategy focuses on the Miles and Snow typology (Olson et al., 2005; Slater and Mohr, 2006). However, both typologies have their flaws. Porter's typology neglects the organizational processes to implement each strategy. The Miles and Snow typology is rather broadly defined and combines different strategies in one category (Walker and Ruekert, 1987). To overcome these limitations, Walker and Ruekert (1987) have defined a hybrid model in which the underlying dimensions of both typologies are incorporated. These dimensions are (1) the basis for competing, i.e. the cost or differentiation, and (2) the intended intensity of product-market change. Their hybrid model proposes three business strategy archetypes: prospectors, low-cost defenders and differentiated defenders. In low-tech industries, operational cost and differentiation are the main strategic drivers (Hambrick, 1983; Von Tunzelmann and Acha, 2005). Consequently, the internal/cost orientation and the innovation orientation are likely to be dominant in these industries. The first allows firms to defend their existing market share. The second enables firms to differentiate their technology base and improve performance.

The internal/cost orientation allows firms to lower cost or increase value. *Internal cost oriented firms* pursue efficiency in all parts of their value chain (Hambrick, 1983; Olson et al., 2005; Porter, 1980). They attempt to reduce costs in primary activities, such as logistics, operations, and sales and marketing. They also attempt to reduce costs in support activities, such as procurement, research and development (R&D), and administrative functions. These firms pursue operational excellence that they can translate into higher sales through lower prices or higher margins (Olson et al., 2005). Furthermore, in pursuing efficiency, these firms focus on cost and time dimensions. Therefore, they have well developed process capabilities to conduct technology development projects in accordance to time, budget and quality constraints. The downside of this internal focus on efficiency is that they are less receptive to changes in customer preferences and environmental developments (McKee et al., 1989). Furthermore, these firms focus on a narrow scope of activities with little variation in standard practices and procedures (Morgan and Strong, 2003). Therefore, they will face difficulties in developing technologies with significant benefits to customers. From these arguments we derive:

H3a: High levels of the internal/cost orientation have a positive effect on the process performance of technology development projects.

H3b: High levels of the internal/cost orientation have a negative effect on the benefits to customers.

The second important strategic orientation is innovation orientation that represents firms intended product-market development (Gatignon and Xuereb, 1997; Han et al., 1998). *Innovation orientation* indicates that the firm is not only open to new ideas but also proactively pursues these ideas in both its technical and administrative domains. These firms seek state-of-the-art technologies, thereby, increasing the potential to differentiate from competitors and diversify into new markets (Gatignon and Xuereb, 1997). An innovation orientation encourages risk taking and enhances the likelihood of developing radically new products (Olson et al., 2005). Furthermore, adopting this strategy entails having the drive to acquire a substantial technological background and to use this in the development of new technologies (Gatignon and Xuereb, 1997). Consequently, these firms dedicate sizeable resources to R&D and have experience in conducting technology development projects (Pavitt et al., 1989). Furthermore, their focus on new technologies and ways to enter or create new markets enables them to mobilize first mover advantages (Morgan and Strong, 2003). Being ahead of competition, these firms are the first to offer substantial benefits to customers. From this given discussion, we obtain:

H4a: High levels of the innovation orientation have a positive effect on the process performance of technology development projects.

H4b: High levels of the innovation orientation have a positive effect on the benefits to customers.

Project performance

In this research, we measure the performance of technology development projects in two ways. First, we assess the process performance of the development project in terms of meeting budget, quality and development time objectives. These performance objectives are dominant in low and medium-tech projects (Shenhar et al., 2001). Second, we measure the performance of the technology in terms of significant benefits to the customer. Low and medium-technology development projects are usually designed to solve a customer's problem (Shenhar et al., 2001) and are aimed at improving operating efficiency, safety or maintainability. The central question regarding the performance of these projects is: what are the benefits of the new technology to the customer compared to the previous generation of technology?

Control variable

Firm size is added as a control variable as size can affect a firm's R&D expenditure. The strategic marketing literature emphasizes the importance of firm size because resource advantages can strongly affect new product performance (Gatignon and Xuereb, 1997). In low-technology industries there is also a low R&D intensity, as a high rate would deplete technological opportunities more quickly than new ones are being created (Klevorick et al., 1995). Therefore, only some of the (probably larger) firms will have developed in-house technological capabilities (Pavitt et al., 1989).

Methodology

Data collection

We used the membership database of the American Road and Transportation Builders Association (ARTBA) which contains 789 US road infrastructure firms with complete contact information. According to the ARTBA their members are responsible for over 90% of the transportation construction industry.

To ensure that we would reach the intended respondents, we sent a pre-survey letter to all 789 firms. The pre-survey consisted of the following three questions. Did you develop any new technologies in the past *three* years? Are your company's main activities heavy construction and highway construction? Are you willing to participate in a study on the effect of the roles of government on the success of technology development? 336 firms responded positively to all questions, 32 companies declined to participate, and 421 companies did not respond.

In administering the final survey, we followed the total design method for survey research (Dillman, 1978). The first mailing packet included a personalized letter, the survey, a priority prepaid envelope with an individually typed return address label, and a list of research reports available for participants. The package was sent by priority mail to 336 firms which agree to participate. We asked the respondent to fill out the questionnaire with a specific technology development project in mind that was executed in the last three years. We emphasized that respondents should select a project that is representative of technology development within their firm. After three follow-up letters, we received completed questionnaires from 115 firms, representing a response rate of 34% (115/336).

Measures

The measures are shown in Appendix 4A. For most measures we used existing scales or adapted existing scales for our objectives. We used a 7-point Likert scale throughout the survey.

For measuring strategic orientation we used the measures developed by Olson et al. (2005) and Narver et al. (2004). Government behavior is subdivided into championship and procurement policy. To measure championing, we took the measurement items on championing behavior used by Howell and Shea (2001) and adapted them to government. Our measurement consisted of eight items. We asked respondents to agree or disagree with the statements on championing behavior. The items referred to government support, conviction and the willingness to solve problems and remove obstacles. No measurement was available at project level for public technology procurement, so we developed a five item measure. We asked respondents to agree or disagree with statements on how the contract was awarded, what specifications were used, who took the initiative, and whether government supported the project technically or financially.

Process performance was measured using three items on meeting budget, quality and development time objectives. The first item asked respondents to assess process performance relative to the firms stated objectives, the second referred to the process performance relative to the firm’s other new technologies and the third asked respondents to evaluate their project against competing technologies.

The benefits of the new technology are measured from the firm’s perspective. Following, Chandy and Tellis (2000), we developed a measure to assess the benefits to customers relative to the previous generation of technology. These benefits resembled the themes in federal support for road infrastructure and performance specifications of government agencies (Federal Highway Administration, 1998, 2004).

Firm size was measured as the natural logarithm of the firm's total revenues over the last year. The amount of revenues is a standard measure of firm size (Finkelstein and D'Aveni, 1994). We used the natural logarithm form to reduce heteroscedasticity (Kerlinger, 1973).

Data analysis

In the factor analysis we examined the loadings of the items of government behavior, strategic orientation and project performance. The factor analysis resulted in six factors: we retained all those items that loaded on the correct factor over the .40 mark and had no cross loadings over the .40 mark. Table 11 shows the factor loadings of the items that were retained.

Following the factor analysis we performed a two-sided Pearson correlations test of the different variables including firm size. The outcomes of the correlation are shown in Table 12. Table 12 also includes the Cronbach Alpha's of the variables. The results suggest that the construct reliabilities are high except for the innovation orientation construct which is also acceptable.

The hypotheses were examined in two regression models using OLS estimation. In Model 1, we analyzed the effect of strategic orientation, government behavior and firm size as independent variables on process performance as the dependent variable. In Model 2, benefits to customers is the dependent variable. To reduce multicollinearity, we used mean-centered variables, as suggested by Jaccard et al. (1990). The variance inflation factors shown in Table 12 are below harmful levels (Mason and Perreault, 1991).

Table 11 Results of exploratory factor analysis

Construct	Item	Factor loading
Government championship	CHAM1	***.684***
	CHAM2	***.819***
	CHAM3	***.631***
	CHAM4	***.935***
	CHAM5	***.926***
	CHAM6	***.925***
	CHAM7	***.936***
	CHAM8	***.917***
Public technology procurement	PROC1	***.954***
	PROC2	***.709***
	PROC3	***.947***
	PROC4	***.952***
	PROC5	***.956***
Internal cost orientation	INT1	***.732***
	INT2	***.836***
	INT3	***.746***
Innovation orientation	INN1	***.698***
	INN3	***.669***
	INN4	***.750***
Process performance	BUD1	***.894***
	QUAL1	***.862***
	TIME1	***.876***
	BUD2	***.849***
	QUAL2	***.857***
	TIME2	***.866***
	BUD3	***.907***
	QUAL3	***.888***
	TIME3	***.868***
Benefits to customers	TPRF1	***.843***
	TPRF2	***.856***
	TPRF3	***.749***
	TPRF4	***.724***
	TPRF5	***.666***

[a] Factor loadings are based on Exploratory Factor Analysis with Varimax rotation.

Table 12 Descriptive statistics and Pearson correlations[a]

	Variable	Mean	s.d.	VIF[d]	1	2	3	4	5	6	7
1.	Championship[b]	4.81	1.16	1.416	*.96*						
2.	Public technology procurement[b]	4.34	1.35	1.316	.37**	*.97*					
3.	Internal/cost orientation[b]	4.30	1.47	1.397	.33**	.41**	*.83*				
4.	Innovation orientation[b]	5.08	1.09	1.361	.41**	.21*	.41**	*.69*			
5.	Firm size[c]	13.02	2.56	1.068	.14	-.09	-.09	-.08			
6.	Process performance[b]	3.72	1.76		.38**	.21*	.31**	.32**	.02	*.98*	
7.	Benefits to customers[b]	5.07	1.31		.39**	.02	.34**	.26**	.08	.56**	*.91*

[a] N = 115

[b] We used a 7-point scale.

[c] We used the natural logarithm on total firm revenues to control for heteroscedasticity.

[d] VIF = Variance Inflation Factor.

** Correlation is significant at the 0.01 level (2 tailed tests).

* Correlation is significant at the 0.05 level (2 tailed tests).

Note: The coefficient alpha for each measure is on the diagonal (and in italics) and the intercorrelations among the measures are on the off-diagonal.

Table 13 Regression results for hypotheses[a]

Independent variables	*Dependent variables* Process performance: **Hypothesis**	**Unstandardized parameter estimate**	**Standard error**	**Standardized parameter estimate**	Benefits to customers: **Hypothesis**	**Unstandardized parameter estimate**	**Standard error**	**Standardized parameter estimate**
Championship	(H_1, +)	.387*	(.154)	.256	(H_1, +)	.395**	(.111)	.350
Public technology procurement	(H_2, +)	.031	(.128)	.024	(H_2, +)	-.236*	(.092)	-.244
Internal/cost orientation	(H_{3a}, +)	.196	(.121)	.164	(H_{3b}, -)	.280**	(.087)	.313
Innovation orientation	(H_{4a}, +)	.229	(.162)	.142	(H_{4b}, +)	.053	(.117)	.044
Firm size		.011	(.061)	.016		.022	(.044)	.042
Adjusted R^2		.162				.218		
F-statistic		5.398**				7.349**		

* p < .05.

** p < .01.

[a]We used mean-centered variables to reduce multicollinearity, as suggested by Jaccard et al. (1990).

Results

Table 13 summarizes the results of the regression analysis. The results show that the two models are significant: process performance (R^2 = .162, $F_{(5,109)}$ = 5.398, p = .0001) and benefits to customers (R^2 = .218, $F_{(5,109)}$ = 7.349, p = .0001).

Government behaviour and project performance

The hypotheses on government behavior, H_1 and H_2, predict a positive relationship between government championship and project performance and positive relationship between public technology procurement and project performance. The results support the positive relationship between government championship and project performance: process (b = .387, t = 2.506) and benefits to customer (b = .395, t = 3.547). Consistent with H_2, there is a positive relationship between public technology procurement and process performance although this finding is not significant (b = .031, t = .245). Counter to our hypothesis, the predicted positive relationship between public technology procurement and the benefits to customers is contradicted by the results. The results suggest a significant *negative* relationship (b = -.236, t = -2.566).

Strategic orientation and project performance

The third and fourth hypotheses consider the effect of strategic orientation on process performance and benefits to customers. H_{3a} predicts that higher levels of internal/cost orientation increase process performance. Although in the expected direction, the results suggest a non-significant relationship between internal/cost orientation and process performance (b = .196, t = 1.615). Counter to hypothesis H_{3b}, the outcomes indicate that the relationship between internal/cost orientation and the benefits to customers is positive and significant (b = .280, t = 3.198). H_{4a} and H_{4b} predict a positive effect for innovation orientation on process performance and benefits to customers. Although the results show that the relationships are in the expected, positive direction, the outcomes are not significant (process performance: b = .229, t = 1.416; benefits to customers: b = .053, t = .450).

Firm size and project performance

The effect of firm size on performance is not significant for both process performance (b = .011, t = .177) and for the benefits to customer (b = .022, t = .494).

Discussion

Low-technology industries are relevant sources of innovative activities and important for growth and employment (Bender, 2006). However, only a small amount of empirical research on the relevance of government behavior and how low-technology firms manage their development activities has been conducted. This study is amongst the first to provide empirical findings about the relevance of government behavior on development project performance. Second, we extend the strategy implementation literature to low-technology industries.

The link between government behavior and technology development outcomes

Our major contribution is the empirical investigation of the effect of government behavior on technology development projects. Our study shows that government championship is an important factor for both process performance and creating benefits to customers. In previous empirical research the importance of government championship was identified (Caerteling et al., 2008; Morris and Hough, 1987), but the importance was not empirically tested. Howell and Shea (2001) have shown that championing behavior can make a decisive contribution to project performance within manufacturing firms. We have shown that government championship is crucial to project performance in road infrastructure.

A second major contribution to literature is the empirical research on public technology procurement. Previous research on public technology procurement primarily addressed contract awarding methods: bidding systems, contests and reward systems (e.g. Anton and Yao, 1990). The importance of public technology procurement was downplayed (Edler and Georghiou, 2007). This research focused on public technology procurement which government used to offer opportunities for experimentation and the demonstration of new technology (Rothwell and Zegveld, 1981; Seaden and Manseau, 2001). We have measured the relevance of contract specification (use of performance specifications), and technical and financial support. The predicted positive relationship between public technology procurement and project performance was not supported by the results. This finding contradicts earlier research on this type of procurement that suggests that public technology procurement can induce significant private R&D investment (Lichtenberg, 1988). Yet, most research on public technology procurement is based on defense contracts specified by government. But most of the technologies in our study were developed on the firm's own initiative. Our results indicate that for those technologies, public technology procurement has a negative effect on how the benefits of the new technology to the customer are perceived. This suggests two options. First, lowest bid selection favors existing technologies with minor improvements, because new technologies with significant improvements are more costly than existing technologies. Second, public technology procurement rarely asks for significant improvements compared to existing technologies, as this might exclude too many firms.

The impact of strategic orientation on technology development outcomes

Our second main contribution is the analysis of strategic orientation in a low-technology industry. Although the literature argues that strategic orientation is important to all firms, little effort has been made to examine low-technology industries. In this study, we used literature to analyze and predict the relevant strategic orientations for firms involved in road infrastructure. Based on this specification, we considered two types of strategic orientation: internal/cost orientation and innovation orientation. We expected both of these orientations to be present, given the dominance of low-cost and differentiated defenders in road infrastructure. Based on our hypotheses we predicted that innovation orientation would have the highest performance as it has a positive effect on both process performance and benefits to customers. We hypothesized that a focus on cost reduction of primary activities and support activities, such as logistics, operations and administrative functions would have a negative effect on benefits to customers. However, counter to our hypothesis this study showed that pursuing operational excellence has a significant, positive effect in creating benefits to customers. This indicates that firms emphasizing operational excellence will outperform their rivals that stress an innovation orientation. This outcome could be explained by the fact that internal/cost oriented firms have acquired ingrained marketplace knowledge of customer preferences, because they focus on a narrow market segment (Morgan and Strong, 2003). This knowledge gives them an edge over less domain-focused firms in providing significant benefits to their customers. Furthermore, the use of cost-based selection criteria by their main customers is likely to stimulate an internal/cost orientation within road construction firms.

Firm size and project performance

The insignificant relationship between firm size and project performance can be attributed to industry characteristics. According to Malerba and Orsenigo (1997), traditional sectors have low levels of opportunity, appropriability and cumulativeness. Consequently, they expect these sectors to have many, geographically dispersed innovators. Breschi et al. (2000) showed that most low-technology industries have a widening pattern of innovation. A widening pattern of innovation refers to "an innovative base which is continuously enlarging through the entry of new innovators and to the erosion of the competitive and technological advantages of the established firms" (2000: 389). These conditions erode the potential advantage of larger firms.

Managerial and policy implications

The implications of this study for managers are threefold. First, this study reconfirms the importance of aligning strategic orientations with the environment. In mature, low-technology industries an internal cost orientation seems more important to improve the competitive position than innovation-oriented efforts. Second, incremental improvements in existing technologies are more likely to succeed under competitive bidding than significant improvements. Government customers have difficulties in prizing the added value of significant improvements, because of cost-based selection criteria. Third, firms should invest in relationships with champions within government. Existing studies of corporate political strategies focus on lobbying and reporting to affect policy and gain access to relevant information (e.g. Baysinger, 1984). Yet, professional ties between firms and government are more likely to have a positive effect on firm performance (Hillman et al., 1999).

From a policy perspective, we can derive several implications from the results. First, government should extend technology policies to include its role as champion. In previous discussions on technology policy this dimension has been neglected. Most efforts have been directed at providing capital, facilitating technology transfer and supporting universities and public research institutes (Feldman and Kelley, 2006; Martin and Scott, 2000; Klette et al., 2000). Although public funding of university research is crucial, Feldman and Kelley (2006) argue that government has to find ways to convince firms to use university research for commercial applications. Government championship is a key element in stimulating commercial applications. Government should develop long-term policies to help firms in their efforts ranging from R&D, prototype development and testing to market launch. For firms to engage in technology development, continuity in technology policy is necessary (Falk, 2007). More important than providing opportunities for demonstration projects and financial support, government officials should:

- Secure the support of top level policy makers.
- Remove regulatory barriers to new technologies that support policy objectives.
- Involve the key officials who decide on the procurement of new technologies.
- Promote the advantages of the new technology throughout the different government levels.

The aforementioned aspects of government championship are more likely to result in a market for new technology than demonstration projects and financial support. Supporting commercialization and the emergence of a market are crucial in low and medium-technology industries where government is a large buyer and first user of new technology.

This research further suggests that public technology procurement does not have a positive impact on the way technologies with significant improvements are valued. Government favors cost-based criteria, but seems unable to price the increased benefits of new technology compared to existing technologies. New technologies are often more expensive and risky than existing ones. We advise government to develop a pricing scheme that weighs the increased performance of new technology against the higher cost and risks. The weighed price of the new technology provides a more realistic comparison with existing technologies.

Limitations and future research

This paper has concentrated on a low-technology industry. The lack of understanding about technology development in these industries and the importance of the government as buyer and user justified this choice. Future research could extend the dimensions of championship and innovative procurement policies to defense and other high-technology industries to compare findings. This research could enrich the discussion on the relevance of government championship and the value of differentiating between low and high-technology industries (Rush et al., 2007).

In this study we have excluded market orientation as the behavioral implementation of business strategy. We have argued that internal cost orientation and innovation orientation match the relevant dimensions of business strategy. Furthermore, existing studies on market orientation have shown mixed results that question the hegemony of market orientation (Noble et al., 2002). However, future research could study strategic orientation in more detail and incorporate market orientation in the framework. This would allow researchers to assess the importance of internal cost orientation in low-technology industries compared to customer and competitor orientation.

Research could also examine the differences in strategic orientation between high and low-technology industries. In high-technology industries with a high level of R&D intensity, there is a strong relationship between advances in basic science and technology development performance. Advances in basic science provide a high degree of technological opportunity and thus a high R&D intensity can be sustained. Consequently, firms in high-technology industries are likely to have more technological opportunities allowing more innovation-oriented strategies.

Conclusion

In this paper we addressed the effect of government behavior and a firm's strategic orientations on the performance of technology development projects in a low-technology industry. This study is among the first empirical research on the effect of government behavior to be conducted at project level. In previous research, government championship has been identified as an important contributing factor in technology success, but empirical grounding was lacking. Our empirical findings underscore the value of championing behavior and show that this behavior can be more important than public technology procurement. The results for this industry even suggest that government championship is more important than a firm's strategic orientation.

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Appendix 4A Study Measures

Government behavior

Government championship

Please indicate how much you disagree or agree with each statement. 1 = strongly disagree; 7 = strongly agree; the numbers between 1 and 7 represent the differing degree of your agreement.

In this selected project, …	ITEM	Strongly disagree						Strongly agree
… government officials enthusiastically promoted the technology's advantages.	CHAM1[d]	1	2	3	4	5	6	7
… government officials got the key decision-makers involved.	CHAM2	1	2	3	4	5	6	7
… government officials expressed strong conviction about the technology.	CHAM3	1	2	3	4	5	6	7
… government officials got problems in the hands of those who could solve them.	CHAM4	1	2	3	4	5	6	7
… government officials persisted their support in the face of adversity.	CHAM5	1	2	3	4	5	6	7
… government officials secured the top level support required.	CHAM6	1	2	3	4	5	6	7
… government officials showed optimism about the success of the technology.	CHAM7	1	2	3	4	5	6	7
… government officials knocked down barriers to the technology	CHAM8	1	2	3	4	5	6	7

Public technology procurement[1]

In this selected project, …								
The technology was developed for a contract awarded through competitive bidding.	PROC1	1	2	3	4	5	6	7
The technology was developed on your company's own initiative.	PROC2[d]	1	2	3	4	5	6	7
The technology was developed with technical support of government.	PROC3	1	2	3	4	5	6	7
The technology was developed using performance specifications.	PROC4	1	2	3	4	5	6	7
The technology was developed with financial support of government.	PROC5	1	2	3	4	5	6	7

[d] This item was removed due to exploratory factor analysis.

Strategic orientation

Please indicate how much you disagree or agree with each statement. 1 = strongly disagree; 7 = strongly agree; the numbers between 1 and 7 represent the differing degree of your agreement.		Strongly disagree						Strongly agree

Internal/cost orientation

In this selected project, …	ITEM							
… improving the operating efficiency of business was a top priority.	INT1	1	2	3	4	5	6	7
… we had a continuing overriding concern for operating cost reduction.	INT2	1	2	3	4	5	6	7
… we continuously sought to improve production processes so we could lower costs.	INT3	1	2	3	4	5	6	7
… achievement of economies of scale and scope were important elements of our strategy.	INT4	1	2	3	4	5	6	7
… we closely monitored the effectiveness of key business processes.	INT5 [d]	1	2	3	4	5	6	7

[d] This item was removed due to exploratory factor analysis.

Innovation orientation

In this selected project, …	ITEM							
… management actively sought innovative ideas.	INN1	1	2	3	4	5	6	7
… competitors recognized us as innovation leaders.	INN2	1	2	3	4	5	6	7
… we were first to market with this technology.	INN3	1	2	3	4	5	6	7
… we were recognized as being at the leading edge of technological innovation.	INN4	1	2	3	4	5	6	7
… innovation was perceived as too risky and was resisted.	INN5 [d]	1	2	3	4	5	6	7

[d] This item was removed due to exploratory factor analysis.

Performance

Process performance

Please indicate whit what you know today, how successful this selected project was or has been using the following criteria.	ITEM	Far less than our stated objectives						Far exceeded our stated objectives
Relative to your firm's stated objectives at the beginning of the project, how successful was this project in terms of:								
Budget	BUD1	1	2	3	4	5	6	7
Quality	QUAL1	1	2	3	4	5	6	7
Development time	TIME1	1	2	3	4	5	6	7

		Far less than our other technologies						Far exceeded our other technologies
Relative to your firm's other new technologies, how successful was this project in terms of:								
Budget	BUD2	1	2	3	4	5	6	7
Quality	QUAL2	1	2	3	4	5	6	7
Development time	TIME2	1	2	3	4	5	6	7

		Far less than competing technologies						Far exceeded competing technologies
Relative to competing technologies, how successful was this project in terms of:								
Budget	BUD3	1	2	3	4	5	6	7
Quality	QUAL3	1	2	3	4	5	6	7
Development time	TIME3	1	2	3	4	5	6	7

Benefits to customers

Relative to the previous technology generation, this technology provides significantly higher benefits to the customer in terms of:	ITEM	Strongly disagree						Strongly agree
Increased reliability standard.	TPFR1	1	2	3	4	5	6	7
Decreased production costs.	TPFR2	1	2	3	4	5	6	7
Shortened production time.	TPFR3	1	2	3	4	5	6	7
Increased safety standard.	TPFR4	1	2	3	4	5	6	7
Reduced environmental impact.	TPFR5	1	2	3	4	5	6	7
Reduced maintenance costs.	TPFR6 [d]	1	2	3	4	5	6	7
Broadened applicability.	TPFR7 [d]	1	2	3	4	5	6	7

[d]This item was removed due to exploratory factor analysis.

[d] This item was removed due to exploratory factor analysis.

Firm size

What was your firm's last years total revenues? $_____________,000

[1] These items are also used in Chapter 5 (see p. 162).

CHAPTER 5

How Relevant Is Government Championing Behavior for Technology Development?

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Abstract

Many studies emphasize the importance of government support in technology development and diffusion. However, we still lack an empirical investigation of the impact of government roles on the performance of technology development projects.

This study is among the first to provide empirical findings on the relevance of government roles for the performance of technology development projects. Based on earlier research and the strategic management literature, we develop a theoretical model and hypotheses to study the relevance of government roles and firms' strategic orientation for technology development projects.

Our study shows that government championship is an important factor for the performance of technology development projects. The results also suggest that the impact of government championing behavior augments when the technology offers more significant benefits. Government championing behavior can help in these cases to create readiness and overcome regulatory barriers.

We also found that both the defensiveness and proactiveness dimension of business strategy are relevant for technology development projects. Previous research emphasized the proactiveness dimension in technology development. However, the defensiveness dimension also contributes to both project performance and benefits to customers.

The paper concludes with implications for practice: companies should invest in building personal relations with champions in government. From a policy perspective, government should extend its technology policies by performing a role as a champion through promoting the advantages of new technology, involving key decision makers and lessening regulatory barriers. Furthermore, for championing behavior to succeed it should be well-embedded in existing technology policies, such as R&D funding and regulations.

Introduction

Existing literature has provided a plethora of internal and external factors that affect the performance of a firm's technology development activities. The internal factors relate to organizational, project team and personal characteristics, such as strategic orientation, critical development activities, cross-functional teams, and the role of boundary spanners and product champions (Ancona and Caldwell, 1992; Brown and Eisenhardt, 1995; Griffin and Hauser, 1996; Markham and Griffin, 1998; Song and Montoya-Weiss, 1998; Venkatraman, 1989). The external factors refer to the role of suppliers and customers, government interventions and industry characteristics, such as market volatility and the pace of technological developments (Faems et al., 2005; Morris and Hough, 1987; Tan and Litschert, 1994).

Previous research has shown that government interventions directly affect a firm's strategic choices and performance (Reger et al., 1992; Tan and Litschert, 1994), and the subsequent decisions on technology development activities (Lefebvre et al., 1997). Furthermore, previous research on a firm's strategic orientation has demonstrated that the relative emphasis of a firm on defensive or proactive dimensions affects technology development performance (Gatignon and Xuereb, 1997; Narver et al., 2004; Talke, 2007).

Unfortunately, very little empirical research addresses both these aspects and their impact on technology development performance. Until now, the literature has been inconclusive about the relative importance of government interventions and a firm's strategic orientation for technology development performance. Furthermore, it is unclear whether policy makers should focus on financial and technical assistance or championing behavior to stimulate technology development, and whether firms should concentrate on defensive or proactive strategic orientations. Existing studies on government financial assistance have reported positive effects (e.g. Lerner, 1999), but also question the effectiveness of public funding of private R&D (Klette et al., 2000; Wallsten, 2000). Studies on government championship are mainly theoretical and indicative and lack an empirical basis (Morris and Hough, 1987; Mowery, 1998).

Additional research is needed to address these issues. This study attempts to make the following contributions. First, we examine the impact of both government assistance and championship, and the strategic orientation of firms on technology development performance. Existing studies on government's roles have mainly focused on industry level instead of firm or project level (Dalpé et al., 1992; Greer and Liao, 1986), and used aggregated data collected for other purposes (e.g. Lerner, 1999; Lichtenberg, 1988). Existing studies on strategic orientation have neglected the impact of government interventions on the effectiveness of strategic orientations (Tan and Litschert, 1994). Second, we examine the relative importance of government assistance versus government championship and the relative effectiveness of the defensive and proactive dimensions in strategic orientation.

These contributions are important because the existing literature does not provide adequate guidance for practice. Our findings will show whether managers have to emphasize the defensive or proactive dimension in strategic orientation and whether they should seek government assistance or government championship to increase performance. Furthermore, our findings will also have policy implications regarding the role of government in technology development. Our results will clarify whether government should leave technology development to firms or provide championship or assistance.

Based on a literature review and prior case studies we built a theoretical model to test the importance of government assistance, government championship, and the firm's defensiveness and proactiveness for technology development performance. Performance is assessed through (1) project performance in terms of budget, quality and time, as well as (2) the benefits of the new technology to the customer.

In this study, the term 'technology' refers to the physical artifact as well as the proprietary design knowledge or 'capability' that can be used in different applications (Das and Van de Ven, 2000). Product technology refers to the design knowledge incorporated in a product. Process technology embodies the design knowledge to manufacture a finished product (Capon and Glazer, 1987).

The rest of this paper has the following outline. In the next section, we develop the theoretical model and research hypotheses to explain the impact of government roles and strategic orientation on the performance of technology development projects. In section 3, we discuss the methodology used and in the section 4, we will describe the results. In the final section, we will discuss our findings and conclude our paper with managerial and policy implications.

Theory and Research Hypotheses

There are many possible dimensions that can affect technology project performance. Previous research about project performance has included success and failure factors (Brown and Eisenhardt, 1995; Cooper and Kleinschmidt, 1987; Griffin and Hauser, 1996), organizational design and project teams (Ancona and Caldwell, 1992; Keegan and Turner, 2002; Markham and Griffin, 1998), and collaborative strategies and arrangements (Faems et al., 2005; Tether, 2002). These studies have shown that multidisciplinary teams, senior management support and process planning activities are important success factors. Furthermore, the development and commercialization of a new technology often extends beyond the boundaries of a single firm, involving customers and suppliers. However, this research has also produced contradicting results because it used varying operationalizations and examined different industries (Garcia and Calantone, 2002; Montoya-Weiss and Calantone, 1994).

Figure 5 shows the dimensions in our theoretical model. The dimensions in this model were derived from our prior research that focused on the roles of government in technology development projects and the relevant strategy dimensions that guide firms' strategic choices in these projects. Over a two year period, we conducted 61 interviews with R&D managers, project team members and government officials. The latter were involved in the project as sponsors, regulators, customers or champions. Questions asked related to project team composition, planning of work and technological and market uncertainties. We asked whether the technologies were developed to defend market position, to serve short-term goals or to seek new opportunities. Furthermore, we asked respondents to reflect on how government in its diverse roles affected these factors and considerations. To support our interview findings, we analyzed business publications, contractual arrangements, design specifications and newspaper articles, and held several workshops with senior management and R&D managers.

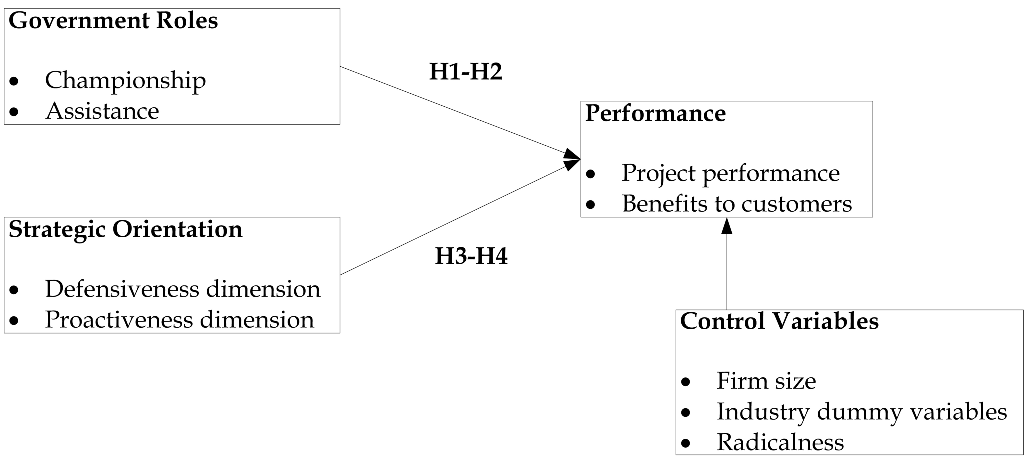

Figure 5 Conceptual model of the impact of government roles and a firm's strategic orientation on performance

The findings of this in-depth, multiple case study showed that there are two relevant government roles in technology development:

championing and assistance. Government championship can create favorable demand conditions and overcome regulatory barriers. Others have also shown the beneficiary effect of this role on technology development projects (Morris and Hough, 1987; Jacobsson and Bergek, 2004). Government assistance in terms of technical and financial support of technologies is a second important role of government. Previous studies substantiate our findings on the relevance of government assistance (Dalpé et al., 1992; Lerner, 1999; Feldman and Kelley, 2006). However, the combined effect of these government roles is often neglected in innovation research.

Another major finding of the prior study was that two strategic orientations were dominant in a firm's technology development projects. These orientations resemble two extremes in the strategic orientation of business enterprises (STROBE) dimensions of Venkatraman (1989). On the one hand, firms emphasize the proactiveness dimension, seeking new opportunities and introducing new products ahead of competition. On the other hand, firms focus on the optimization of their internal business processes to preserve one's product and market domain. This is the defensiveness dimension in Venkatraman's strategy concept. Others also suggest that, in essence, the strategic dimensions of business strategy can be analyzed as a hybrid of proactive and defensive strategies (Tan and Litschert, 1994; Walker and Ruekert, 1987).

In the remainder of this section, we will discuss these factors in our theoretical model and develop our research hypotheses.

Government roles

Previous studies on government roles and technology development are mainly limited to the role of government assistance, particularly in terms of funding and tax incentives (Edler and Georghiou, 2007; Falk, 2007; Klette et al., 2000).

However, our prior research showed that besides assistance government championship is an important role. Analogous to the championing behavior in the NPD literature, government can act as a champion (Morris and Hough, 1987). Champion behavior is an important way to stimulate the development and commercialization of *specific* technologies. Champion behavior is defined as making a decisive contribution to the innovation by actively and enthusiastically promoting its progress through the critical development stages (Howell and Shea, 2001). Champions ensure that key decision-makers are involved, knock down regulatory barriers and promote the technology's advantages. Government championship affects project performance in several ways. First, it secures top level support by influencing government officials' perceptions of new technologies, labeling them as an opportunity (Howell and Shea, 2001). Furthermore, champions actively promote the technology's advantages among government officials and targeted customers, emphasizing the benefits of the technology (Howell and Shea, 2001). It can emphasize the increased reliability or safety of the new technology, or the positive effect the technology has on production costs. Second, champions involve key decision-makers and are able to overcome regulatory barriers. This role can reduce development time by quickening approval and permit procedures. Furthermore, they ensure encountered problems get in hands of those that can solve those problems (Howell et al., 2005). These activities have a positive effect on project performance and reduce project cycle time (Markham and Griffin, 1998). Taken together, this role smoothens the technology development process and enthusiastically promotes the technology's advantages. Consequently, government championship increases project performance and the perceived benefits. Therefore, we hypothesize that:

H1a: The higher the government championship, the higher the *project* performance.

H1b: The higher the government championship, the higher the *benefits to customers*.

Government assistance is often seen as a means of overcoming market failure (Falk, 2007; Wallsten, 2000). The social returns of R&D are said to be much greater than the private returns to the firms because of knowledge spillovers (Lerner, 1999). Therefore, public funding can compensate for the market failure of profit-maximizing firms, because it funds projects that otherwise would not be undertaken (Klette et al., 2000; Wallsten, 2000). Furthermore, government assistance can have a substantial effect on employment and sales growth of the funded firms (Lerner, 1999. We define government assistance as the provision of financial or technical support to firms to prevent underinvestment in new technology.

Financial support has a positive effect on project performance as it can compensate the costs of initial setbacks or attract additional funds, thereby, enabling a project that would otherwise be terminated. Lerner (1999) has demonstrated that tax incentives compensating labor costs of R&D have a positive effect on R&D employment. Furthermore, public financial support can attract private venture capital (Lerner, 2002), lessening budgetary constraints. At the same time, there are several studies that question the positive effect of public financial support (e.g. David and Hall, 2000; Wallsten, 2000). These studies suggest that public financial support crowds out private investment. On the other hand, financial support can allow firms to continue their R&D activities at a constant level rather than cutting back (Wallsten, 2000).

Complementary, technical assistance can have a positive effect on project performance. Technical assistance is a form of consultancy to compensate potential information asymmetries (Stoneman and Diederen, 1994). It increases the awareness of relevant developments and technical specifications, speeding up the development project and increasing product quality. In addition, it can help in setting up collaborative arrangements with suppliers, research institutes or venture capitalists (Rothwell and Dodgson, 1991). Technical assistance in experimentation can accelerate problem-solving, shortening development cycles and reducing overall development time (West and Iansiti, 2003). Furthermore, design iterations improve design and product quality and thereby increase the benefits to customers (Eisenhardt and Tabrizi, 1995).

H2a: The higher the government assistance, the higher the *project* performance.

H2b: The higher the government assistance, the higher the *benefits to customers*.

Strategic orientation

Defensiveness

The defensiveness dimension is defined as an emphasis on cost reduction and efficiency seeking methods to defend a firm's current technology and market position (Venkatraman, 1989). Firms that emphasize this dimension translate operational excellence into higher sales through lower prices or higher margins (Olson et al., 2005). Furthermore, in pursuing efficiency, these firms will focus on improving existing process technologies to enhance product quality (Venkatraman, 1989).

Firms that emphasize this dimension have well-developed project management capabilities that allow them to execute projects within stringent budget and time constraints. Planning and control methods are used to regularly assess project performance, eliminating those projects that are underperforming (Engwall, 2003; Keegan and Turner, 2002). Consequently, these firms are likely to adhere to the predefined budget, quality and time objectives. Furthermore, firms accentuating this dimension focus on their core technologies and product-market domain. They operate in a stable narrowly-defined market domain to optimize operating efficiency (McKee et al., 1989; Morgan and Strong, 2003). Their internal focus on operating efficiency also leads them to reduce costs in support activities, such as research and development (R&D), and administrative functions (Olson et al., 2005). Backside of this internal focus is that these firms have limited adaptive capabilities (McKee et al., 1989). In contrast, developing new technologies with substantial benefits to customers requires adaptability, ample time and transaction costs to make sure the customer receives precisely what it wants (McKee et al., 1989; Treacy and Wiersema, 1993). Therefore, these firms face difficulties in developing technologies that offer significant higher benefits to the customer.

H3a: The higher the defensiveness dimension of firms, the higher the *project* performance.

H3b: The higher the defensiveness dimension of firms, the lower the *benefits to customers*.

Proactiveness

The second important strategic orientation is proactiveness that represents a firm's ability for exploiting emerging opportunities; mobilize "first-mover" advantages and eliminate operations in the declining stages of the life cycle (Morgan and Strong, 2003; Venkatraman, 1989). Proactive firms seek state-of-the-art technologies, thereby, increasing the potential to differentiate from competitors and diversify into new markets (Gatignon and Xuereb, 1997). Furthermore, proactiveness entails the will to acquire a substantial technological background and use it in the development of new technologies (Gatignon and Xuereb, 1997). Proactiveness encourages risk taking and enhances the likelihood of developing radically new products (Olson et al., 2005).

Their ability in grasping emerging opportunities allows them to respond quickly to changes in the project environment and risks inherent to technology development projects. These firms are responsive to changing environmental trends (Venkatraman, 1989). Therefore, these firms are likely to use project management techniques as a baseline against which alternatives are measured once changes occur rather than as a linear model based on control (Lyneis et al., 2001). As such, they are able to deal more efficiently with changes that affect budgetary, quality and time constraints. Also, these firms have a higher R&D intensity, increasing their experience and resources in technology development (Pavitt et al., 1989; Souitaris, 2002). Therefore, these firms are likely to have well-developed capabilities in performing technology development projects.

Furthermore, their ability to mobilize first mover advantages allows them to offer higher benefits to customers (Morgan and Strong, 2003). As a first supplier of a new technology, proactive firms have an information advantage concerning product quality and risk-averse buyers over later entrants (Kerin et al., 1992). These learning curve economies allow proactive firms to develop technologies that have significant benefits over the earlier technology generation and competitive technologies. In addition, being first on the market, the technology is likely to attract much attention and affect the attributes that buyers perceive as important (Lieberman and Montgomery, 1988). As such, proactive firms can shape the perceptions and preferences of buyers, giving them an advantage over later entrants.

H4a: The higher the proactiveness dimension of firms, the higher the *project* performance.

H4b: The higher the proactiveness dimension of firms, the higher the *benefits to customers*.

Performance

In this research, we measure the performance of technology development projects in two ways. First, we assess the process performance of the development project in terms of meeting budget, quality and development time objectives. These performance objectives are dominant in project management (Shenhar et al., 2001). Second, we measure the performance of the technology in terms of significant benefits to the customer. Technology development projects are usually designed to solve a customer's problem (Shenhar et al., 2001). These projects are aimed for improved operating efficiency, safety or maintainability. Central question to the performance of these projects is: what are the benefits of the new technology to the customer compared to the previous technology generation?

Control variables

We considered two control variables, firm size and type of industry. Firm size can affect a firm's R&D expenditure. The strategic marketing literature emphasizes the importance of firm size because resource advantages can strongly affect new product performance (Gatignon and Xuereb, 1997). Furthermore, we controlled for industry effects. Depending on the industry characteristics in terms of appropriability conditions and technology intensity, each industry has its own innovation dynamic (Smits, 2002; Pavitt et al., 1989). Therefore, government roles and firms' dominant strategic dimension are also likely to vary across industries (Gatignon and Xuereb, 1997; Martin and

Scott, 2000). In addition, the radicalness of the technology is likely to affect new technology performance. Radical new technologies require targeted customers to change their operations and often emerge ahead of demand (Garcia and Calantone, 2002). These features limit compatibility and thereby the potential success of the new technology (Souder and Song, 1997). Furthermore, radical technologies embody high degrees of new knowledge and involve high uncertainties about market, technological and support infrastructure leading to setbacks and delays (Song and Montoya-Weiss, 1998).

Methodology

Data collection

In choosing our sample of firms, we had an important reason to study a specific industry. Our prior research is based on findings in road infrastructure and we wanted to replicate our case study findings in a larger sample. However, we were also interested in testing the generalizability of our ideas across industries. Following, Finkelstein and D'Aveni (1994), we therefore included road construction firms in a wider sample of manufacturing and pharmaceutical firms. Our sample of US road construction firms is drawn from the membership database of the American Road and Transportation Builders Association (ARTBA) which contains 789 road infrastructure firms with complete contact information. According to the ARTBA their members are responsible for over 90% of the transportation construction industry. To ensure we would reach the intended respondents of the road construction firms, we sent a pre-survey letter to all 789 firms. The pre-survey consisted of the following three questions. Did you develop any new technologies in the past *three* years? Is your company's main activity heavy and highway construction? Are you willing to participate in a study on the effect of the roles of government on the success of technology development? 336 road construction firms responded positively to all questions, 32 declined to participate, and 421 did not respond.

he manufacturing and pharmaceutical firms in our sample are a random selection of 1,500 firms listed in *World Business Directory and Reference USA*. The manufacturing and pharmaceutical firms include electronic and electrical equipment manufactures (industry codes: 3621, 3629, 3632, 3633, 3651, 3652, 3679, 3694, 3695, 3699, 3711, 3713, 3714, 3715, 3792), pharmaceutical, drugs and medicine (industry codes: 2833, 2834, 2835, 2836, 5047), telecommunications equipment (industry codes: 3661, 2663 2669, 4812, 4813, 4822, 3669, 723.9, 724.1, & 724.2) and semiconductors and computer related products (3577, 3571, 3572, 3575, 3674, 5054). Similar to the road construction firms we sent a pre-survey to the manufacturing and pharmaceutical firms. This pre-survey consisted of the same questions but the question regarding their main activity was removed. The pre-survey letter was sent to all 1,500 manufacturing and pharmaceutical firms. 567 qualified firms agreed to participate. 48 firms declined to participate, 87 letters returned due to invalid contact person or addresses, and 798 companies did not respond.

In administering the final survey, we followed the total design method for survey research (Dillman, 1978). The first mailing packet included a personalized letter, the survey, a priority postage-paid envelope with an individually typed return address label, and a list of research reports available to participants. The package was sent by priority mail. We asked the respondent to fill out the questionnaire with a specific technology development project in mind that was executed in the last three years. We emphasized that respondents should select a project that is representative of technology development within their firm.

For road construction, the 336 firms that agreed to participate were sent this package. After three follow-up letters, we received completed questionnaires from 115 road construction firms, representing a response rate of 34% (115/336). For manufacturing and pharmaceutical industries, the 567 firms that agreed to take part were also sent this package. After three follow-up letters, we received completed questionnaires from 266 manufacturing and pharmaceutical firms, representing a response rate of 47% (266/567). Our total sample size is 381 firms of which 77% of the respondents was male and 88% had a bachelor degree or higher. To prevent a bias towards successful projects, we asked respondents to select a recently completed project that they found representative for their firm's technology development projects.

Measures

The measures are shown in Appendix 5A. As suggested by Churchill (1979), the domain of each construct was clearly defined in terms of what would be included. For each measure we searched the literature for relevant measures. When no relevant measures were available we developed new measures using multiple items to increase reliability. Most measures used are existing scales or adapted from existing scales in the literature. We used a 7-point Likert scale throughout the survey.

For measuring strategic orientation we used the measures developed by Olson et al. (2005) and Narver et al. (2004). Government roles are subdivided in championship and assistance. To measure championship, we used the measurement items of Howell and Shea (2001) on champion behavior and adapted those items to government. Our measurement consisted of eight items. We asked respondents to agree or disagree with the statements on champion behavior. The items refer to government support, conviction and willingness to solve problems and remove obstacles. For government assistance, no measurement was available at the project level. Therefore, we developed a four item measure. We asked respondents to agree or disagree with statements on how the contract was awarded, what specifications were used, and whether government supported the project technically or financially.

Project performance was measured using three items on meeting budget, quality and development time objectives. The first item asked respondents to assess project performance relative to the firms stated objectives. The second item referred to the project performance relative to the firm's other new technologies. The third item asked respondents to evaluate their project against competing technologies.

The benefits of the new technology are measured from firms' perspective. Following Chandy and Tellis (2000), we developed a measure to assess the improvement of the technology relative to the previous technology generation. This improvement resembles the themes that customers are likely to find important: increased operating efficiency, reduced environmental impact, increased reliability and safety standards (Norberg-Bohm, 2000; Tidd et al., 2001).

Firm size was measured as last year's total revenues. The amount of revenues is a standard measure of firm size (Finkelstein and D'Aveni, 1994). We used the natural logarithm form to reduce heteroscedasticity (Kerlinger, 1973).To account for industry effects, we added dummy variables for four industry categories: electronic and electrical equipment manufactures, pharmaceutical, drugs and medicine, telecommunications equipment, semiconductors and computer related products. Following Garcia and Calantone (2002), a radical innovation is defined as embodying new technology that results in a new market or industry. Radicalness was measured through three items, reflecting this definition. The first item refers to the degree of new knowledge embodied in the technology. The second item relates to the impact on industry, whereas the third item addresses the emergence of a new market.

Data analysis

To check for the possibility of a biased sample, we assessed the range in the performance measurement items, means and standard deviations. This assessment does not suggest that we have a biased sample. The descriptive statistics are shown in Table 14. This table also lists the construct reliability, the two-sided Pearson correlations and the Variance Inflation Factors. All construct reliabilities are near or above the acceptable mark of .80.

Table 14 Descriptive statistics: means, standard deviation, correlation matrix and construct reliability[a]

Construct	Mean	Standard deviation	Variance Inflation Factor	Construct reliability	PERF	TPFR	CHAM	ASSIS	DEF	PRO	SALES	ELECT	PHARM	TELE	SEMI	ROAD	RAD
Project Performance (PERF)	3.79	1.72	N/A	0.97	1.00												
Benefits to customers (TPRF)	5.11	1.23	N/A	0.88	0.52*	1.00											
Government Championship (CHAM)	4.71	1.17	1.511	0.97	0.37*	0.41*	1.00										
Government Assistance (ASSIS)	4.38	1.44	1.306	0.99	0.29*	0.19*	0.39*	1.00									
Defensiveness (DEF)	4.60	1.31	1.421	0.83	0.39*	0.44*	0.30*	0.36*	1.00								
Proactiveness (PRO)	5.01	1.09	1.553	0.80	0.43*	0.40*	0.48*	0.21*	0.46*	1.00							
Firm Sales (in millions) (SALES)	11.64	2.97	1.353	N/A	0.04	0.07	0.10	0.01	0.03	0.02	1.00						
Electronics (ELECT)	0.08	0.27	N/A	N/A	-0.03	0.02	-0.02	-0.02	-0.02	-0.07	-0.17	1.00					
Pharmaceutical (PHARM)	0.13	0.34	N/A	N/A	-0.03	-0.03	0.01	-0.05	0.02	0.02	-0.24*	-0.11	1.00				
Telecommunications (TELE)	0.27	0.44	N/A	N/A	0.08	0.03	-0.03	0.02	0.08	-0.02	0.23*	-0.17*	-0.23*	1.00			
Semiconductors (SEMI)	0.22	0.42	N/A	N/A	-0.01	0.00	0.00	0.04	-0.01	0.00	-0.29*	-0.15*	-0.21*	-0.33*	1.00		
Road Construction (ROAD)	0.30	0.46	N/A	N/A	-0.02	-0.02	0.04	-0.01	-0.07	0.04	0.31*	-0.19*	-0.25*	-0.40*	-0.35*	1.00	
Radicalness (RAD)	4.42	1.24	N/A	0.77	0.40*	0.36*	0.48*	0.37*	0.45*	0.56*	-0.06	-0.07	0.05	0.03	0.01	-0.03	1.00

[a]N = 381

* Correlation is significant at the 0.01 level (2 tailed tests).

We used the natural logarithm on firm sales to control for heteroscedasticity.

Table 15 Exploratory factor analysis results: factor loadings for N = 381

	Factor1	Factor2	Factor3	Factor4	Factor5	Factor6
BUD3	***0.873***	0.101	0.059	0.144	0.152	0.113
BUD1	***0.869***	0.062	0.135	0.146	0.099	0.126
TIME1	***0.851***	0.087	0.149	0.223	0.120	0.148
TIME3	***0.851***	0.111	0.085	0.200	0.116	0.122
QUAL3	***0.842***	0.208	0.023	0.162	0.107	0.177
BUD2	***0.836***	0.188	0.114	0.219	0.098	0.081
QUAL2	***0.832***	0.211	0.122	0.203	0.077	0.098
TIME2	***0.829***	0.119	0.129	0.205	0.098	0.145
QUAL1	***0.827***	0.192	0.054	0.230	0.064	0.130
CHAM4	0.135	***0.949***	0.166	0.150	0.047	0.144
CHAM7	0.118	***0.945***	0.166	0.147	0.047	0.141
CHAM5	0.144	***0.938***	0.148	0.148	0.065	0.134
CHAM6	0.134	***0.938***	0.160	0.143	0.065	0.149
CHAM8	0.150	***0.929***	0.170	0.144	0.042	0.154
CHAM2	0.231	***0.677***	0.054	0.129	0.096	0.109
CHAM3	0.080	***0.594***	0.177	0.088	0.174	0.250
ASSIS5	0.134	0.206	***0.954***	0.049	0.146	0.049
ASSIS3	0.132	0.206	***0.950***	0.053	0.147	0.047
ASSIS1	0.124	0.204	***0.948***	0.039	0.139	0.042
ASSIS4	0.145	0.203	***0.946***	0.045	0.149	0.044
TPRF2	0.286	0.146	0.010	***0.769***	0.158	0.148
TPRF1	0.184	0.113	0.066	***0.730***	0.166	0.085
TPRF5	0.207	0.228	0.022	***0.696***	0.135	0.179
TPRF4	0.244	0.258	0.015	***0.635***	0.044	0.273
TPRF3	0.267	0.106	0.047	***0.604***	0.112	-0.079
DEF2	0.118	0.077	0.143	0.104	***0.750***	0.075
DEF1	0.137	0.029	0.185	0.165	***0.738***	0.242
DEF3	0.153	0.232	0.134	0.173	***0.660***	0.177
DEF4	0.207	0.029	0.150	0.377	***0.467***	0.180
PRO3	0.235	0.176	0.040	0.078	0.157	***0.715***
PRO2	0.245	0.221	0.036	0.147	0.187	***0.579***
PRO1	0.074	0.302	0.009	0.051	0.271	***0.570***
PRO4	0.164	0.206	0.076	0.228	0.062	***0.549***

Note: Please see Appendix 5A for the question item on the first column. Factors 1 – 6 explain 24.7% of the variance.

The results of the factor analysis are shown in Table 15. Factor loadings are based on a principal component analysis with varimax rotation. In the factor analysis, we examined the loadings of the items of government roles, strategic orientation and performance. The factor analysis resulted in six factors. These factors explain 24.7% of the variance. Of the six relevant factors we retained all those items that loaded on the correct factor over the .40 mark and had no cross loadings over the .40 mark.

Before we tested our hypotheses, we performed several diagnostic tests to evaluate the appropriateness of the assumptions of linearity and homoscedasticity. An examination of the residual plots suggested that these assumptions were appropriate. We also applied the collinearity diagnostic procedure outlined by Mason and Perrault (1991). According to Mason and Perrault, the Variance Inflation Factor (VIF) should be below 10. Our results indicate that the maximum VIF for the regressions is 1.592. Therefore, we concluded that collinearity had no substantive impact on the coefficient estimates.

The hypotheses were examined in a multiple regression model. In this model, we used the road construction industry as a baseline and added four dummy variables for the other industries. In the multiple regression model, we analyzed two equations. The first equation is the effect of government roles, strategic orientation, firm size and the industry dummy variables as independent variables on project performance as the dependent variable. The second equation involves the same independent variables but benefits to customers as the dependent variable. To analyze these two equations we used Seemingly Unrelated Regression (SUR) estimation instead of OLS regression. SUR is an extension of regression analysis to examine multiple equations, which might have correlated error terms. OLS estimation presumes unrelated equations in a model. In our case, the correlation between the equations results from the use of the same database. By using SUR the equations are estimated jointly, thereby, the parameters are estimated more efficiently (Zellner, 1962). Notably, SUR estimation is based on GLS estimation rather than OLS.

Alternative models

Our hypothesized model assumed a direct relationship between government roles and performance, and between strategic orientation and performance. To see whether alternative models fit better with the data collected, we also ran various mediator and moderator models. None of the mediation models resulted in a mediation effect.

In the moderator models, we analyzed whether government championship and government assistance moderated the strategic orientation-performance relationship. We also tested whether the defensiveness and proactiveness dimensions moderated the government roles-performance relationship. The empirical results do not support a moderating effect.

Therefore, we only report the results of our hypothesized model.

Results of Seemingly Unrelated Regression Estimation

Table 16 summarizes the results of the Seemingly Unrelated Regression estimation for the two dependent variables, N = 381. The results show that the regression model has substantial explanatory power as the system weighted R^2 is 0.24.

Government roles and performance

As hypothesis H_{1a} predicts government championing behavior has a positive effect on project performance. The results show a significant positive relationship between government championship and project performance (b = .23, t = 2.88). Also hypothesis H_{1b} is supported by the results. There is a significant positive relationship between government championing behavior and benefits to customers (b = .27, t = 4.86).

Consistent with H_{2a}, our results show a positive relationship between government assistance and project performance (b = .13, t = 2.17). Counter to our hypothesis H_{2b}, the positive relationship between assistance and benefits to customers was not supported. However, this relationship is not significant: (b = -.05, t = -1.28).

Strategic orientation and performance

As suggested by hypothesis H_{3a}, the effect of a defensiveness orientation is positive for project performance. There is a significant relationship (b = .23, t = 3.39). Counter to our hypothesis H_{3b}, the outcomes also indicate that the relationship between defensiveness and benefits to customers is positive and significant: (b = .30, t = 6.10).

Consistent with hypothesis H_{4a}, proactiveness has a positive effect on project performance (b = .39, t = 4.50). The results also confirm hypothesis H_{4b}. There is a significant relationship between proactiveness and benefits to customers (b = .17, t = 2.80).

Table 16 Results of Seemingly Unrelated Regression estimation

Independent Variables:	Dependent Variable: Project Performance (PERF)				Dependent Variable: Benefits to Customers (TPRF)			
	Parameter Estimate	*Standard Error*	*t Value*	*Standardized Parameter Estimate*	*Parameter Estimate*	*Standard Error*	*t Value*	*Standardized Parameter Estimate*
Intercept (ROAD)	-1.10*	0.57	-1.93	0.00	1.57***	0.40	3.90	0.00
Government Championship (CHAM)	0.19**	0.08	2.37	0.13	0.26***	0.06	4.47	0.24
Government Assistance (ASSIS)	0.11*	0.06	1.79	0.09	-0.06	0.04	-1.49	-0.07
Defensiveness (DEF)	0.21***	0.07	2.96	0.16	0.28***	0.05	5.76	0.30
Proactiveness (PRO)	0.33***	0.09	3.52	0.21	0.14**	0.07	2.19	0.13
Firm Sales (in millions) (SALES)	0.01	0.03	0.34	0.01	0.02	0.02	0.89	0.04
Electronics (ELECT)	0.07	0.32	0.22	0.01	0.25	0.23	1.12	0.05
Pharmaceutical (PHARM)	-0.07	0.27	-0.25	-0.01	-0.07	0.19	-0.37	-0.02
Telecommunications (TELE)	0.25	0.20	1.24	0.07	0.05	0.14	0.38	0.02
Semiconductors (SEMI)	0.02	0.23	0.11	0.01	0.10	0.16	0.59	0.03
Radicalness (RAD)	0.16**	0.08	2.03	0.12	0.07	0.06	1.25	0.07

System weighted R^2 = 0.24. N = 381.

Note: ***p< .01; ** p< .05; * p< .10. The significance was based on a two-tail test.

Following Finkelstein and D'Aveni (1994) and Kerlinger (1973), we used the natural logarithm of firm sales.

Firm size and industry effects

The effect of firm size on performance is not significant, although the sign is in the expected direction. Both for project performance (b = .01, t = 0.20) and benefits to customers (b = .02, t = 0.80), the results show no effect on the project outcomes.

Likewise, the industry dummy variables are not significant. The results show no distinct differences between road infrastructure and the other industries.

The technology's radicalness is positively related to project performance (b = .16, t = 2.03), but the effect of radicalness on benefits to customers is not significant (b = 0.07, t = 1.25).

Discussion and Implications

This study has addressed two important questions. First, we examined the relative importance of government championship and assistance. Second, we assessed the relative effectiveness of a firm's defensiveness and procactiveness in technology development activities. As the results show, government assistance and championship have a substantial effect on technology development projects. Furthermore, it show which dimension managers have to emphasize to achieve project performance or benefits to customers.

The relative importance of government championship and assistance

One of the major contributions of this study is the empirical confirmation that government championship is the most important for supporting technology development performance. Government championship is more important than government assistance for project performance and for the benefits of the new technology to the customer. Additional pair wise *t*-tests show that the coefficient for government championship is significantly different to that of government assistance for the benefits to customers. This result suggests that championship is over three times more important than government assistance for benefits to customers. In enthusiastically promoting a new technology's advantages, involving key decision makers and knocking down regulatory barriers, government championship enhances the benefits of the new technology to customers. Government championship encourages new technology that has significant increases in reliability and safety standards and that reduces the environmental impact. The implication for policy makers is that government championship can be a powerful instrument in stimulating the adoption and diffusion of new technology.

The implication for management is that firms should interact with champions in government to boost their technology development projects. Consistent with literature on corporate political strategies, lobbying, informing through technical reports and personal visits are important to influence policy and regulations (Baysinger, 1984; Birnbaum, 1985; Hillman et al., 1999). In contrast, most of these corporate political strategies are used to reduce uncertainty about policy decisions affecting the firm (Hillman et al., 1999). Our findings suggest that firms should influence champions within government to create readiness and facilitate the diffusion among targeted customers. By actively and enthusiastically promoting the advantages of the new technology, government championship creates additional attention to the new technology, thereby, strengthening the firm's first mover advantages (Lieberman and Montgomery, 1988).

A surprising result is the negative relationship between government assistance and benefits to customers. Although previous research suggests that R&D funding has a positive net effect on R&D undertaken by firms, it is difficult to assess the actual benefit based on aggregated data (e.g. Klette et al., 2000). Our findings suggest that financial and technical support have a positive effect on project performance. But this effect is modest. A pair wise *t*-test showed that the most important factor, proactiveness, is three times more important than government assistance. From a policy perspective, this indicates that providing resources alone is not sufficient to increase technology development activities to overcome underinvestment. From a managerial perspective, this finding suggests that seeking government assistance to increase project performance, in terms of meeting budget, time and quality objectives, is less effective than building up technology development capabilities.

The effectiveness of proactive and defensive strategic orientations

Another major contribution of this study is the finding that the proactiveness dimension is most important for achieving project performance. Experience in technology development projects will increase the ability to complete these projects within budget, on time and in accordance with quality requirements. This is consistent with earlier studies (Pavitt et al., 1989; West and Iansiti, 2003). Furthermore, the defensiveness dimension is most important for enhancing the benefits of the new technology to customers. Existing studies showed that the defensiveness dimension supports business profitability, whereas the proactiveness dimension is positively related to exploiting market opportunities (Morgan and Strong, 2003; Talke, 2007). Our study shows that these dimensions should not be seen as opposites but complementary in achieving project performance and benefits to customers.

In particular, the finding regarding the defensiveness dimension is surprising. In our study, we hypothesized a negative relationship, but the outcomes suggest that this dimension has the highest positive impact. A possible explanation for this outcome is that a defensive firm has ingrained marketplace knowledge of customer preferences, because they focus on a narrow market segment (Morgan and Strong, 2003). This knowledge gives them an edge over less domain-focused firms in providing benefits to their customers. Furthermore, in highly volatile and hostile markets firms are likely to emphasize the defensiveness dimension (McKee et al., 1989; Tan and Litschert, 1994). A further explanation is that firms do not need extensive in-house R&D resources and skills to develop technologies with significant benefits to customers. Increasingly firms adapt innovative ideas from external sources (Chesbrough, 2003). Furthermore, as technological uncertainty increases, firms are more likely to develop technologies in alliances, spreading risks and combining complementary capabilities (Robertson and Gatignon, 1998). Therefore, firms can have an internal focus, leveraging their internal processes, and respond to changing customer needs, as they do not have to go through the entire process of skill acquisition themselves (Hamel, 1991).

Finally, our findings indicate that, for project performance, a firm's strategic behavior is more important than factors in the external environment. This is consistent with existing literature (McGahan and Porter, 2002; Ruefli and Wiggins, 2003). For benefits to customers we found mixed results. Although the defensiveness dimension is most important, government championship is the second most important factor.

The relevance of firm size, industry effects and radicalness

We considered three control variables in the analysis: firm size, industry effects and radicalness. For firm size no significant relationship was found. This suggests that the effect of firm size on performance is more complex than the main effect examined. We measured firm size in terms of total revenues, but this may be a rather crude measure to assess R&D resources. Gatignon and Xuereb (1997) have used a relative measure. They assessed a firm's marketing and R&D resources relative to its competitors in the same product category. They find a positive relationship between resources and innovative performance.

The industry dummy variables are also not significant. Their coefficients suggest that the differences across the industries studied are negligible. This contradicts earlier findings that suggest that innovation dynamics differ significantly across industries, because of social, economic and technological factors (Pavitt et al., 1989; Smits, 2002). However, others have shown that industry characteristics only have a limited effect on firm performance (e.g. Ruefli and Wiggins, 2003) and that firms' strategic behavior is the major determinant in business performance (McGahan and Porter, 2002).

Surprisingly, radicalness positively affects project performance, while it has no significant effect on benefits to customers. The literature suggests that radical innovations take more time and resources (Song and Montoya-Weiss, 1998) and would negatively impact project performance, while radical innovations are often positively related with significant benefits to customers (e.g. Chandy and Tellis, 2000).

Limitations and future research

This paper has concentrated on the effect of government championship and assistance on the performance of technology development projects. The lack of understanding about the impact of government as a sponsor and champion on technology development justified this choice. Future research could extend these roles to include other government interventions, such as public technology procurement, standards setting and regulations. This research could provide empirical results about the combined effect of government roles as a buyer, champion, regulator and sponsor on technology projects. This could enrich the discussion on technology policy and the effectiveness of various policies.

In this study, we have excluded several dimension of the STROBE construct (Venkatraman, 1989). Based on earlier research, we have argued that the defensiveness and proactiveness dimensions are the relevant dimensions to consider in examining technology development projects. Consistent with existing studies, we considered these dimensions as a hybrid model of business strategy (Tan and Litschert, 1994; Walker and Ruekert, 1987). However, future research could incorporate the analysis and futurity dimensions in the framework. These dimensions have shown to complement the defensiveness and proactiveness dimensions in their positive effect on business performance (Morgan and Strong, 2003; Talke, 2007). This would increase the comparability of our findings with existing studies on strategic orientation of business enterprises.

In this research, we addressed R&D managers to measure government roles, firms' strategic behavior and project performance. This design was chosen to facilitate the data collection process. Furthermore, the measures were drawn from existing literature. However, the use of a single respondent per firm has its limitations as argued in the literature (e.g. Podsakoff et al., 2003). Future research could conduct similar research with an optimized survey design to reduce common-method bias. Suggestions are to use two respondents per firm, to let different respondents report on the independent and dependent variables and to avoid negatively worded items.

Finally, we measured project performance using two sub constructs: project performance and benefits to customers. We have defined the benefits to customers as an improvement of the operational processes of the customer. This is strongly linked with incremental improvement, whereas a radical improvement often redefines the operational processes of the customer. We incorporated the radicalness of the new technology in our survey. The results suggest that radicalness does not affect the benefits of the new technology to customers, although existing research has shown that a technology's radicalness affects the willingness to adopt a new technology (e.g. Souder and Song, 1997). Furthermore, government championship and assistance might promote different types of technology. Championship is associated with mission-oriented policies that encourage specific, often radical new technologies. Examples are the SEMATECH program and defense-related technologies (e.g. Mowery, 1998). On the other hand, government assistance is diffusion-oriented to facilitate technology transfer (Giesecke, 2000). Further research could examine how the radicalness of the new technology affects the relevance of government championship and assistance.

Conclusion

In this paper we addressed the effect of government assistance and championship and a firm's strategic orientation on the performance of technology development projects. The results of our study show that government championship is an important factor for project performance and benefits to customers. As a champion, government involves key decision makers, knocks down regulatory barriers and enthusiastically promotes the technology's advantages. This championing behavior speeds up technology development and helps to create readiness among targeted customers. Furthermore, championing behavior is more important than government assistance.

We also found that both the defensiveness and proactiveness dimension of business strategy are relevant for technology development projects. Previous research emphasized the proactiveness dimension in technology development. However, the defensiveness dimension also contributes to both project performance and benefits to customers.

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Appendix 5A Study Measures

Government roles

Please indicate how much you disagree or agree with each statement. 1 = strongly disagree; 7 = strongly agree; the numbers between 1 and 7 represent the differing degree of your agreement.		Strongly disagree						Strongly agree

Government championship

In this selected project, …	ITEM							
… government officials enthusiastically promoted the technology's advantages.	CHAM1[d]	1	2	3	4	5	6	7
… government officials got the key decision-makers involved.	CHAM2	1	2	3	4	5	6	7
… government officials expressed strong conviction about the technology.	CHAM3	1	2	3	4	5	6	7
… government officials got problems in the hands of those who could solve them.	CHAM4	1	2	3	4	5	6	7
… government officials persisted their support in the face of adversity.	CHAM5	1	2	3	4	5	6	7
… government officials secured the top level support required.	CHAM6	1	2	3	4	5	6	7
… government officials showed optimism about the success of the technology.	CHAM7	1	2	3	4	5	6	7
… government officials knocked down barriers to the technology	CHAM8	1	2	3	4	5	6	7

Government assistance[1]

In this selected project, …								
The technology was developed for a contract awarded through competitive bidding.	ASSIS1	1	2	3	4	5	6	7
The technology was developed on your company's own initiative.	ASSIS2[d]	1	2	3	4	5	6	7
The technology was developed with technical support of government.	ASSIS3	1	2	3	4	5	6	7
The technology was developed using performance specifications.	ASSIS4	1	2	3	4	5	6	7
The technology was developed with financial support of government.	ASSIS5	1	2	3	4	5	6	7

Strategic orientation

Please indicate how much you disagree or agree with each statement. 1 = strongly disagree; 7 = strongly agree; the numbers between 1 and 7 represent the differing degree of your agreement.		Strongly disagree						Strongly agree

Defensiveness dimension

In this selected project, …	ITEM							
… improving the operating efficiency of business was a top priority.	DEF1	1	2	3	4	5	6	7
… we had a continuing overriding concern for operating cost reduction.	DEF2	1	2	3	4	5	6	7
… we continuously sought to improve production processes so we could lower costs.	DEF3	1	2	3	4	5	6	7
… achievement of economies of scale and scope were important elements of our strategy.	DEF4	1	2	3	4	5	6	7
… we closely monitored the effectiveness of key business processes.	DEF5 [d]	1	2	3	4	5	6	7

[d]This item was removed due to exploratory factor analysis.

Proactiveness dimension

Please indicate how much you disagree or agree with each statement. 1 = strongly disagree; 7 = strongly agree; the numbers between 1 and 7 represent the differing degree of your agreement.		Strongly disagree						Strongly agree
In this selected project, …	ITEM							
… management actively sought innovative ideas.	PRO1	1	2	3	4	5	6	7
… competitors recognized us as innovation leaders.	PRO2	1	2	3	4	5	6	7
… we were first to market with this technology.	PRO3	1	2	3	4	5	6	7
… we were recognized as being at the leading edge of technological innovation.	PRO4	1	2	3	4	5	6	7
… innovation was perceived as too risky and was resisted.	PRO5 [d]	1	2	3	4	5	6	7

[d]This item was removed due to exploratory factor analysis.

Performance

Project performance

Please indicate whit what you know today, how successful this selected project was or has been using the following criteria.	ITEM	Far less than our stated objectives						Far exceeded our stated objectives
Relative to your firm's stated objectives at the beginning of the project, how successful was this project in terms of:								
Budget	BUD1	1	2	3	4	5	6	7
Quality	QUAL1	1	2	3	4	5	6	7
Development time	TIME1	1	2	3	4	5	6	7

		Far less than our other technologies						Far exceeded our other technologies
Relative to your firm's other new technologies, how successful was this project in terms of:								
Budget	BUD2	1	2	3	4	5	6	7
Quality	QUAL2	1	2	3	4	5	6	7
Development time	TIME2	1	2	3	4	5	6	7

		Far less than competing technologies						Far exceeded competing technologies
Relative to competing technologies, how successful was this project in terms of:								
Budget	BUD3	1	2	3	4	5	6	7
Quality	QUAL3	1	2	3	4	5	6	7
Development time	TIME3	1	2	3	4	5	6	7

Benefits to customers

Relative to the previous technology generation, this technology provides significantly higher benefits to the customer in terms of:	ITEM	Strongly disagree						Strongly agree
Increased reliability standard.	TPFR1	1	2	3	4	5	6	7
Decreased production costs.	TPFR2	1	2	3	4	5	6	7
Shortened production time.	TPFR3	1	2	3	4	5	6	7
Increased safety standard.	TPFR4	1	2	3	4	5	6	7
Reduced environmental impact.	TPFR5	1	2	3	4	5	6	7
Reduced maintenance costs.	TPFR6 [d]	1	2	3	4	5	6	7
Broadened applicability.	TPFR7 [d]	1	2	3	4	5	6	7

[d]This item was removed due to exploratory factor analysis.

Control variables

Firm Sales

What were your firm's last year's total revenues? $________, 000

Radicalness

Please indicate how much you disagree or agree with each statement. 1 = strongly disagree; 7 = strongly agree; the numbers between 1 and 7 represent the differing degree of your agreement.	ITEM	Strongly disagree						Strongly agree
The technologies developed for this project are clear departures from the state of current knowledge and embody high degrees of new knowledge.	TECH1	1	2	3	4	5	6	7
This project caused significant changes in our industry.	TECH2	1	2	3	4	5	6	7
This project relied on technology that has never been used in our industry before.	TECH3	1	2	3	4	5	6	7

[1] As argued in Chapter 4 (p. 107-108), government provides assistance through its role as a buyer of technology in road construction. When procuring new technology in this industry, government offers technical or financial support and affects performance specifications. In manufacturing and pharmaceutical industries, public procurement is a fraction of total sales. In these industries, government as a sponsor offers technical and financial support, and advises on performance specifications to prevent underinvestment in new technology. Although these are two distinct roles, the type of assistance offered is the same and relates to technical and financial support and performance specifications. Therefore, the measurement items for government assistance (Chapter 5) are the same as the items for public technology procurement (Chapter 4).

CHAPTER 6

Discussion and Reflection

In this final chapter, we discuss the findings from this research and draw conclusions responding to our original research questions. Furthermore, we reflect on the theoretical and methodological implications and the relevance for policymakers and managers. We conclude this chapter with suggestions for further research.

At the beginning of this dissertation we stressed the relevance of the public sector and the importance of increasing our understanding of technology development in this sector. We provided an overview of relevant perspectives on the roles of government in technology development. This overview highlighted the importance of both supply- and demand-side policies. Furthermore, it emphasized that the role of government as a buyer and user had been neglected. In our research, we focused on road infrastructure, seen as a large technical system in which government affects technology development through its roles as buyer, owner, operator, regulator, and champion.

Recent developments in the provision of road infrastructure suggested a shift in tasks and roles. Based on these developments, we had two propositions. First, the role of system builder would become blurred, with no single organization powerful enough to direct technological change. Consequently, we expected coalitions of public and private actors to act as system builders rather than government alone. This suggested a change in government roles and, therefore, indicated a need to understand what the relevant government roles were and how they affected technology development. Second, we expected road construction firms to develop their strategic and systems integration capabilities in order to be able to respond successfully to the changes in tasks and roles. This would affect their corporate strategy in developing and commercializing new technology. Therefore, we examined what the relevant dimensions of firms' strategic behavior were and how they affected technology development.

These suppositions resulted in three research questions:

- What are the relevant government roles and how do they affect technology development projects?
- What are the relevant dimensions of firms' strategic behavior and how do they affect technology development projects?

- How important are the various government roles for the performance of technology development projects?

In the next section we will discuss the main findings and contributions of this dissertation, and answer the research questions.

Main Findings and Contributions

Chapter 2

In Chapter 2, we addressed the first research question. Results indicate that an extensive range of government policies affect technology development projects. We identified several supply- and demand-side policies, such as funding of private R&D, championing new technology, and procuring new technology. Further, we addressed the regulatory framework and took account of tax incentives, the property rights regime, and standards setting. Our findings show that these policies are dispersed across various government agencies at different levels of government. This leads to the uncoordinated implementation of both supply-side and demand-side policies which has several consequences.

First, inconsistencies between government championship (supply-side), on the one hand, and public procurement (demand-side), on the other, hinders the emergence of a market for new technology. Championship promotes technology champions, whereas procurement policy should not favor one firm over another. Government is supposed to be "technology-blind". In addition, this finding highlights the tension between championing specific technological developments and procuring new technology. Consistent with Edquist and Hommen (2000), this finding shows that whereas championing is based on cooperation between government and specific suppliers, public technology procurement is based on open tendering with little or no interaction between the procuring agency and the bidders.

Second, government's priorities are a compromise between multiple and competing objectives. This makes government hesitant to commit itself to a specific course of action. Therefore, government cannot guarantee to create a market of a certain size for a specific technology. As a consequence, firms face additional uncertainties in assessing market opportunities and the potential of new technologies.

Third, the dominant position of government, and the persistence of competitive bidding, erodes the effectiveness of Intellectual Property Rights. Therefore, investing in patent activities to capture the profits of a new technology does not provide a competitive advantage in this industry.

Fourth, our results suggest that the step from demonstration to commercial application is troublesome. Public technology procurement often involves other officials than the actual users. In their evaluation of US energy efficient technology procurement projects by the US Department of Energy, Ledbetter et al. (1999) found that including the user is essential for diffusion. In addition, within government, public technology procurement is dispersed over various agencies and levels. In line with Edler et al. (2005), we found a diversity of agencies and departments involved, including technical staff, policymakers, procurers, and users. Team creation and coalition building are central to the success of public technology procurement. Therefore, the success of public technology procurement depends on having advocates in office that enthusiastically promote the technology's advantages and persuade key decision makers. This reconfirms the importance of champions within government.

Taken together, the results in Chapter 2 suggest that government championing behavior, public technology procurement, and, to a lesser extent, public funding of private R&D are the crucial roles in technology development projects. These roles influence both the development and the diffusion of new technology. Of these roles, government championship seems key to the success of technology development projects in road infrastructure.

Contributions

In this chapter, we have reviewed and analyzed the impact of government roles on technology development. Previous research reported in the management literature has largely focused on the effect of government as regulator or sponsor on private R&D. However, this research has shown that government roles extend beyond regulation and funding. Government as a champion and buyer is a significant factor in the success of technology development projects. Our research findings emphasize that championing new technology is an important instrument in technology development and diffusion.

Chapter 3

Chapter 3 considers a road construction firm's strategic behavior at the project level and explores the second research question. In this chapter, we distinguished four strategic orientations based on the strategic management literature. These orientations were adapted to the project level to examine strategy implementation in project-based firms, as are seen in the road construction industry. We concentrated on project definition and the analysis of information regarding customers, competitors, innovation, and operational processes. We saw that project definition and the analysis of information heavily relied on the specific targets of the specific project. In some instances, this led to inconsistencies between the strategic orientation used at the project level and the intended strategy at the corporate level. As a result, the utilization of established capabilities and resources was impeded. Further, the road construction firms studied seemed unable to develop "economies of repetition", that is to re-use capabilities, routines, and resources in similar technology development projects. Their focus on single projects prevented them assessing the potential for follow-on contracts and the strengths and weaknesses relative to competitors and existing technologies. In addition, the results indicate that firms largely adopt innovation and customer orientations in their technology development projects. Firms react to the explicit needs of their customers and develop new technology as and when necessary to meet these needs. In developing new technology they depend on external technology sources and market intelligence. All the firms studied needed others to assess market opportunities or develop new technologies.

Counter to our expectations, road construction firms have not yet developed strategic and system integration capabilities in technology development. Our findings show that most technology development projects are still considered as one-offs. Project characteristics dominate in choosing a strategic orientation. In most of the projects studied, customer and innovation orientations dominated. These orientations do not always match the intended strategy of the firm. At the senior management level, program management, as a technique to integrate the strategic orientation at the project level with the intended strategy, is underdeveloped.

Contributions

First, we have developed a framework that can be used to analyze strategy implementation in project-based firms. Such a framework was previously lacking. Second, this chapter has enriched the literature on strategic management in project-based firms, a field in which previous studies had mainly focused on the resource-based view and the corporate level. In this chapter, we examine strategy implementation at the project level. We have used the strategic orientations described by Olson et al. (2005) to examine strategy implementation at the project level. Unlike multi-product firms, the project-based firms studied lacked a functional marketing department that could coordinate and integrate the simultaneous use of various strategic orientations. Therefore, program management needs to be seen as a central technique which can align technology development projects and business strategy and so improve performance. Senior management in project-based firms need to apply program management to coordinate and integrate the diverse orientations of technology projects.

Chapter 4

Chapter 4 relates to the second and third research questions concerning road construction firms. Further, the results of the survey on road infrastructure are used to substantiate the findings in Chapters 2 and 3.

Following the results of Chapter 2, we focused on government as a buyer and champion. These roles would be dominant in explaining the impact of government on project performance. Further, the results of Chapter 3 led us to argue that internal/cost and innovative orientations would be important because most road construction firms seek to defend their market share and, as a basis for their competitive position, road construction firms would focus on cost minimization or differentiation.

The findings show that, analogous to championing behavior in firms (e.g. Howell and Shea, 2001), government championship can make a decisive contribution to project performance. Unlike earlier research (e.g. Lichtenberg, 1988), we found a negative relationship between public technology procurement and project performance, which is consistent with our results in Chapter 2. In Chapter 4 we provide two possible explanations for this negative relationship. First, we argued that lowest bid selection in public technology procurement favors existing technologies with only minor improvements. New technologies with significant improvements are more costly and riskier than existing technologies, limiting their chances of a winning bid. Second, public technology procurement rarely demands significant improvements relative to existing technologies since this might exclude too many firms. The rationale underlying public technology procurement is open tendering and price competition. Therefore, a minimum number of bidders is required to ensure competitive pressures.

Based on our findings in Chapter 3, and the strategic management literature, we hypothesized that the proactiveness dimension, reflected by an innovation orientation, would be the most relevant dimension in a firm's strategic behavior. We expected that the defensiveness dimension, reflected by an internal orientation on the efficiency of primary and support activities, would be less relevant in developing new technologies. The results contradicted these expectations and show that the defensiveness dimension is more important to road construction firms than the proactiveness dimension.

Contributions

We have extended the strategic management literature to road construction, a low-technology industry. Existing studies in the management literature tend to focus on medium- and high-technology industries. We have examined the strategic dimensions of road construction firms in developing and commercializing new technology.

Further, the findings of Chapter 4 show the relative importance of government roles and of strategic orientation in project performance. The results confirm the importance of championing behavior and even suggest that road construction firms perceive government championship to be more important than their own strategic orientation. The contradictory result on public technology procurement is surprising. Many studies claim a positive relationship (e.g. Lichtenberg, 1988) and our opposite finding warrants further research on the effects of public technology procurement.

Contrary to the existing literature, this chapter shows that pursuing an internal orientation has a significant, positive effect on the benefits delivered to customers. This indicates that firms emphasizing operational excellence will outperform rivals that stress an innovation orientation. This finding can be explained by the fact that internally oriented firms have acquired ingrained marketplace knowledge of customer preferences through their focus on a narrow market segment (Morgan and Strong, 2003). This knowledge gives them an edge over less domain-focused firms in providing significant benefits to their customers. Furthermore, the use of cost-based selection criteria by government agencies is likely to stimulate an internal orientation within road construction firms.

In addition, we developed a measurement for public technology procurement. Although we tried to reflect all the relevant dimensions in this measurement, further refinement is necessary. A refined measurement could include the effect of public technology procurement on standards setting and market creation.

Chapter 5

In Chapter 5, we generalized our findings on the relative importance of government championship, addressing our third research question.

In a larger sample, that included road construction, manufacturing and pharmaceutical firms, we replicated our investigation of the significance of government championship. As public technology procurement is less relevant to manufacturing and pharmaceutical firms, we compared the relative importance of government championship with that of government assistance. Government assistance was defined as the financial and/or technical support provided to overcome underinvestment in new technology. A key area is the public funding of private R&D. The results of this research can guide government in determining which policy is more effective in stimulating innovation: championing behavior or assistance. The results of Chapter 5 suggest that government championship is far more important for performance than government assistance, in all three sectors studied. The implication for technology policy is that government should concentrate more on reducing barriers and promoting new technology, than on funding private R&D projects. This is consistent with other studies that have questioned the effectiveness of R&D funding (David and Hall, 2000; Klette et al., 2000; Wallsten, 2000), and emphasize the role of champion in public technology programs (Ledbetter et al., 1999).

Again expanding on Chapter 4, we compared these government roles with a firm's strategic orientation. The new findings showed similar results regarding the importance of an internal, defensive orientation. This result is even more surprising in this instance given the large number of manufacturing and pharmaceutical firms in the sample. Overall, the findings indicate that industry differences are negligible in the aspects considered.

Contributions

The findings show that government championship is the second most important factor in creating customer benefits. In this respect, government championship has a significantly higher impact than government funding. Therefore, involving key decision makers and enthusiastically promoting a technology's advantages are important for its diffusion. Others have argued that diffusion policies should be more sophisticated (Stoneman and Diederen, 1994). Further research could examine championing behavior and technology diffusion in more detail. Understanding championing behavior and its effect on the adoption and diffusion of technology could be a first step in improving diffusion policies.

Furthermore, our findings confirm the importance of the defensiveness dimension in creating benefits for customers. Consistent with the existing literature, the proactiveness dimension was found to be the most important when it comes to ensuring that a project meets budget, quality, and time objectives.

Effect of government roles and a firm's strategic orientation on technology development projects' performance

In Figure 6, we summarize the findings of each chapter. Our findings show that government championing behavior and government assistance both have a positive effect on the performance of technology development projects. Government championship is the second most important factor in creating benefits to customers, after defensiveness. Government assistance in terms of financial and technical support has a positive effect on project performance in terms of meeting budget, quality, and time objectives.

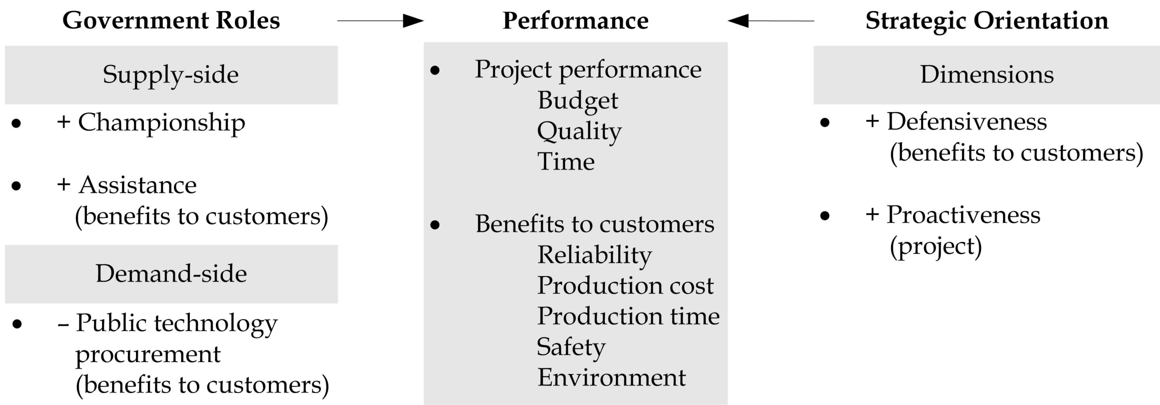

Figure 6 Effect of government roles and a firm's strategic orientation on technology development projects' performance

However, the findings of Chapter 2 also seem to support the suggestion in the literature that public funding of private R&D crowds out private investment (David and Hall, 2000; Klette et al., 2000; Wallsten, 2000). In our study, the finding is based on only three firms and, therefore, we should be cautious in generalizing this finding. Further research at the project level seems warranted to assess the effect of public R&D funding. Also, our negative finding for the effect of public technology procurement contradicts other earlier conclusions (e.g. Lichtenberg, 1988) and the current advocacy of public technology procurement. The result requires further research, and a refinement of the measurement used would be beneficial.

Furthermore, the findings on the effect of the relevant dimension of a firm's strategic behavior show that both the defensiveness and proactiveness dimensions have a positive effect on performance. Consistent with the existing literature, the proactiveness dimension is most important in ensuring a project meets budget, quality, and time objectives.

Similarities and Differences in the Findings

The results show no major inconsistencies throughout the dissertation. In conducting the quantitative research, we were not able to test all the propositions in Chapter 2. Owing to the limitations of survey research, we could only examine a few variables. We decided to concentrate on government as champion, buyer, and sponsor. In Chapter 4, we chose to focus on government championship and public technology procurement in road infrastructure. In Chapter 5, government championship and assistance are studied with a larger sample. We were interested in the relative importance of championing behavior compared to public technology procurement and assistance. Further, the existing empirical data neglects the importance of a combined effect of the various government roles. Moreover, we explored the relative importance of government roles compared to a firm's strategic orientation. The overall survey results confirm a positive relationship between government championship and performance. The results of the survey research reveal that government championship is a key variable in explaining project performance. Further, the results suggest that government championship is more important than public technology procurement and assistance.

Road construction compared with manufacturing and pharmaceutical firms

The findings of Chapter 5 suggest that there are no significant differences between road construction firms and manufacturing and pharmaceutical firms. However, when comparing Chapters 4 and 5, we see a difference in the relative importance of government championship and the dimensions in a firm's strategic behavior. In the large sample of firms, including road construction, manufacturing, and pharmaceutical firms, the positive relationship between government championship and performance is substantial but less strong than in the sample of only road construction firms.

Further, in the total sample, there is a preference for the defensiveness dimension in creating customer benefits. Contrary to the existing literature, our results indicate that firms perceive defensiveness to be the most important dimension in creating benefits for customers. From the large sample of mixed firms, the conclusion was that a higher level of proactiveness will increase project performance in terms of meeting budget, quality, and time objectives. Road construction firms value the defensiveness dimension for its benefits to both customers and to project performance.

Road Construction as a Large Technical System

In Chapter 1, we decided that large technical systems should be a guiding perspective in this dissertation. Road infrastructure, like telecommunications and railways, is a network of both physical and non-physical components. Most large technical systems have the characteristics of natural monopolies, owing to their size and high levels of capital investment. These characteristics have led to centralized control structures to maximize capacity utilization, and government ownership and regulation to overcome market failure.

Existing studies on large technical systems have mainly focused on energy, railways, and telecommunications (Davies, 1996; Geyer and Davies, 2000; Hughes, 1983; Jacobsson and Bergek, 2004; Markard and Truffer, 2006). These utilities have witnessed a shift from public operation and ownership to private exploitation which has led to substantial changes in their business operations (Geyer and Davies, 2000; Markard and Truffer, 2006). Privatization initiated restructuring and separation of former state-owned operators. As a consequence, the knowledge, skills, and resources for the business operations and system design were divided among several parties. In former state-controlled sectors, such as telecommunications and railways, privatization accelerated the restructuring and the outsourcing of tasks to suppliers (Davies, 2004). Suppliers manufactured the components and subsystems, and were increasingly involved in operational services. This allowed them to link product design to operational practices. As such, these suppliers gained important knowledge and skills that operators need to optimize a system. Consequently, privatization has initiated a transfer of the system builder role from the vertically managed state-owned operator to coalitions of private organizations (Geyer and Davies, 2000; Jacobsson and Bergek, 2004). This creates a new dynamic in developing and commercializing new technology. All the actors involved in a privatized large technical system need each other to direct technical change. This encourages and facilitates cooperation and the exchange of information among different actors. Further, the increasing involvement of suppliers in operational services has led to them offering so-called "integrated solutions" encompassing the product technology and complementary services, such as maintenance, finance, and exploitation (Davies, 2004). In addition, government interventions are now primarily cooperative or catalytic, to ensure societal goals, such as safety, reliability, and universal service, are met (Geyer and Davies, 2000). Government's main concern in these privatized large technical systems is to align technical change with societal needs. The added value of government intervention is in creating the conditions for a new technology to become self-sustaining. These conditions relate to coalition building among private capital and technology advocates in order to support the emergence of technology-specific system builder coalitions (Jacobsson and Bergek, 2004).

Our findings related to road infrastructure show that government is still the most important actor in technology development. Road construction firms perceive government championship as more important to performance than their own strategic orientation. Although developments in road infrastructure provision have led to outsourcing and performance-based tendering (Gann et al., 1998; Ivory et al., 2003), the involvement of road construction firms and other suppliers in operational services is low. The use of contracts that outsource design tasks are increasing, but the use of contracts that incorporate maintenance and operations are rare. Even in the UK, which leads in the outsourcing of operational services, there are few contracts that combine design, build, maintenance, and exploitation. Since the start in 1992, such contracts have only been applied in about eight road infrastructure projects (National Audit Office, 2007). In the Netherlands, four road infrastructure projects involving private financing, maintenance and/or exploitation have started since 1999 (Committee on Private Financing of Infrastructure, 2008). Thus, overall, the restructuring in tasks is far less radical than in, for example, telecommunications and energy. Further, the reduction in technical staff in the Dutch and US Highways agencies has been limited, and these government agencies still retain considerable knowledge on system operations and design.

Further, the results in Chapter 3 indicate that firms do not yet have the capabilities needed to take on the role of system builder in road infrastructure. In particular, traffic management and operation remain capabilities of the highway agencies. As the operator and owner, these agencies have a direct interest in the technologies developed. These agencies identify opportunities for technical change, determine their priorities, and decide on how to implement technical changes. In road infrastructure, government intervenes to ensure its intrinsic needs are fulfilled. Government remains the lead user that puts future needs on the agenda and adapts new technologies to fit its operational practices (Von Hippel, 1988). This creates a different dynamic than in privatized large technical systems.

Overall, government has a distinct effect on technology development in road infrastructure. As buyer, owner, and operator, government has a direct interest in new technologies. Furthermore, government still controls the financial, societal, and technical developments of the road infrastructure system. Therefore, government remains the system builder in road infrastructure.

Methodological Reflections

In this research project, we started with a literature review and some qualitative research. The findings of the qualitative research led to a refined literature review and the subsequent quantitative research. One consequence of this approach is that we struggled with the operationalization of the various constructs in the research project. While qualitative and quantitative approaches both require the definition of constructs, they apply a different logic. In our qualitative study, we explored phenomena, and construct definition was used as a focusing device. Therefore, the initial definition of our constructs was intentionally broad. In our quantitative study, we tried to establish causal relationships between certain types of behavior and project performance. In the quantitative study, we therefore sought construct operationalizations that had high internal and external validities. Consequently, we opted for validated measurement items. This led to slightly different definitions of our constructs. An example is the construct championship: in Chapter 2, we used a broad definition of championship: *"we define government championship as a supply-oriented policy to provide technical assistance, political support and human resources to firms engaged in technology commercialization."* This definition covered the observed behavior in the qualitative study and was in line with existing definitions in qualitative research (e.g. Morris and Hough, 1987). For the quantitative study, we adapted items on championing behavior that had been developed in the new product development literature. Here, for championship, we adopted the definition of Howell and Shea (2001): *"championing behavior is making a decisive contribution to any innovation by actively and enthusiastically promoting its progress through the critical development stages."*

In analyzing the data, we made different choices in Chapters 4 and 5. In Chapter 4, we used an Ordinary Least Square (OLS) regression analysis. In Chapter 5, we instead used a Seemingly Unrelated Regression analysis because the dependent variables (project performance and benefits to customers) were likely to have correlated error terms, and OLS presupposes unrelated regression equations. This suggests that the results in Chapter 5 are statistically more robust.

This research project started out by highlighting the continued importance of the public sector and the neglect of technology development in this sector. To examine technology development in the public sector, we chose to focus on road infrastructure. Focusing on road infrastructure proved helpful in understanding government's diverse roles and the potential conflict between the government roles of buyer and of champion of new technology. However, this decision affects the generalizability of the results for the public sector. As a partially public good, road infrastructure certainly has parallels with other partially public goods, such as energy, telecommunications, health, and railways. However, most of these other goods have been largely privatized, whereas road infrastructure remains largely publicly owned. Therefore, the impacts of the diverse government roles on technology development projects are likely to be greater in road infrastructure than in the other partially public goods. Nevertheless, an increased understanding of the interdependencies among the diverse roles of government and their relative impact on road infrastructure is a valuable starting point for further research into other partially public goods.

Implications

Implications for management

The management implications of this study are threefold.

- First, it has shown that road construction firms have to cope with varying degrees of customer involvement in their technology development projects. Road construction firms are used to working to customer order despite government customers being unable to provide certainties about size and timing of demand, or about the scope of a new technology. Further, government is not allowed to favor one firm or technology over another as it has to be unprejudiced and transparent in awarding contracts. Because of this, government customers favor cost-based selection criteria. However, the added value of significant technical improvements is difficult to establish as most new technologies are unproven and involve substantial risks. Further, these risks require cooperation, information exchange, and mutual adaptation between procurers and suppliers. Such an interaction seems to be precluded by the tendering system (Edquist and Hommen, 2000). Consequently, the current practice in public procurement is more likely to encourage incremental improvements in existing technologies rather than significant innovations. Further, given the dominance of cost-based selection criteria, firms that emphasize the defensiveness dimension in their corporate strategy are expected to outperform rivals that stress innovation-oriented behavior.
- Second, in road infrastructure, customers have traditionally engineered the required infrastructure in considerable detail and specified what materials to use. Construction firms have then to provide the resources needed to build the required infrastructure. Subsequently, the operation and maintenance of the infrastructure would be left to the customer. Working under these conditions, road construction firms developed few capabilities in system design and operational services. However, in recent years, the construction of infrastructure has been combined with the delivery of services. These services can involve engineering, financing, maintaining and/or exploiting the infrastructure. As a result, road construction firms now have to consider the design, maintainability, and lifecycle costs of their offerings. This has consequences for the required

capabilities in technology development and commercialization. Increasingly, road construction firms have the ability to feed operational experience and skills back into their technology development activities. As they become involved in operational activities, they have an incentive to develop reliable and more efficient technologies (Davies, 2004). In this process, relevant issues include the educational background of their people, the existence of external linkages to universities and suppliers, and organizational support (Hansen and Tatum, 1989). At the project level, technology development involves a network of suppliers, customers, regulators, and financiers, and so system integration capabilities are required. These capabilities are necessary in order to integrate the diverse knowledge inputs in a way that meets technical, financial, and social requirements (Davies and Brady, 2000). At the cross-project level, senior management needs these capabilities to manage the technology project portfolio and diversify into new lines of business (Davies and Hobday, 2005).

- Third, it is worth *road construction firms investing in professional relationships with champions within government*. The importance of championing behavior in the success of technology development projects emphasizes the relevance of interacting with government officials. This interaction works two ways: on the one hand, it provides access to information about policy developments and regulations, on the other, it provides opportunities to affect government processes (Baysinger, 1984). Although corporate political strategies can hint at corruption (Baysinger, 1984), they are an accepted reality in the competitive strategies of firms (Baron, 1995; Hillman et al., 1999; Shaffer and Hillman, 2000). Strategies involving lobbying and contributions to interest groups are widely known (e.g. Hillman et al., 1999). Generally, corporate political strategies are more important when more market opportunities are controlled by government (Baron, 1995). Further, if the dependence on government increases, firms are likely to pursue influence strategies, such as personal visits and informing government officials about the effect of legislation or technological developments (Birnbaum, 1985). Our results suggest that successfully influencing champions within government will increase the effectiveness of such corporate political strategies.

Implications for policy

From a policy perspective, the implications are complicated. As mentioned earlier, government has diverse and possibly conflicting interests that hinder the emergence of a market for new technology.

- The first implication refers to government as innovator. To stimulate new technologies that meet societal needs, government has several potential policy options. Supply-side policies, such as subsidies, tax incentives, and other fiscal measures are usually limited in duration to just a few years. Therefore, such policies are not effective in bringing about substantial changes because significant new technologies take several years to reach the commercial stage. Public procurement seems better placed to create a market for new technology (Edler and Georghiou, 2007). In this respect, the Launching Customer concept of the Dutch Treasury is interesting. The Dutch government has made it a formal policy to procure innovative technologies and create a market for new technologies provided they serve wider societal needs. This reflects the cooperative and catalytic types of public technology procurement described by Edler et al. (2005). *An important consideration in these types of public technology procurement is that it must be buyer-driven.* The lessons learned from the US energy-efficient technology procurement projects highlight this fact. Public technology procurement programs should allow for the emergence of a critical mass of target buyers. Technology procurement is not a one-step function that ends with the market introduction of a new technology (Ledbetter et al., 1999). Likewise, timing the demand enables suppliers to develop the necessary level of sophistication (Edquist et al., 2000a). Further, public technology procurement has to provide opportunities to incorporate technological improvements (Edquist et al., 2000a). This will enable firms to redesign and refine their technologies to solve initial problems. We would recommend that the various procuring agencies develop a comprehensive policy regarding innovation and define goals, budget, and time schedules.
- A second policy implication relates to the difficulty of valuing new technology. As suggested, the strongest incentive for firms to develop socially desirable technologies is the emergence of a market for those technologies. However, the cases show that government procurement tends to be based on cost criteria. *The use of technologies that meet societal needs could be enhanced if procurement criteria rewarded such technologies.* As a result, firms would be encouraged to develop and commercialize these technologies. In the UK, for example, general procurement policy

is designed as an instrument of technology policy. Innovation is a general criterion in tenders and in the assessment of tender documents (Edler et al., 2005).

- Third, *government could increase technology development and commercialization through government championship*. The Dutch government, as elsewhere, has increasingly left the supply of public goods and services to private organizations. Privatization and liberalization have become the fashion in public office over the past two decades. However, the private organizations involved require information about public policy issues, relevant regulations, and changes in legislation and procedures if they are to deliver public goods and services. Without this information, and government officials facilitating this process, private organizations will find it difficult to provide goods and services that improve service quality and meet the changing needs of society. This research and previous studies have shown that the technical staff in government agencies do perform this championing role. Technical staff members are well aware of user needs and their problems with existing technologies. At the same time, they are aware of new ideas and innovations and introduce these to users and political decision-makers (Edler et al., 2005). These staff members are the boundary spanners that help policy makers learn about technology and market issues (Ledbetter et al., 1999). The technical staff can create internal acceptance, assess appropriate functionalities, and develop specifications (Edler et al., 2005). As such, technical staff identify opportunities, influence top management perceptions, and motivate key participants. Further, they are able to discuss the reasonableness of specifications and requirements with industry members to increase the success of public technology procurement (Edler et al., 2005; Ledbetter et al., 1999). Our case study findings substantiate the importance of technical staff within government agencies. Technical staff members convince procurers to allow new technologies and are involved in drafting requirements and defining tender criteria. Technical staff members bridge the gap between external technical developments and internal user needs. Unfortunately, given this finding, the US and Dutch Highway Agencies are cutting their technical staff. In outsourcing design, and other tasks and responsibilities, these governments anticipate their technical staff becoming obsolete. Our findings suggest the opposite.

Agenda for Future Research

In this dissertation, we have taken an important step in assessing the importance of government roles for technology development and commercialization. However, further steps need to be taken to advance understanding of technology development and commercialization in the public sector. The findings in this dissertation suggest five important topics for future research.

- First, our research shows the relevance of government championship. This will enrich the ongoing debate about government's role in technology development and diffusion. In the present debates, scholars focus on technology transfer between universities and firms (e.g. Breznitz et al., 2008; Radosevich and Kassicieh, 1993; Shane, 2002; Sherwood and Covin, 2008) and the different levels of government (e.g. Kaiser, 2003; Kuhlmann, 2001). Our research has highlighted the importance of a cooperative attitude between government and its suppliers in technology development projects. Government's technical staff members, as potential champions, are important in creating awareness of new technologies. Future research could examine how to nurture and foster champions within government and how to make them visible for firms. Research opportunities exist to analyze the personality characteristics of existing government champions in order to identify the type of person that is likely to act as a champion (Howell et al., 2005). Another research opportunity is to identify those organizational characteristics that facilitate champion behavior (e.g. Markham and Griffin, 1998).
- Second, this dissertation shows that project-based firms warrant greater attention in strategic management research and literature. Our findings suggest that, in project-based firms, orientations can vary from project to project depending on project characteristics and specific customer needs and requirements. Further, other research suggests that the existing project management tools cultivate the notion that each project is unique (Lyneis et al., 2001). This makes achieving a comprehensive strategy across projects difficult. In addition, most project-based firms have to cope with the difficulties of aligning their technology project portfolio with their network of customers, suppliers, and financiers (Tikkanen et al., 2007). How to manage strategic orientations across multiple projects and in diverse project-related networks is an area of research that has hardly been addressed. Most strategic management research concentrates on the intra-firm environment and how to align strategic orientation with marketing and development activities.

Future research could focus on managing a portfolio of project-related strategic orientations. A fascinating topic would be to look at information sharing and the interdependencies between the various organizations in project-related networks. Existing research in project-based firms has shown that cross-project learning and the project-organization interface are challenging for project-based firms (e.g. Gann and Salter, 2000; Prencipe and Tell, 2001). Another important issue might be the confidentiality and availability of the information required to guide strategic behavior.

- Third, an important supposition underlying this research was that if a firm is heavily dependent on one (type of) customer, that this customer will affect the firm's strategy and investment in new technology. Although this notion is not new (e.g. Christensen and Bower, 1996), it shows that government procurement can be an important instrument in stimulating and directing technology development. Many governments have acknowledged the importance of procurement in innovation, but little progress has been made in understanding practices that lead to successful innovation (Edler and Georghiou, 2007). Other studies have revealed that market intelligence and risk sharing are topics that need attention (e.g. Edler et al., 2005). Unresolved issues include how to assure that government achieves a good understanding of technological opportunities without favoring one firm over the other, and how to share risks and returns such that firms are willing to invest in new technology without all the risks being transferred to society. Current literature on public procurement stresses the need to be transparent and unbiased, and favours arms-length transactions (Edquist and Hommen, 2000). However, the fact that transactions are not discrete events, but are embedded in a history of prior transactions and relationships, is ignored (Gulati et al., 2000). Transactions and relationships are defined and shaped through the social networks in which firms and government are embedded (Gulati, 1998). In the literature on alliances and networks, much progress has been made by accepting the social embeddedness of economic transactions. Risk reward systems, coordination mechanisms, and knowledge sharing routines (e.g. Gulati and Singh, 1998; Dyer and Singh, 1998) are seen as important topics for research about technology alliances and joint ventures in the public sector. Also, behavioral aspects of inter-organizational relationships are an important theme. Interest in partnerships between government and construction firms is rising, but an understanding of behavioral incentives is still lacking (Bresnen and Marshall, 2000). Further research could focus on behavioral aspects that affect success, such as communication behavior and conflict resolution techniques (e.g. Mohr and Spekman, 1994).

- Fourth, another issue is that there is no clear definition of supply- and demand-side policies in technology policy studies. Some use a more differentiated definition and include indirect or environment-oriented policies as a third category (e.g. Moon and Bretschneider, 1997; Shyu and Liu, 2002). Some define demand-side policies as strictly public demand (Moon and Bretschneider, 1997; Shyu and Liu, 2002), while others use a broader characterization of demand-side policies including demand subsidies to stimulate private demand (Edler and Georghiou, 2007). Edler and Georghiou's work on supply- and demand-side policies is an important first step, but further research is needed to not only categorize policy instruments, but define a clear taxonomy of these policies.
- Finally, we were faced with the difficulty of measuring the effect of public technology procurement at the project level. Most research on public technology procurement is indicative, or uses aggregated data (e.g. Edquist and Hommen, 2000; Lichtenberg, 1988). Although we did devise a measurement for public technology procurement, further refinement is needed.

Apart from these topics for future research, there are several limitations in our study that could be overcome by further research. These limitations have been addressed in the limitations and future research sections of the various chapters and include aspects such as the combined effect of other relevant dimensions of government behavior, customer and competitor orientation, and customer involvement.

We are confident that we have contributed to a better understanding of technology development in the road construction industry. Further, our research is a significant step in offering managerial and policy measures that could improve the innovative performance of road construction firms. Perhaps most importantly, we have clarified the interdependencies between the diverse government roles in technology development and commercialization, and the impact of these roles on the performance of technology development projects. Given the wider discussion on technology policy instruments, our research has shown that government championship can be an important complementary policy to public technology procurement and stimulate innovation and diffusion.

Summary

This dissertation contributes to both the academic and policy debates on the roles of government in technology development in the public sector. In the literature, there are many perspectives that deal with government's roles in technology development. These perspectives include competition, property rights, market failure and science and education. Depending on these perspectives and their emphasis on demand pull or technology push, scholars have advocated a laissez-faire approach or an active role in encouraging R&D investments and the development and diffusion of new technology. Only few perspectives address both supply and demand-side roles, these include national system of innovation and large technical systems. In this study we use large technical systems as a guiding concept. Large technical systems are characterized by a capital-intensive infrastructure, a broad range of technical components and the involvement of a variety of actors and institutions. Examples are energy and road infrastructure.

In this study, we concentrate on road infrastructure. Road infrastructure consists of physical and non-physical components such as roads, bridges, regulations and traffic monitoring equipment. These components form a network that hierarchically links roads of various classes. There are several reasons why we have studied road infrastructure. In this industry, road construction firms have to cope with significant government involvement in their development activities. In most countries, government is the sole buyer of road infrastructure and, therefore, has substantial buying power. Furthermore, as a regulator, government has a high concern for public safety and the environment. Road construction involves a high degree of social responsibility. As a consequence, there are many construction-related regulations which lead to conservatism in design. In addition, the government agencies are bound by regulatory and procurement policies and so these policies play an important part in shaping the direction of technological change.

In recent years, the attitude of governments towards construction firms has changed. In the United States, the Department of Transport has started the Research and Technology Coordinating Committee to encourage innovation and the transfer of federally funded technology to the private sector. In Europe, the reports about rethinking construction have had a substantial impact upon policies towards procurement and innovation in several countries, including the Netherlands. Based on these reports about the deficiencies in

construction, government has made changes in their procurement policies. A significant change is the integration of design and construction. Government expects that this change will reduce costs and improve overall performance. Furthermore, using the knowledge of construction firms in the design broadens the scope of the technological solutions offered. Besides these general changes in procurement policy, the Dutch government is reducing its technical staff, creating the need for outsourcing of design and other tasks and responsibilities. It has shifted its focus towards creating the conditions for innovation rather than developing innovative designs by itself.

This research project has aimed to enrich our understanding of technology development processes within road infrastructure and the relevance of government behavior for the development and adoption of new technology. Furthermore, this research project intended to identify the interdependencies between the diverse roles of government in technology development and commercialization and develop an analytic model to assess the impact of government roles.

Based on these objectives we had formulated the following research questions:

- What are the relevant government roles and how do they affect technology development projects?
- What are the relevant dimensions of firms' strategic behavior and how do they affect technology development projects?
- How important are the various government roles for the performance of technology development projects?

At the start of this research project we expected that the role of system builder would become blurred, indicating that no single organization would be powerful enough to direct technological change. Consequently, we expected coalitions of public and private actors to act as a system builder rather than government alone. This suggested a shift in government roles and, therefore, we needed to understand what the relevant government roles were and how they affected technology development. Furthermore, we expected road construction firms to develop their strategic and systems integration capabilities to respond successfully to the shift in tasks and roles. This would affect their corporate strategy in developing and commercializing new technology. Therefore, we examined what the relevant dimensions of firms' strategic behavior were and how they affected technology development.

To extend the generalizability of our findings we included a group of manufacturing and pharmaceutical firms. This has allowed us to examine the relevance of government behavior in industries that are considered to be less dependent on government as a customer.

To answer our research questions we have subdivided the research project into four steps.

First, we conducted an exploratory research to examine the relevant roles and dimensions of government and firms regarding technology development. This exploratory research entailed a literature review of public management, technology policy, new product development, strategic management and project-based firms.

Second, we carried out a qualitative research to confront the findings in literature with the empirical findings about technology development in road construction. The qualitative study allowed us to refine the conceptual models based on the literature and include additional factors not mentioned in the literature. The qualitative research consisted of a multiple case study in three road construction firms and spanned eight technology development projects.

Third, we conducted a large-scale survey in the United States to quantitatively examine and test the conceptual models.

Finally, we reflected on the research findings and their implications.

Our results regarding the first research question indicate that government has an extensive range of policies that affect technology development projects. We identified several supply- and demand-side policies, such as funding of private R&D, championing new technology and the procurement of new technology. Furthermore, we addressed the regulatory framework and accounted for tax incentives, the property rights regime and standard setting. Our findings showed that these policies are dispersed over various government agencies across different levels of government. This leads to the uncoordinated implementation of both supply-side and demand-side policies and has several consequences. First, the inconsistency in government championship (supply-side), on the one hand, and public technology procurement (demand-side), on the other, hinders the emergence of a market for new technology. Championship promotes technology champions, while public technology procurement cannot favor one firm over the other. Government has to be "technology-blind". Second, government's priorities are a result of a compromise between multiple and competing objectives. This makes government hesitant to commit itself to a specific course of action. Therefore, government cannot guarantee to create a market of a certain size for a specific technology. As a consequence, firms face additional uncertainties in assessing market opportunities and the potential of new technologies. Third, the dominant position of government and the persistence of competitive bidding erode the effectiveness of Intellectual Property Rights. Therefore, investing in patent positions to capture the profits of new technology does not provide a competitive advantage. Taken together, these results suggest that government championing behavior, public technology procurement and, to a lesser extent, public funding of private R&D are the relevant roles that affect technology development projects. These roles influence both the development and the diffusion of new technology.

The second research question concerns the implementation of business strategy in developing and commercializing new technology. We distinguished four strategic orientations that guide technology development activities. We saw that project definition and the analysis of information strongly relied on the specific targets of the project. In some instances, this led to inconsistencies between the strategic orientation used at the project level and the intended strategy at the corporate level. As a result, the utilization of established capabilities and resources was impeded. In addition, the results indicate that firms mainly employ an innovation and a customer orientation in their technology development projects. Firms react to explicit needs of their customers and develop new technology when necessary to meet these needs. In developing new technology they depended on external technology sources and market intelligence. All firms studied needed others to assess market opportunities or develop new technologies.

The third research question was covered by the survey. The results of the survey substantiate the relative importance of government roles for the performance of technology development projects. In road construction, government championing behavior is more important than firms' strategic behavior. For manufacturing and pharmaceutical firms, government championship is less crucial to the success of technology development projects, although it is the second most important factor in creating benefits to customers. Surprisingly, for all firms in the survey an internal focus on cost and process optimization is most important in creating benefits to customers.

This research project has made four main contributions to literature:

- First, *we have made a review and analysis of the combined impact of government roles on technology development.* Previous research in the management literature has mainly focused on the effect of government as a regulator or sponsor on private R&D. However, this research has shown that government roles extend beyond regulations and funding. Government as a buyer and champion is a significant factor in the success of technology development projects. Our research underscores that championing new technology is an important instrument in technology development and commercialization.

- Second, we have developed a framework to analyze strategy implementation in project-based firms. This framework was lacking. The framework shows that there are insufficient incentives and capabilities at the cross-project level to apply solutions from technology development projects into business projects. The lack of program management in technology development projects seems to limit the opportunities for new lines of business. Also, the extensive use of external sources of technology impedes the accumulation of knowledge and the development of routines for efficient execution of similar projects, thereby, restricting the opportunities for "economies of repetition".
- Third, we have conducted a large-scale survey and developed a measurement for government championship. We have tested the relevance of government championship in several industries, and its relative importance compared to public technology procurement, government assistance, and a firm's strategic orientation.
- Fourth, we have extended the strategic management literature to road construction, a low-technology industry. Existing studies in the management literature are biased towards medium- and high-technology industries. We have examined the strategic orientation of road construction firms in developing and commercializing new technology.

Our findings show that government championing behavior is key in the success of technology development projects. The relative impact of championing behavior on performance exceeds both public technology procurement and government assistance. The surprising result on the negative effect of public technology procurement on performance warrants further research. Furthermore, the defensiveness dimension in a firm's strategic orientation is most important for enhancing the benefits of the new technology to customers. Existing studies showed that the defensiveness dimension supports business profitability, whereas the proactiveness dimension is positively related to exploiting market opportunities. Our study shows that these dimensions should not be seen as opposites but complementary in achieving high performance.

Nederlandse Samenvatting

Technologieontwikkeling in de wegenbouw

Hoe de rollen van de overheid het projectresultaat beïnvloeden

Deze dissertatie levert een bijdrage aan zowel de wetenschappelijke als maatschappelijke debatten over de rollen van overheid in technologieontwikkeling in de publieke sector. In de literatuur zijn vele perspectieven die de rollen van de overheid in technologieontwikkeling bespreken. Deze perspectieven hebben betrekking op concurrentie, eigendomsrechten, marktfalen, wetenschap en onderwijs. Afhankelijk van het gekozen perspectief en de nadruk op "demand pull" en "technology push" hebben wetenschappers een laissez-faire of een actieve houding van de overheid bepleit in het stimuleren van investeringen in onderzoek en ontwikkeling en de diffusie van innovaties. Er zijn echter maar enkele perspectieven die zowel aanbod- als vraaggestuurde beleidsinstrumenten behandelen. De perspectieven Nationale systemen van innovatie en Grote technische systemen doen dit wel. In dit onderzoek gebruiken we Grote technische systemen als overkoepelend perspectief. Grote technische systemen worden gekarakteriseerd door een kapitaalintensieve infrastructuur met een variëteit aan technische componenten, instituties en actoren. Voorbeelden zijn de energievoorziening en de transportinfrastructuur.

In dit onderzoek richten wij ons op de transportinfrastructuur. Het Grote technische systeem Transportinfrastructuur bestaat uit fysieke en niet-fysieke componenten zoals wegen, bruggen, dynamisch verkeersmanagement en verkeersregels. Er zijn een aantal redenen waarom wij naar transportinfrastructuur kijken. In dit systeem is de overheid de belangrijkste afnemer en de overheid heeft daardoor aanzienlijke inkoopmacht. Daarnaast is de transportinfrastructuur een sterk gereguleerde sector. Infrastructuur is een publiek goed en daarmee is er vanuit de overheid een grote zorg voor de veiligheid en het milieu. Dit leidt tot veel regels en behoudende ontwerpen. De transportinfrastructuur lijkt daarmee een geschikte sector om het effect van de verschillende rollen van de overheid op technologieontwikkeling te onderzoeken.

In de afgelopen jaren is de houding van de overheid ten aanzien van (wegen)bouwbedrijven veranderd. In de Verenigde Staten heeft het ministerie van Transport een commissie opgestart om innovatie en de verspreiding van publiek gefinancierde technologie naar bedrijven te stimuleren. In Europa zijn ook verschillende initiatieven gestart die tot een andere manier van denken over aanbesteden en innovatie hebben geleid. In Europa en in de Verenigde Staten is meer aandacht voor contractvormen waarin ontwerp en uitvoering integraal worden uitbesteed. Overheden verwachten dat deze veranderingen zullen leiden tot lagere kosten en een betere prestatie van de geleverde producten en diensten. Ook wordt door de andere contractvormen meer gebruik gemaakt van de kennis van bouwbedrijven, waardoor er een grotere variëteit aan technologische oplossingen kan worden aangeboden. Buiten deze algemene ontwikkelingen in de houding van de overheden wereldwijd, is de Nederlandse overheid ook bezig met het verminderen van haar technische staf. Dit leidt tot een grotere behoefte aan het uitbesteden van ontwerp- en andere taken. De Nederlandse overheid verschuift haar blik van het in eigen huis ontwikkelen van nieuwe technologische toepassingen naar het creëren van condities die innovaties stimuleren.

Dit onderzoek heeft tot doel het begrip van technologieontwikkeling in de publieke sector te verbeteren en het inzicht in de relevantie van overheidsrollen voor technologieontwikkeling en –adoptie te vergroten. Daarom hebben we ons de volgende drie vragen gesteld:

- Wat zijn de relevante rollen van de overheid in technologieontwikkeling en welk effect hebben deze rollen?
- Welk effect hebben de relevante dimensies in het strategisch handelen van bedrijven op technologieontwikkeling?
- Hoe belangrijk zijn de relevante rollen van de overheid voor de uitkomsten van technologieontwikkeling?

In tegenstelling tot het meeste onderzoek naar overheidsrollen neemt dit onderzoek niet het meso- of macroniveau, maar technologieprojecten binnen wegenbouwbedrijven als analyseniveau. De onderzoeksvragen zijn in vier stappen beantwoord. De eerste stap was een uitgebreid literatuuronderzoek in de velden: technologiebeleid, productontwikkeling, projectorganisaties, strategisch management en publiek management.

Met behulp van deze literatuur zijn conceptuele modellen ontwikkeld die het kwalitatieve onderzoek hebben gestuurd, de tweede stap in het onderzoek. In deze tweede stap zijn een drietal bouwbedrijven nader bekeken en acht technologieprojecten geanalyseerd. De uitkomsten van de kwalitatieve studie hebben geleid tot een verfijning van de conceptuele modellen.

In de derde stap is een kwantitatieve studie gedaan, waarin een drietal rollen van de overheid nader zijn belicht, te weten: de overheid als kampioen, afnemer en als sponsor. De kwantitatieve studie is uitgevoerd in de Verenigde Staten vanwege het geringe aantal wegenbouwbedrijven in Nederland dat regelmatig voor de rijksoverheid werkt. De conceptuele modellen uit de vorige stap zijn verder uitgewerkt tot een aantal hypothesen dat is getoetst. Om de resultaten van de Amerikaanse resultaten in perspectief te plaatsen is dezelfde vragenlijst ook voorgelegd aan Nederlandse wegenbouwbedrijven. De vergelijking van deze resultaten is te vinden in Appendix 1A.

Ter afronding hebben we het effect van de overheid als kampioen en als sponsor vergeleken tussen wegenbouwbedrijven en elektronica en farmaceutische bedrijven. Onze verwachting was dat het effect voor de wegenbouwbedrijven sterker zou zijn, omdat zij meer afhankelijk zijn van de overheid als kampioen en sponsor.

De resultaten met betrekking tot de eerste onderzoeksvraag laten zien dat de overheid over een breed palet aan instrumenten beschikt die een effect hebben op technologieontwikkeling. Voorbeelden zijn subsidiëren van private ontwikkelingsprojecten, het promoten van specifieke technologie of het inkopen van nieuwe technologie. Deze instrumenten zijn echter verspreid over verschillende ministeries en agentschappen, en meerdere overheidslagen. Het gevolg is dat deze instrumenten onvoldoende worden gecoördineerd. Dit heeft verschillende gevolgen. Ten eerste, de inconsistentie tussen de overheid als kampioen en als afnemer bemoeilijkt het ontstaan van een markt voor nieuwe technologie. De overheid als kampioen stimuleert specifieke technologie en bedrijven, terwijl de overheid als afnemer de ene technologie of aanbieder niet mag prefereren boven de ander. Daarnaast zijn de prioriteiten van een overheid vaak een compromis van vele, om voorrang strijdende doelen. Daarom is de overheid terughoudend om zichzelf vast te leggen en een markt voor een specifieke technologie te garanderen. Dit betekent dat bedrijven geconfronteerd worden met extra onzekerheden bij het inschatten van marktkansen en de potentie van nieuwe technologie. En ander aspect is de dominante positie van openbaar aanbesteden bij de overheid als klant. Openbaar aanbesteden beperkt de effectiviteit van patenten om een bevoorrechte marktpositie te verwerven. De overheid mag immers geen monopolist steunen. Het gevolg is dat investeren in patenten om de opbrengsten van nieuwe technologie zeker te stellen geen concurrentievoordeel opleveren. Uit deze resultaten blijkt dat kampioen, afnemer en, in minder mate sponsor, de dominante rollen zijn van de overheid in technologieontwikkeling en commercialisatie.

De tweede onderzoekvraag richt zich op het strategisch handelen van bedrijven. De resultaten illustreren de worsteling van bedrijven om hun bedrijfsstrategie te implementeren in hun technologieprojecten. De wegenbouwbedrijven zijn sterk projectgedreven en zij richten zich op de strategische doelstellingen van de individuele projecten. Het gevolg is dat er een geringe consistentie is in de strategische oriëntatie op business unit en projectniveau. Ook wordt daarom weinig gebruik gemaakt van elders in de organisatie ontwikkelde competenties en middelen. De resultaten laten zien dat de bedrijven voornamelijk gericht zijn op wat de klant wil. Als voor de behoefte van de klant nieuwe technologie ontwikkeld moet worden, dan wordt dat gedaan. De bedrijven richten zich daarbij op de expliciete klantbehoeften en niet op toekomstige of latente behoeften. Ook zijn de bedrijven bij de ontwikkeling van nieuwe technologie sterk afhankelijk van derden. Zowel voor de technische ontwikkeling als de commercialisatie worden derden ingeschakeld.

De derde onderzoeksvraag is beantwoord met de resultaten van de kwantitatieve studie. Deze studie onderbouwt het relatieve belang van de overheid als kampioen en afnemer voor technologieontwikkeling in de transportinfrastructuur. In deze sector lijkt de overheid als kampioen belangrijker dan het strategisch handelen van bedrijven voor de uitkomsten van de technologieprojecten. Voor elektronica and farmaceutische bedrijven is de overheid als kampioen minder belangrijk voor technologieprojecten, maar nog altijd de tweede factor in het creëren van toegevoegde waarde voor de klant. Opvallend is dat voor alle bedrijven in het kwantitatieve onderzoek een focus op interne procesverbetering het meest belangrijk is in het creëren van toegevoegde waarde voor de klant.

Concluderend kan gezegd worden dat de overheid in zijn rollen als kampioen en afnemer cruciaal is voor de uitkomsten van technologieontwikkeling. De bevindingen laten zien dat het gedrag van de overheid als kampioen in de publieke sector relatief belangrijker is dan de overheid als afnemer of sponsor.

Dit onderzoek heeft vier belangrijke bijdragen aan de literatuur opgeleverd.

- Ten eerste, is een uitgebreid(e) overzicht en analyse gemaakt van de impact van overheidsrollen op technologieontwikkeling. Voorgaande studies in de management literatuur hebben zich vooral gericht op het effect van de overheid als regelgever of sponsor van onderzoek en ontwikkeling. Dit onderzoek laat zien dat de relevante overheidsrollen meer bestrijken dan regelgeving en subsidieverlening. De overheid is als afnemer en kampioen

een significante factor in het succes van technologieontwikkelingsprojecten.
- Ten tweede, hebben wij een conceptueel model ontwikkeld om strategie-implementatie in projectgestuurde organisaties te analyseren. Het model maakt duidelijk dat strategische doelen op projectniveau leidend zijn in een project en dat de afstemming met de bedrijfsstrategie onvoldoende plaatsvindt. Het gevolg is dat elders in de organisatie opgedane kennis en middelen onvoldoende worden benut. Het gebrek aan programmamanagement om de kloof tussen project en business unit te overbruggen, beperkt de mogelijkheden voor het ontwikkelen van nieuwe business.
- Ten derde, hebben wij een grootschalige studie gedaan naar het effect van overheidsrollen en daarvoor een meetinstrument voor de overheid als kampioen ontwikkeld. Vervolgens hebben we het belang van de overheid als kampioen getest in verschillende sectoren. Daarnaast is duidelijk geworden wat de relatieve impact van de overheid als kampioen is vergeleken met de overheid als afnemer en sponsor, en de strategie van bedrijven.
- Ten vierde, hebben we de managementliteratuur uitgebreid door de strategische oriëntatie van wegenbouwbedrijven te onderzoeken. Voorgaande studies hebben zich vooral gericht op hoogwaardige sectoren, zoals elektronica, chemie en farmacie. We hebben deze literatuur uitgebreid met de analyse van een technologisch minder hoogwaardige sector.

Dit onderzoek heeft zeker geleid tot een beter begrip van technologieontwikkeling in de wegenbouw en de impact van de overheid op de uitkomsten van technologieprojecten. Ons onderzoek maakt duidelijk dat de overheid als kampioen een belangrijke complementaire rol heeft naast de overheid als afnemer om technologieontwikkeling te stimuleren.

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About the Author

Jasper Caerteling was born in 1979 in Doetinchem, the Netherlands. In August 2002, he received his M.Sc. in civil engineering and management at the University of Twente, Enschede. From September 2002 until late 2003, he has worked at the University of Twente as a research assistant. In December 2003, he started as a PhD candidate in the Department of Civil Engineering and Management, University of Twente. His Ph.D. research is about technology management in road construction firms and the roles of government in innovation processes.

He has published about his research project in the Journal of Product Innovation Management and has given presentations about this topic at several international conferences.

Appendix 1A Comparison US and Dutch Sample

We have researched road construction qualitatively in the Netherlands and quantitatively in the United States (US). To examine whether different institutional settings might affect our results we have conducted a small sample survey in the Netherlands. The main reason to use a sample of road construction firms in the US was the limited number of road construction firms in the Netherlands that work in heavy and highway construction. We used the translated questionnaire of the US sample for the Dutch survey. To ensure a high response rate and the participation of the larger firms we applied the following strategy. First, we used a mailing package that included a personalized letter, the questionnaire and a freepost envelope. This mailing package was sent to the small- and medium-sized road construction firms. Second, we made an appointment with the R&D managers of the larger firms to help them fill out the questionnaire. Our intended sample consisted of all road construction firms with an asphalt production plant to exclude the pavior firms. Of the 29 firms fourteen filled out the complete questionnaire, two firms declined to participate and thirteen did not respond. The respondents represent about 70 percent of the annual turnover in the Dutch heavy and highways construction industry. In Table 17, we have summarized the means and standard deviations of the Dutch and US sample.

Table 17 Means and standard deviation of Dutch and US sample

	Dutch sample		**US sample**	
	Mean	*s.d.*	*Mean*	*s.d.*
Championship	3.77	1.50	4.81	1.16
Public technology procurement	3.96	1.37	4.34	1.35
Internal/cost orientation	3.69	1.54	4.30	1.47
Innovation orientation	4.95	1.33	5.08	1.09
Firm size[a]	19.0	2.20	13.02	2.56

[a] We used the natural logarithm of last year's total revenues as an indicator for firm size

The results in Table 17 show that in the Dutch sample government championship is valued considerably less than in the US sample and has a larger standard deviation. The other means do not differ much except for firm size. The Dutch sample has relatively more large firms. This can be attributed to the data collection methodology. The results show that government championship is assessed differently; the other values do not indicate any significant differences between the Dutch and US situation. Concluding, further research is necessary about the way Dutch and US road construction firms interpret government championship. Yet, there is no reason to assume that the relevance of the diverse government roles will be different in the US compared to the Netherlands.