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How national institutions influence technology policies and firms' knowledge-building strategies: A study of fuel cell innovation across industrialized countries

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ABSTRACT

The central thesis advanced in this study is that firms' knowledge-building strategies can be usefully explained by the variations in their national institutional contexts. Using an inductive approach, a study of fuel cell innovation across the U.S., France, Japan and Norway demonstrates how countries' socio-political institutions – characterized by their levels of statism and corporatism – contribute to variations in technology policies pertaining to investment, collaboration, internationalization, and diversity. These technology policies are sources of advantages (and disadvantages) for firms, with implications for their knowledge-building strategies. The proposed theoretical framework is especially relevant in the context of industry emergence and R&D internationalization.

1. Introduction

A cross-national comparison of technology policies demonstrates that large variations in key dimensions such as the nature of R&D investments, collaboration, internationalization, and technological impact, persist even within the group of industrialized countries (OECD, 2007). How can we explain these variations in innovatory approaches and what are their implications for the knowledge-building strategies of firms in an emergent technology sector? Understanding the determinants of the cross-national variations in technology policies and their affects assumes special significance not only for new industry creation, but also when making location choices as multinational firms internationalize their R&D activities (Patel and Pavitt, 1991; Pavitt and Patel, 1999; Penner-Hahn and Shaver, 2005).

A large number of studies have recognized knowledge resources as a vital component of firms' innovatory and competitive advantage (Winter, 1987; Kogut and Zander, 1992; Zander and Kogut, 1995). By adopting an institutional perspective to explain technology policy variations and the associated impacts on knowledge-building, this study draws on the established wisdom that national innovation systems are embedded in a long history of interactions between the political and economic elites creating distinctive national systems of property rights, contractual relationships and governance systems adopted by resident firms (Fligstein, 2001; Guillen, 2001; Vitols, 2001; Casper, 2001; Casper and Matraves, 2003).

Based on simple indicators, the study evaluates the relevance of social and political institutions – reflected in the levels of statism and corporatism – for understanding the central tendencies pertaining to the key macro indicators of national technology policies. Next, to establish the salience of this institutional typology in the context of a specific industry, the study uses a case-based inductive approach to compare fuel cell technology policies in the U.S., France, Norway and Japan, in four key areas—the allocation of public resources, collaboration involving public and private actors, extent of foreign participation and technological diversity in the national innovation system. The variation in technology policies revealed by this analysis maps closely to the core institutional characteristics of countries reflected in their degrees of statism and corporatism. Finally, drawing on this comparative analysis of fuel cell technology policies that are embedded in distinctive national institutions, the study proposes firm-level implications for knowledge-building.

2. Cross-national variations in innovatory approaches: an institutional perspective

An appreciation of the macro institutional influences on the development and commercialization of emergent technologies has led to a large number of studies on how national institutions have either supported or constrained innovation in specific industries

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(Van de Ven and Garud, 1989; Porter, 1990; Dobbin, 1994; Murtha and Lenway, 1994; Mezias and Kuperman, 2001; Garud et al., 2002; Garud and Karnoe, 2003; Edquist, 2004; Murmann, 2004).

National institutions are important because they shape the technology policies, and the resultant opportunities and capabilities of firms engaged in technological development (Fligstein, 1991; Dobbin, 1994; Murtha and Lenway, 1994; Bartholomew, 1997; Lundvall, 1998; Mowery and Nelson, 1999; Soskice, 1999; Malerba, 2002; Casper and Whitely, 2004). Viewed from an institutional perspective, innovation is as much a social and political activity as it is a technical and rational process (Van de Ven, 2004). Thus, the emergence of new technologies is situated in a collective enterprise involving firms, government organizations, universities and consumer groups, such that firms not only engage in economic activity but are also involved in social relationships (Swaminathan and Wade, 2001).

Consistent with these findings, the Organization of Economic Cooperation and Development (OECD) in its recent report comparing innovation policies across industrialized countries noted that variations in industrial performance can be attributed in large measure to two factors—the role of government and the nature of cooperation among firms and non-firm actors (OECD, 2007). In a related study, Spencer et al. (2005) developed a theoretical framework suggesting that cross-national variations in the role of government and the nature of cooperation among societal actors can be usefully explained by juxtaposing two constructs – the levels of statism and corporatism – that characterize the socio-political institutional context of industrialized countries. They argued that national institutions characterized by a high level of corporatism (e.g. Japan and Germany) are usually more equitable in terms of distribution of technological and financial resources. In addition, corporatism results in extensive collaboration and high degree of welfare orientation that often pressures private firms to share social burdens (Schmitter, 1974). Whereas collective requirements and duties are stressed under corporatist systems,[1] individualism in interests and choices are more prominent in less corporatist or pluralist systems (Cawson, 1985). In less corporatist systems of society of which the U.S. and U.K. are cited as primary exemplars[2] (Hicks and Kenworthy, 1998), multiple and widely dispersed interests create competition but can also lead to cleavages and conflicts over policy preferences (Jankowski, 1989; Crouch and Streeck, 1997; Whitley, 2000; Royo, 2002).

Similarly, the level of statism characterizes the role of government in setting national technology policies and priorities[3] (Spencer et al., 2005). Highly statist models observed in Japan and France, for example, feature an imagery of central administration and planning of society or what Dyson (1980) called "integrated models of public power". The state in this model is the primary locus of social rationality, and politics are grounded in an objective search for national interests (Dyson, 1980; Badie and Birnbaum, 1983). In contrast, more societal or liberal systems found in Norway and the U.S., for example, locate authority in society at large, with government acting as an instrument and expression of society with less independent legitimation and standing (Skocpol, 1985; Katzenstein, 1978). The level of statism impacts the competitive landscape because policies instituted by government have implications for property rights allocated between public and private actors and the governance of transactions (Dyson, 1980; Hart, 1992; Murtha and Lenway, 1994).

The motivation for using the statist and corporatist dimensions of the national institutional environment in the present study is based on their utility for explaining both innovation and collaboration. The state, represented by the government, plays an important role in the development of new technological breakthroughs such as fuel cell technologies that are likely to impact the national and global economies. Further, new technologies such as fuel cells require extensive knowledge-building to allow for the transition to a hydrogen-based economy that is expected to make existing energy technologies obsolete in a variety of applications. Such an effort requires knowledge transfer through participation and involvement of a variety of firm and non-firm actors that are involved with producing and using fuel cell technologies. The nature of collaboration, therefore, can play a crucial role for addressing issues concerning technological hurdles and social acceptance that are perceived as deterrents to the successful diffusion of fuel cell technologies. The corporatist dimension helps better understand the proclivity of society to engage with different actors that constitute it and the social drivers for such engagement.

The relevance of these socio-political constructs in understanding the antecedents of the distinctive innovatory approaches is corroborated by an examination of relevant indicators of national technology policies across industrialized countries. Based on a 2-way analysis of variance, Tables 1 and 2 illustrate how the key indicators of national innovation systems obtained from the Science Technology and Industry Scoreboard (OECD, 2007) across 21 industrialized countries vary significantly across groups of countries according to their levels of corporatism and statism. Countries associated with each polity[4] (or system of rules that incorporate the characteristics of the state and civil society) are based on their core institutional structures, so that the existence and efficacy of statism and corporatism may be regarded as a matter of degree, and countries may vary in their proximity to the ideal type (Jepperson, 2002; Williamson, 1989).

2.1. Investment sources

Analysis of the data presented in Tables 1 and 2 shows that the percentage of government investment in civilian R&D tends to vary significantly across levels of corporatism. Less corporatist or pluralist countries like the U.S. and France, for instance, where multiple interest groups compete for resources, receive less government investment in civilian R&D. Higher government investment in more corporatist countries like Japan and Norway, for instance, likely results from a more unified collective bargaining apparatus. When considering the role of venture capital, the data suggests that this type of private investment is considerably smaller in countries characterized by strong states such as France and Japan compared to the U.S. and Norway, where the state plays a more facilitative role. Consequently, the data suggests that higher levels of corporatism and lower levels of statism embodied in the social-corporatist environment of Norway, for example, generates

[1] Corporatist theory can be applied to the macro, meso and micro levels of analysis (Cawson, 1985). In some countries like Germany, corporatism manifests itself at the macro level through extensive industry-level coordination. In Japan, the concepts of meso-level or group-level coordination such as the keiretsu are also in evidence. Micro-level corporatism may be observed when a monopoly exists and/or large or powerful firms can directly negotiate investment strategies with the state as in France (Chesnais, 1993). Our analysis, however, pertains primarily to macro- and meso-level corporatism.

[2] Hicks and Kenworthy (1998) and Kenworth (2003) provide a more detailed explanation of the measures used to develop corporatism scores based on the extent to which interest groups collaborate in society.

[3] Previous works categorized countries as statist or societal based on their composite scores on a number of dimensions such as the size of bureaucracy (Nettl, 1968), amalgamation of the political and administrative functions of government (Badie and Birnbaum, 1983), involvement of the government in industrial planning, investments, and banking practices, and business and government relations (Wright, 1988).

[4] Examples of countries corresponding to high and low levels of statism and corporatism are provided in Table 5.

Table 1
Analysis of variance for technology policy indicators.

	Investment sources		Collaboration		Internationalization		Innovatory performance
	%Government investment in civil R&D	%R&D financed by venture capital	%Firms collaborating with government	%Firms collaborating	%Business R&D financed by abroad	%Patents with foreign co-inventors	Relative performance of cited scientific articles
Statism	0.43	6.56*	2.46	0.73	0.37	0.64	9.15**
Corporatism	14.04**	0.32	11.57**	15.47**	0.55	0.26	1.60
Statism × Corporatism	0.66	3.23*	4.68**	3.27*	0.77	0.05	0.16
R^2	0.47	0.37	0.55	0.56	0.09	0.05	0.39

F-value (*p*-value); Total number of countries = 21; high statism countries = 11; low statism countries = 10; high corporatism countries = 11; low corporatism countries = 10.
* $p < 0.05$.
** $p < 0.01$.

Table 2
Scheffe's test for difference in means.

Variable	Difference in means statism (high-low)	Difference in means corporatism (high-low)
%Government investment in civil R&D	−0.03	0.20*
%R&D financed by venture capital	−0.07*	0.02
%Firms collaborating with government	−5.2	11.5*
%Firms collaborating	−4.4	16.9*
%Business R&D financed by abroad	−2.1	−2.4
%Patents with foreign co-inventors	−4.6	−2.1
Relative performance of cited scientific articles	−0.21*	0.09

* $p < 0.05$.

the most government and private venture capital investments for innovation.

2.2. Collaboration

Tables 1 and 2 reveal that firms in highly corporatist countries tend to collaborate significantly more when compared to firms in less corporatist countries. This contrast is also highlighted by the data on the percentage of firms collaborating with government institutions. The nature of alliances can contribute to knowledge sharing, contribute to social capital and also confer legitimacy to firms (Dacin et al., 2007). At the same time, collaboration involves additional costs of governance, relation-specific investments and the loss of unintended knowledge that can stifle a firm's competitive advantage.

2.3. Internationalization

A larger proportion of business enterprise R&D activity financed by abroad and co-inventions with foreign scientists suggests greater participation of foreign actors in the national innovation system. As can be seen from Tables 1 and 2, the differences in internationalization reflected in these indicators are not significant across levels of statism and corporatism. At the same time, it is worthwhile to note that the U.S. when considered separately conveys a distinctively higher level of inclusiveness through foreign participation than most other industrialized countries.

2.4. Innovatory impact

As a result of their technology policies, countries also vary in terms of their innovatory impact worldwide, as evidenced from a simple measure capturing the relative performance of cited scientific articles. The analysis reported in Tables 1 and 2 reveals that less statist countries perform significantly better than more statist countries. This finding is consistent with the view that governments in strong states may sometimes require resident firms to pursue narrowly defined technological paths that may have little relevance outside of their own national innovation systems (Spencer et al., 2005). In addition, greater societal participation in the decision-making process versus the prevalence of a strong state and greater separation between public and private roles and responsibilities, may lead to more informed decisions about the merits and demerits of technologies, and lead to technological choices that have a broader appeal.

Although the preceding analysis relies on simple measures, it provides valuable insights into the varied approaches to innovation across industrialized countries. It also helps establish the relevance and validity of the polity types for explaining cross-national variations in technology policies, and extends the idea of the interplay between economic actors and non-market forces to the innovation domain. Despite the relevance of polity types at the level of the national innovation system, the application of this institutional framework to a specific technology or industry sector remains to be investigated. To fulfill this objective, I examine whether the polity types demonstrate consistent variations when applied to the context of the emergent fuel cell technology sector.

3. Relevance to fuel cell technology development

3.1. Socio-economic benefits

The characteristics of fuel cells make it an appropriate context for undertaking a comparative analysis of technology policies and associated firms' strategies for a number of reasons. First, given the large potential for meeting the growing energy needs in multiple sectors including transportation, stationary power generation and portable device applications, fuel cell technology development has witnessed increasing public and private sectors investments in most industrialized countries. Fuel cell technology involves controlled catalytic electrochemical combustion of hydrogen and oxygen producing electricity, water, and heat, thereby offering a clean and efficient method for producing energy with greater power density compared to existing energy technologies.

The primary driver for public-sector engagement in fuel cells, however, varies across countries, ranging from national security considerations in the U.S., to environmental targets in Europe. In Japan, prospects for economic power and market dominance together with environmental goals have played an increasingly important role in garnering public support for the development of fuel cell technologies. Thus, given the economic, environmental and strategic benefits of the emergent technology, multiple actors in society including business and government play a decisive role in its development and commercialization, though their roles and motivation for engagement can vary across countries (Murmann, 2004; Garud and Karnoe, 2003).

3.2. Competing products and applications

Although a few technologies such as proton exchange membrane and phosphoric acid fuel cells appear to be the best candidates for a wide range of small and large applications, there is considerable technological variation across applications and countries. Direct methyl fuel cells for example, are especially suited to the small-scale portable device segment and high temperature molten carbonate and solid oxide fuel cells are more appropriate for large-scale applications in distributed power generation. As the earliest alkaline fuel cell technologies used by the U.S. government's Apollo Space Program in 1965 still remain in the R&D or testing stages, recent innovations such zinc-air fuel cells that are based on a closed-loop regenerative technology and share the characteristics of batteries have progressed more rapidly towards commercialization (Mima and Criqui, 2003). Even as new products and improved designs such as the microbial and proton ceramic fuel cell that eliminates the intermediate step of producing hydrogen through the costly reforming process have emerged in recent years, the earliest fuel cell technologies continue to attract investments from the public and private sector. A brief description of the main types of fuel cells is provided in Table 3. The multiple technological choices and applications raise important policy questions pertaining to country differences in how technological choices are made and how resources are allocated under conditions of competing technological approaches. These policies for resource allocation can play an important role in influencing market acceptance and commercialization, but can also trigger competence destruction given the considerable uncertainty and competition across multiple technological products (Malerba and Orsenigo, 1993; Breschi and Malerba, 1997).

Alongside the diversity and competition within fuel cells technologies, breakthroughs in other high technology areas such as nanotechnology and semiconductors that either complement or compete with fuel cell technologies affect the prospects for commercialization. Semiconductor technologies, for example, that improve the power density of lithium-ion battery technologies, for instance, may weaken the prospects for commercialization of

Table 3
Attributes of fuel cell technologies.

Fuel cell technology	Attractive attributes	Undesirable attributes
Phosphoric acid (PAFC)	-Low temperatures suitable for portable device applications -Ability for variable power output -Broad fuel choice	-Uses expensive platinum as a catalyst -Electrolyte is poor conductor at low temperatures
Proton exchange membrane (PEM)	-Low operating temperature suitable for transportation and portable devices -High power density	-Uses expensive platinum as a catalyst -Sensitivity to fuel impurities
Molten carbonate (MCFC)	-High operating temperature improves efficiency for base load power plants	-Not suitable for small-sized applications
Solid oxide (SOFC)	-High operating temperature improves efficiency for base load power plants -Solid electrolyte improves conductivity	-Electrolyte is made from ceramics and solid zirconium oxide that is a rare mineral
Alkaline fuel cells (AFC)	-Low temperature and high fuel-to-electricity efficiency	-Requirement of pure hydrogen and allergic to carbon dioxide
Direct methanol fuel cells (DMFC)	-Eliminates need for fuel reformer drawing hydrogen directly from the anode -Low temperatures suitable for portable devices	-Fuel crossing from anode to cathode without producing electricity
Regenerative fuel cells	-Closed loop, regenerating water from which hydrogen is drawn	-Additional energy requirements to split the water molecule
Zinc-air fuel cells (ZAFC)	-Regenerative, closed loop -Abundance of zinc reduces material costs	-Additional energy to regenerate zinc oxide
Protonic ceramic fuel cell (PCFC)	-Exhibit benefits of both high and low temperature fuel cells	-Electrolyte is made from ceramics and solid zirconium oxide that is a rare mineral

Source: Mima and Criqui (2003); www.fuelcells.org.

Table 4
Appropriateness of the fuel cell technology development context.

Fuel cell technology characteristics	Potential for social and political interventions	Relevant technology policy and strategy questions
Potential for meeting growing energy and environmental needs	Economic and environmental benefits can trigger participation of multiple societal groups such as business, NGOs, and political actors in government	Which actors participate? What is their motivation? Which actors lead, direct and invest in innovation?
Multiple technologies and applications	Applications across multiple sectors such as power generation and transportation, and a variety of technological approaches can create competition for resources among actors	How is competition for resources managed? How are technological choices made? How are technological standards developed?
Requires knowledge integration and creation of new knowledge	The need for knowledge-building requires integration of capabilities across multiple scientific disciplines and stakeholders	How does knowledge-building occur? What is the nature of collaboration?

fuel cells. Moreover, since fuel cells rely on controlled catalytic electrochemical combustion of hydrogen and oxygen to produce electricity, they are expected to encounter resistance from suppliers of existing conventional energy technologies. In this regard, technology policies and standards can play an important role in creating appropriate incentives and infrastructure for the commercialization of fuel cells.

3.3. New knowledge-building

Finally, strategies such as joint venturing and formation of industrial teams have been critical for knowledge-building and associated cost reductions through technological and economic efficiencies (International Finance Corporation, 2001). Teece et al. (1997) observed, for example, that in technologies characterized by hypercompetition (D'Aveni and Gunther, 1994), learning would be the greatest for firms that develop strategies that leapfrog other firms in rapid moves and countermoves.

Learning reflected by cost reductions can occur in two ways—by increasing production volumes and through R&D investments in a variety of areas such as, stack power density, high temperature membranes, stable thin-electrolytes, internal reforming processes, power electronics and system integration technologies. Over the period 2000–2020, fuel cell technologies are estimated to have a learning factor of 89%, thereby implying that for every doubling in installed capacity, costs are reduced by 11% (Bauen and Hart, 2000). The learning factor, however, varies across fuel cell technologies, firms, and countries.

In summary, even though technological progress is evident from the growing number of fuel cell installations that are in various stages of R&D and demonstration in more than nineteen countries, there is still a great degree of flux and uncertainty in terms of which technological approaches and applications will emerge as the winners. The price of fuel cell prototypes would need to fall by at least one-half to make them more competitive with existing energy technologies (International Finance Corporation, 2001). The high price of fuel cells has triggered considerable intra-technology competition aimed at lowering component costs, and improving fuel conversion efficiency, fuel reformation, storage systems, and the modularity and miniaturization features (Mima and Criqui, 2003). The first applications of fuel cells will likely emerge in niche areas where their non-standard performance attributes compensate for high costs (Mima and Criqui, 2003). Countries that become early adopters of fuel cell technologies will also most likely influence technological standards and become leaders in other niche technologies (International Electrotechnical Commission, 2004). These trends – the rapid growth of the industry and continuing technological experimentation – are not only indicative of the promising prospects for fuel cell technologies, but also signal considerable variation in the technological trajectories across market segments and countries as the technology evolves (Nelson, 1990). Technology policies and associated knowledge-building strategies will, therefore, play a decisive role in the successful commercialization of fuel cells (Table 4).

4. Data collection and methodology

An examination of fuel cell patents filed with the U.S. Patents and Trademarks Office reveals that there are approximately 260 firms from 16 countries competing to establish a presence in the international market for fuel cells. More than half these firms and inventors are located in the U.S. and Japan, but a large number of firms reside in other countries in Europe such as France, Italy, U.K., Germany, Norway, and Denmark.

Detailed accounts of technology policies and associated approaches for fuel cell innovation were collected for four countries—the U.S., France, Japan and Norway. Even though the countries selected for the case study are highly industrialized, they vary across key dimensions such as the size of the economy, historical background, geographical location and inventive activity (OECD, 2007). The countries also represent polar cases of statist and corporatist national institutions, and therefore, enable a comparison of technology policies across the key exemplars of each polity type (Jepperson, 2002). The U.S. fares low on both dimensions of statism and corporatism, and thus, conforms most closely to the characteristics of liberal-pluralist polities. By contrast, Japan is state-corporatist, and is high on both dimensions. France is a state-nation and conforms to the statist character of Japan and the pluralist character of the U.S., and Norway being a social-corporatist country blends together the corporatist character of Japan and the liberal character of the U.S. (Jepperson, 2002).

Descriptions of countries' fuel cell technology policies were gathered from multiple sources including documents published by fuel cell associations, government agencies and multilateral organizations such as the OECD. The USPTO patent data helped identify the key players including firms, government agencies and research institutions. News reports concerning fuel cell technology development were collected through websites and from the Lexis Nexis database that contains archives of over 670 business magazine and newspaper titles worldwide. Direct communication via e-mail with executives also revealed important characteristics of fuel cell technology innovation across countries. The e-mail communication provided insights about the characteristics of firms, the nature of their partnerships with other public and private sector actors, and the types of fuel cells in which they carried out R&D.

Using an inductive approach, the qualitative and quantitative evidence gathered for each country was used to demonstrate the close connection between the emergent theory and empirical evidence (Eisenhardt, 1989; Eisenhardt and Graebner, 2007). Such an approach that intertwines theory with case evidence has been deployed in prior inductive studies aimed at theory-building (Aguilera and Jackson, 2003; Graebner and Eisenhardt, 2004). The following section presents the narratives for each country broken down into four key areas – allocation of public resources, engagement with foreign actors, nature and role of partnerships involving public and private actors, and technological diversity – illustrating cross-national variations in technology policies.

5. Fuel cell technology policies: a comparison across polity types

5.1. How are public resources allocated?

Propelled by the prospects of establishing a leadership position in the global market for fuel cell technologies, most industrialized countries have witnesses a sharp increase in both public and private sector R&D investments. The data on fuel cell investments suggests, however, that less statist countries like the U.S. and Norway tend to offer a greater variety of private investment sources including equity from stocks, venture capital, corporate venturing and internal R&D programs (Breakthrough Technologies Institute, 2003a). By contrast, in statist Japan and France, apart from the public sector resources, investments in R&D are largely made by large private sector firms. Firms' investments in statist countries are motivated by greater government protection against economic downturns and technological risks, reducing their susceptibility to economic volatility and technological uncertainty (Breakthrough Technologies Institute, 2003a; Avadikyan and Harayama, 2003).

Public investments also vary in the extent to which they are disbursed to private sector firms based on competitive criteria versus selective allocation. Evidence suggests that in less statist countries such as the U.S. and Norway, disbursements of public resources are made largely through competitive grants and are directed towards priorities identified by the private sector actors themselves. By contrast, in Japan and France these allocations are made through preferential selection of firms whose R&D efforts are aligned with the national economic and technological priorities determined by the state.

The U.S. which is characterized by a low degree of statism emphasizes highly competitive approaches to access public funds. As an illustration, public-sector funding through programs such as the Advanced Technology Program managed by the U.S. Department of Commerce is disbursed through competitive grants (U.S. Department of Energy, 2002). The Advanced Technology Program, among other government-sponsored initiatives like the Hydrogen Program is guided by a national vision for a hydrogen economy that emphasizes breakthrough approaches and a strong mission orientation, consistent with the individualistic character of society that rewards distinctiveness (Garud and Karnoe, 2003; Ergas, 1987; Spencer et al., 2005).

Like the U.S., the government in Norway participates through the Norwegian Research Council, but it is observed to play a relatively limited role in assuming leadership in devising strategies for new technologies (Nygaard, 2004). Norwegian oil companies such as Statoil, Norske Hydro and Aker-Kvaerner have led most projects for fuel cell technology development in partnership with other societal actors including universities and research institutions. This trend has emerged even more clearly following the deregulation of the Nordic energy markets in the 1990s (Godoe and Nygaard, 2006). As noted in an official statement issued by the Norwegian government, Norway has no well-defined policies for hydrogen and fuel cell technologies (Riis and Midtsundstad, 2005); instead, policies have emerged in response to the priorities of private sector actors and the solutions they devise to meet the energy and environmental needs of the society. The participation of the public-sector through agencies such as Enova – a public-sector agency providing energy subsidies – can therefore be understood as one of providing incentives for small-scale projects in broadly defined technological areas such as clean energy for environmental benefits (Enova, 2005; Godoe and Nygaard, 2006).

In contrast to the U.S. and Norway, and consistent with a highly statist institutional structure, fuel cell technology development projects sponsored by Japan's Ministry of Economy Trade and Industry (METI) have followed a highly targeted approach – both in terms of the technologies and firms – that receive investments. In most cases publicly funded firms are selected based on an established track record of successful R&D in areas deemed as national priorities. As an example, the Japanese Moonlight Project for developing molten carbonate and phosphoric acid fuel cell technologies was carried out by selected firms that were already involved in other projects of national interest (Avadikyan and Harayama, 2003). Similarly, Japan's New Energy Development Organization (NEDO) chose large firms with significant internal R&D budgets such as Sanyo Electric, Mitsubishi Electric, Aishin Seiki, Asahi Glass and Asahi Chemicals for the development of the proton exchange membrane fuel cells. As in Japan, public sector support in statist France has been concentrated in a few of the largest firms such as Gaz de France, Alstom, Renault and PSA Peugeot regarded as the national champions for sustaining France's competitive position in the global automotive industry (Bourgeois, 2004). Policies that include large-scale concentration of government subsidies on one hand can contribute to greater efficiency in resource allocation, but on the other hand they can also stifle innovation by tying scarce public resources to unproductive uses (Murtha, 1991).

5.2. What is the nature of engagement with foreign actors?

Consistent with its liberal character, technology policies in the U.S. have been largely supportive of participation of foreign firms in domestic projects for fuel cell technology development. Such an approach seems to have worked well for U.S. government laboratories in serving the purpose of strategic monitoring of foreign competitors. As an example, the Los Alamos Laboratory of the U.S. Department of Energy and the Texas A&M University has worked in collaboration with the Canadian fuel cell leader, Ballard, to accelerate the commercialization of the proton exchange membrane fuel cell. At the same time, such engagement has allowed for keeping a close watch on the breakthroughs by foreign innovators. Similarly, the California Fuel Cell Partnership managed by the University of California in Irvine has since its inception in 1999 invited participation from not only U.S. firms but also foreign firms including Honda, Toyota, Nissan, Shell and Volkswagen (CAFCP, 2005). Evidence of foreign participation within Norway is relatively limited. However, the global character of the Norwegian oil industry offsets this limitation by virtue of its ability to attract foreign capital and inventive capabilities.

Even though Japanese firms are active participants in government- and industry-sponsored projects in foreign innovation systems, few foreign firms are engaged in fuel cell technology development projects in Japan. Similarly, a review of fuel cell technology development projects in France reveals little evidence of foreign participation in the national innovation system. Recognizing the impediment that exclusionary policies can cause for technological innovation, the French Deputy Minister for Research François d'Aubert emphasized the importance of conducting joint research within the European Union's research program (d'Aubert, 2004). In response to recent policy shifts in France, and projects funded by the European Union such as the Fuel Cell Bus, firms from France have increased efforts for internationalizing their R&D activities. Technology policies that are responsive to foreign competition have emerged as an important element of the fuel cell technology development program in France, though foreign participation continues to be limited in domestic projects.

Thus despite the restrictions concerning the participation of foreign firms in Japan and France, large firms in these statist countries have been able to overcome the limited exposure to foreign firms within the national innovation system by participating more actively in the global innovation system.

5.3. What is the nature of partnerships involving public and private actors?

Partnerships are a prominent feature of fuel cell technology innovation across most countries. However, the structure of these partnerships is observed to vary significantly according to the level of corporatism characterizing the national institutional environment. In contrast to highly enduring, encompassing and hierarchically organized network approaches led by government agencies and a few large private firms in corporatist Japan and Norway, partnerships in the U.S. and France are often fragmented and short-lived and in most instances initiated by private actors themselves.

A distinctive characteristic of fuel cell technology development in the U.S. is that multiple partnerships with both large and small firms, spanning a wide range of capabilities exist in parallel with little overlap among them. To illustrate this dynamic, General Motors has forged several alliances with diverse players including the Sandia National Laboratory, Dow Chemicals, and Toyota for developing hydrogen storage technologies and operating hydrogen-based fuel cells. Unlike Japan where most public–private partnerships are coordinated by the Ministry for Economy, Trade and Industry, in the U.S. a plethora of national laboratories and public-sector research institutions such as the University of California conduct R&D jointly with the private sector. In addition to the efforts of the U.S. Department of Energy, the U.S. Department of Defense, through partnerships with smaller firms such as MTI MicroFuel Cells has played an important role in the development of phosphoric acid fuel cells for portable device applications (Breakthrough Technologies Institute, 2003b).

Like Japan, the Ministry of Research in France plays a central coordinating role in fuel cell technology development networks such as the Piles à Combustible (PaCo) that link industry and government organizations (Bourgeois, 2004). However, unlike highly corporatist Japanese networks that are dense and inclusive, the PaCo excludes many large and small enterprises (IEA, 2004). It is noteworthy that consistent with the low level of corporatism in France, there is evidence of greater delegation of powers and decision-making authority to the organizations coordinating specific projects within the PaCo. Moreover, a greater number of industry representatives are chairing committees that traditionally were the prerogatives of public officials in the French government.

As an illustration of the highly encompassing networked approaches in corporatist Japan, the World Energy Network (WE-NET) launched in 1998 with an estimated $3 billion in public-sector funding, encompasses all Japanese hydrogen and fuel cell projects. The WE-NET is planned as a large-scale project engaging Japanese firms with the long-term goal of establishing the necessary infrastructure for transitioning to a hydrogen economy (Avadikyan and Harayama, 2003). The Fuel Cell Commercialization Strategy Group and the Fuel Cell Commercialization Conference of Japan comprising 134 members from various industries adhering to a roadmap for commercialization also provide evidence of organized interest groups in Japan (Maeda, 2003). Other umbrella organizations involved in fuel cell demonstration and testing projects include the Japan Electric Vehicle Association (JEVA) and the Engineering Advancement Association of Japan (ENAA), which is the largest industrial association in Japan including firms from nearly all sectors (Avadikyan and Harayama, 2003). Organized efforts at such a large scale do not exist in countries like the U.S. and France where the private sector operates through loose associations and multiple alliances.

Even though Norway shares the characteristics of corporatist networks with Japan, the low degree of statism in Norway limits the involvement of government agencies in technology development projects. As an example, Statoil initiated the Norcell projects involving nearly all energy firms such as Hydro, Statkraft and Sintef and research institutions such as the University of Oslo (Riis and Midtsundstad, 2005). Similarly, more recent efforts such as the HyNor project aimed at establishing a hydrogen infrastructure to meet local needs involves participation from most players in the hydrocarbon industry.

Collaborative arrangements vary across more and less corporatist (or pluralist) countries according to their density and inclusiveness, as well as the centrality of public sector actors in coordinating activities. Whereas in more corporatist countries such as Japan, and Norway, fuel cell innovation proceeds through highly participatory approaches, in less corporatist or pluralist countries such as the U.S. and France, networks tend to be fragmented and sparse, and roles and responsibilities are more evenly distributed across members.

5.4. What is the extent of technological diversity?

Given the many types of fuel cells and their diverse applications across sectors such as transportation, portable devices and stationary power generation, technology policies of countries play an important role in determining technological diversity. Unlike Japan and most countries in Europe that are investing in fuel cell technologies for primarily transportation applications, in the U.S., investments are spread across stationary power generation and transportation applications, even though the latter constitutes the bulk of the potential market for fuel cell technologies (Bourgeois and Mima, 2003). Most fuel cell innovations in the U.S. have been developed in parallel as evidenced from the nearly equal distribution of R&D investments across various technologies across time (USDOE, 2004). Since the earliest inventions of General Electric to power the Gemini space missions using alkaline fuel cells in the 1950s, innovative activity in the U.S. has been spurred by market-based competition aimed at bringing down costs and increasing efficiency (Nail et al., 2005).

Further, public-sector disbursements made by the Advanced Technology Program in the U.S. have been based on the principle of technology neutrality. According to this approach, all types of fuel cells for a variety of applications are eligible for funding so long as they meet the technical and economic criteria. The Freedom Car initiative, for example, focuses on fuel cell technologies for transportation applications, and the Solid State Energy Conversion Alliance (SECA) aims at reducing costs of solid oxide fuel cells for stationary power applications. In addition, multiple partnerships have channeled resources in a variety of technologies in all segments of fuel cell applications. These observations suggesting a greater variety of technologies, are consistent with the principles of competition reflected in low levels of corporatism.

In contrast to the U.S., fuel cell technology development in corporatist Japan can be described as a highly targeted approach involving close coordination between public and private actors. In the 1990s, Japanese investments shifted towards solid oxide and proton exchange membrane technologies and the creation of a hydrogen infrastructure to support the commercialization of fuel cells (Avadikyan and Harayama, 2003). These efforts followed large investments in molten carbonate and phosphoric acid fuel cells throughout the 1980s creating a sizeable stock of technological knowledge among firms in the energy, electronics and transportation sectors.

For Japanese firms the choice for proton exchange membrane fuel cells in transportation was spurred by the discovery by scientists at the U.S. Department of Energy's Los Alamos National

Laboratory concerning reduced requirements of platinum—a precious metal comprising a significant portion of the component costs in fuel cells. As evidenced from the various policy announcements for fuel cell technology programs, Japanese innovation appears to be motivated by the prospects of capturing U.S. markets in the transportation segment (Maeda, 2003). Consequently, the Japanese government has selected specific fuel cell technologies over different time periods and adopted a highly coordinated approach for their development.

In Norway the approach to innovative activity is characterized by gradual incrementalism rather than rapid and risky investments (Godoe and Nygaard, 2006). Norwegian firms in the energy sector have been investing in in-house R&D, mostly in hydrogen technologies to develop the requisite competencies that would allow for their participation in an imminent hydrogen-based economy. Using a bibliometric analysis, Godoe and Nygaard (2006) showed that the patenting profile of Norwegian firms were mostly oriented towards hydrogen storage and production technologies. As is evident from the preceding discussion, industrialized countries vary considerably in their policies and orientation towards fuel cell technology innovation. Much of this variation can be explained by the core characteristics of statism and corporatism inherent in the national institutional environment. This comparative analysis, therefore, paves the way for a more nuanced understanding of the knowledge strategies of firms residing in these countries.

6. Implications for firms' knowledge-building strategies

In the following sections I discuss how distinctive technology policies across the polities[5] in the four key areas discussed above present both opportunities and challenges for firms' knowledge-creation and knowledge-diffusion strategies.

6.1. Liberal-pluralist

In liberal-pluralist countries like the U.S., a higher degree of individualism that rewards distinctiveness, aided by the availability of multiple sources of private equity such as venture capital funds and internally funded corporate R&D perpetuates investment in the more risky and cutting-edge segments of the technology. With the inherent emphasis on pluralism, and availability of venture capital in the U.S., entrepreneurial firms that fuel new and creative ideas are faced with fewer entry barriers. In addition to private investment, government-funded early stage grants provided to start-up firms such as Plug Power, Avista, H-Power and Nuvera, for instance, made it possible for these firms to acquire comprehensive patents in unique areas. The intellectual property thus developed, helped these firms to attract additional corporate venture financing. At the same time, smaller firms in the U.S., may suffer from lower survival rates, partly because highly volatile stocks coupled with the threat of acquisitions often detracts attention from knowledge-building (Bourgeois and Mima, 2003).

Moreover, in liberal-pluralist countries such as the U.S. where multiple interests compete for public resources, firms are often faced with greater uncertainty about the direction of technological change, and in determining the likely technological winners. There is also greater ambiguity about whether public-sector investments are motivated by a genuine commitment towards the technology. Industry observers have speculated, for instance, that public-sector investment may be intended to ward off interest groups such as environmental lobbyists or to safeguard the interests of large oil companies that supply the hydrogen for fuel cells (Breakthrough Technologies Institute, 2003a).

These two aspects of the institutional environment – competition and uncertainty – have resulted in the creation of a diverse pool of capabilities within the national innovation system. To safeguard from uncertainties and unexpected industry shifts, larger firms have cultivated a broad portfolio of technological capabilities through alliances, for instance. Such an approach allows larger firms to respond by building dynamic capabilities as the industry evolves (Zahra and George, 2002), but smaller firms with niche capabilities may not survive the transition. Greater competition and technological diversity may also stifle knowledge flows across firms.

U.S. firms such as Arthur D. Little and Amerada Hess Corporation have also shown alacrity in acquiring knowledge from foreign competitors, as evidenced from their recent acquisition of the Italian firm De Nora, that had been at the forefront of fuel cell development in Europe for several years. The acquisition led to the launch of Nuvera and greater internationalization with operations in proton exchange membrane fuel cells in both the U.S. and Italy (Bourgeois and Mima, 2003). The experience of U.S. firms in successfully garnering technological knowledge from not only domestic but also foreign innovation systems suggests valuable capabilities in developing globally integrated knowledge.

Despite a number of positive aspects of the U.S. innovation system described above, some industry analysts view "playing all horses" as potentially disadvantageous by creating a state of confusion and slowing the pace of technology development. As one U.S. government official observed, the approach for new knowledge creation has often been guided by ambitious short-term interests reflecting breakthrough approaches rather than by modest long-term gains. Thus, it remains uncertain if the U.S. would lead the commercialization phase of the technology (Breakthrough Technologies Institute, 2003a).

6.2. Social-corporatist

The liberal environment of Norway allows firms to decide about their technological direction. The Norwegian government has no well-defined technological priorities for hydrogen and fuel cell technologies (Riis and Midtsundstad, 2005). Instead, these policies have emerged in response to the priorities of the private sector actors and the solutions they devise to meet the needs of the society. Hence, Statoil's hydrocarbons business, justifies its investments in creating new knowledge relevant to hydrogen-related technological approaches, even though other innovators in Norway such as the Oslo University have pursued the development of solid oxide fuel cells. Given Norway's corporatist character, however, there is greater collaboration among the energy producing firms, and hence greater degree of specialization in hydrogen technologies. The consortium approach to technology development also allows for the development of complementary capabilities, and a more efficient allocation of resources.

At the same time, anecdotal evidence suggests that a highly collaborative approach based on the expectation of enduring relationships may result in slower knowledge acquisition. This tendency can be especially harmful if the partner is embedded in an environment that emphasizes deliberate and opportunistic learning. For example, in an alliance between the U.S. firm Ceramatec and the University of Oslo, the U.S. firm acquired knowledge from its Norwegian partner in a short period, and capitalized on this newly acquired intellectual property to launch a subsidiary SOFCo in the U.S. For the Norwegian partner, the alliance termination was perceived as unexpected and premature, disrupting their technology development (Godoe and Nygaard, 2006). Given that nearly one-half of fuel cell technology development alliances involve cross-border relationships, knowledge acquisition efforts

[5] I would like to thank an anonymous referee for highlighting that the explanatory utility of the theoretical framework emerges from the implications for firms' knowledge-building strategies across countries.

may not yield expected benefits unless the partners account for the institutional differences within which the partners are embedded.

6.3. State-nation

In state-nation countries like France, large firms' often benefit from preferential access to public resources, and tend to focus on developing knowledge that is consistent with national priorities.

Seymour (2004) found striking contrasts in the patent profiles of firms from the U.K and France. While the British firms' focused mainly on fuel cell catalysts and hydrogen storage/reforming consistent with the general trends worldwide, the French specialized in a special fluid flow valve technology indicative of a specialized mechanical component business in France. Although the French patents tend to be particularly novel, they are not likely to fall in the mainstream of the worldwide commercialization process. Hence, despite the novelty and distinctiveness of innovations produced in state-nation countries like France, the prospects for large-scale knowledge diffusion can be quite limited, unless resident firms undertake serious efforts to engage internationally.

To overcome the constraints arising from limited access to foreign innovators within the national innovation system, French multinational firms such as Air Liquide, Alcatel, Peugeot, Renault, Electricité de France, Atofina (Total) and Sagem that are involved in fuel cell technology development are actively engaged in internationalizing their R&D activities. Such a strategy allows French firm to acquire and build on the knowledge that resides in the global innovation system. Air Liquide, for example, has 550 researchers dedicated to fuel cell technology innovation dispersed in research centers across the U.S., Germany, Japan, India and China. Renault, the French automaker has formed an alliance with Nissan from Japan to address problems related to hydrogen supply and on-board reformation. Similarly, the automaker, Peugeot, has formed alliances with Daimler Chrysler and Ford for the use of compressed hydrogen in proton exchange membrane fuel cells. A substantial number of smaller firms such as Axane, Sorapec and Helion that are contributing to fuel cell technology development in France, however, continue to remain disenfranchised from the global innovation system.

6.4. State-corporatist

A strong state in Japan provides a more stable and secure environment for innovation. Firms in state-corporatist countries like Japan tend to form domestic alliances with the objective of co-specializing or developing complementary knowledge for the technology. Collaborative networks in turn are able to influence public investments in nurturing and supporting industry emergence (Hall and Soskice, 2001). In Japan for instance, large automotive firms tend to form consortia with the suppliers of components, energy producers and small firms. In many instances, these consortia are often led by large firms and pursue a specific technology. Moreover, direct competitors rarely reside within the same consortia (Avadikyan and Harayama, 2003).

While on the one hand, a greater degree of co-specialization could foster greater complementarities and efficient resource utilization, the tightly knit networks characteristic of corporatist structures, on the other hand, could pose a barrier for the infusion of new knowledge. Moreover, in addition to creating entry barriers for new knowledge flows and curtailing knowledge search outside of the network for fear of sanctions by the network members, a high degree of corporatism contributing to dense and enduring networks in Japan could also lead to knowledge redundancy (Morris-Suzuki, 1994).

In an effort to offset the limited exposure to foreign firms within the national innovation system, Japanese firms have been active participants in foreign consortia such as the California Fuel Cell Partnership in the U.S., and with international organizations such as the International Standards Organization (ISO) and the International Electrotechnical Commission (IEC) for developing international standards for fuel cells (Avadikyan and Harayama, 2003).

The proclivity to pick winners and cultivate national champions in state-corporatist settings like Japan can deprive some firms of public support and resources that could help nurture their latent technological capabilities. Firms that are not fostered by the government may look to foreign partners for their knowledge-building efforts because they are excluded from working with domestic actors. As a result of these highly selective policies of a statist government, capable innovators may be lost to foreign innovation systems. The Sharp example in the flat panel display industry (FPD) illustrates this point (Spencer et al., 2005). Even though the Japanese Ministry of Economy, Trade and Industry did not include Sharp in the domestic FPD consortium, Sharp entered into the FPD industry through a different route by engaging with foreign actors and succeeded. Firms that innovate within corporatist networks, therefore, may incur benefits from their network participation, but at the same time, they may risk locking-out capable firms, and locking-in resources in relationships that are difficult to terminate.

Table 5
National polity types and implications for firms' knowledge strategies.

High statism	
State-nation (low corporatism)	State-corporatist (high corporatism)
Strengths	
-The emphasis on distinctiveness can lead to the creation of novel knowledge	-Targeted approaches and credible commitments by government reduce risk and uncertainty
-Efforts for outward integration can increase knowledge acquisition	-Government coordination of industry interest groups facilitates the creation of complementary knowledge
Weaknesses	
-Novelty can reduce worldwide knowledge diffusion	-Limited participation of foreign actors within the national innovation system
-Preferential treatment of larger firms may disenfranchise smaller firms	-Selective approaches can exclude capable firms
	-Closed networks can present barriers to entry
(e.g. France, Italy, Spain, Greece, Portugal)	(e.g. Germany, Japan, Korea, Austria, Belgium)
Low statism	
Liberal-pluralist (low corporatism)	Social-corporatist (high corporatism)
Strengths	
-Range of investment options (e.g. venture capital) can favor entrepreneurial activity, diversity of ideas and experimentation	-A coordinated approach between government and industry allows for knowledge creation in areas that are consistent with firms' capabilities and expertise
-Mission orientation can lead to breakthroughs	-Greater degree of collaboration can increase knowledge diffusion within the network of dense relationships
-Competitive approaches foster technological diversity	
-More deliberate approaches to learning favor new knowledge creation	
Weaknesses	
-Competition and propensity for risky investments can lead to higher failure rates, industry exists, acquisitions	-Expectation of longer term relationships may lead to less knowledge acquisition from partners that seek short-term relationships
-Greater knowledge protection may lead to less knowledge diffusion	-Dense networks may curtail the participation of actors outside of the network
(e.g. U.S., U.K., Australia, Canada, New Zealand)	(e.g. Norway, Sweden, Denmark, Netherlands, Finland, Switzerland)

The preceding discussion highlights how national institutions provide unique opportunities, but also impose constraints on firms' approaches for knowledge-building, such that no one type of national institutional environment can be regarded as the ideal (Table 5). It is perhaps for this reason that even as firms concentrate the bulk of their innovative activity in their home country (Patel and Pavitt, 1991; Pavitt and Patel, 1999), they also seek to internationalize their R&D activities (Cantwell, 1995; Carlsson, 2006).

7. Discussion and conclusions

Juxtaposing the levels of statism and corporatism, a country's innovatory approaches and associated knowledge strategies can be usefully described by the four polity types as shown in Table 5. This typology extends our insights about the varieties of capitalism by providing a more fine-grained understanding of cross-national variations in terms of not only the extent to which interactions between economic actors are highly coordinated versus market driven (Hall and Soskice, 2001; Soskice, 1999), but also in the context of the socio-political institutional interactions that influence economic activities.

While drawing attention to the socio-political variations within industrialized countries, this study has highlighted that countries adopt different paths for achieving shared technological goals. For example, government plays an important role in new technology development in all national innovation systems. But this role is more central and direct in Japan and France, compared to the U.S. and Norway, where government plays a more indirect role. The importance of collaboration involving business, universities and government in spurring innovation is also well recognized across all countries. At the same time, the drivers of collaboration and the associated outcomes vary. In Japan and Norway, for instance, alliances are encompassing and enduring, leading to dense networks. In these countries, social capital benefits play an important role while selecting partners. By contrast, alliances in the U.S. and France are deliberate and short-termed resulting in more fragmented networks, with expectations of technological gains.

Similarly, technological diversity could manifest itself differently across countries. In Japan and Norway, firms may pursue different technologies, but these technologies fit together as pieces of the same innovation. The diversity, therefore, manifests itself in the form of complementarities among firms' capabilities. In the U.S. and France, by contrast, the diversity stems from plurality and competitiveness, where technological capabilities separate winners from losers. Applying March's (1991) organizational learning perspective, the study suggests that exploitation and exploration occur through different mechanisms across countries. In the U.S., for instance, technological development can be characterized by 'ambidexterity' (Benner and Tushman, 2003), whereby loosely coupled and differentiated organizations purse both exploration or experimentation, and exploitation or refinement of existing capabilities, simultaneously. In Japan, by contrast, the approach to technological development is more temporally differentiated, such that over time new technological directions are explored sequentially.

Lastly, the benefit of engaging with foreign actors is recognized across all countries, but the approach for achieving this goal varies considerably. In the U.S., a large number of foreign firms participate in the national innovation system. In Japan and France, fewer foreign firms participate in the national innovation system, but firms from these countries offset this limited exposure to foreign firms, by participating in other national innovation systems. These differences in approaches have important implications for firms' knowledge-building strategies and associated performance outcomes, providing a rich avenue for future empirical investigation.

This contribution, however, comes with the caveat that technology policies and firms' strategies, do not always correspond with the institutional expectations (Ergas, 1987; Ruttan, 2006), and it is perhaps appropriate to identify certain boundary conditions. First, the extent to which firms' knowledge strategies are shaped by their national institutional contexts is determined in large measure by the extent to which innovation resides within the national innovation system. Even though most R&D in high technology areas like fuel cells and semiconductors tend to be concentrated within a firm's home country (Macher et al., 2007), as firms seek global markets to recover their R&D investments, the effect of national institutional contexts may begin to erode (Kostova et al., 2008). Multinational firms are especially likely to be exposed to the interactions between multiple conflicting institutional contexts. The proposed framework, is therefore, most relevant to domestic firms that are deeply embedded in their national innovation systems. More research, however, is needed to better understand the differences across the institutional responses of domestic and multinational firms.

Second, even though the framework developed in this study integrates both the statist and corporatist dimensions of national institutions, the interactions between these two dimensions can generate interesting results that have not been fully explored. For example, in the case of France, a strong state could dilute the pluralism of society resulting in national goals that are determined by the government. Conversely, a more pluralist society in France could counterbalance a strong state in formulating technology policies. In Japan, the dialectic between inclusiveness emerging from corporatism and greater selectivity as a consequence of targeted approaches adopted by the government has yielded some mixed technology policies. Similarly, in the U.S., a mission-oriented approach in new technology development is reflective of the individualistic character of society that places a premium on breakthroughs rather than incremental progress (Garud and Karnoe, 2003; Ergas, 1987). Thus, future research could make important contributions by examining the interactions between these institutional dimensions. Finally, this study does not consider the role of additional dimensions like globalization that operate at the supranational level, or the interactions with subnational institutions like industry clusters and associations. It would be interesting to study for instance, how globalization is shaping the technology policies and firms' knowledge strategies in the four polities discussed in this study.

In conclusion, the theoretical framework that emerges from this study informs three inter-related streams of literatures. By identifying the key technology policy dimensions and comparing them across industrialized countries, the study contributes to the literature on national innovation systems. Most importantly, it demonstrates that technological progress and globalization have not resulted in the convergence of institutional boundaries and national governments continue to matter for innovation. At the same time, globalization could manifest itself differently across the four polities, presenting an important area of future study. Further, the study suggests that national institutional environments can influence the approach for innovation, with direct relevance for firms' knowledge strategies and associated technological capabilities. Finally, given the impetus for R&D internationalization, firms' decisions to locate R&D units across countries or form cross-border alliances could be better informed by accounting for the social and political dimensions of national institutions that are sustained by the complementarities that they generate over time.

References

Aguilera, R.V., Jackson, G., 2003. The cross-national diversity of corporate governance: dimensions and determinants. Academy of Management Review 28 (3), 447–465.

Avadikyan, A., Harayama, Y., 2003. The Japanese R&D system in the field of fuel cell vehicles. In: Avadikyan, A., Cohendet, P., Héraud, J. (Eds.), The Economic Dynamics of Fuel Cell Technologies. Springer, New York, pp. 23–42.
Badie, B., Birnbaum, P., 1983. The Sociology of the State. University of Chicago Press, Chicago.
Bartholomew, S., 1997. National systems of biotechnology innovation: complex interdependence in global system. Journal of International Business Studies 28 (2), 241–266.
Bauen, A., Hart, D., 2000. Assessment of the environmental benefits of transport and stationary fuel cells. Journal of Power Sources 86 (1–2), 482–494.
Benner, M., Tushman, M., 2003. Exploitation, exploration, and process management: the productivity dilemma revisited. Academy of Management Review 28 (2), 238–256.
Bourgeois, B., 2004. France Case Study: Fuel Cells. Retrieved on May 20, 2005 from www.oecd.org/dataoecd/12/45/31964792.pdf.
Bourgeois, B., Mima, S., 2003. Rationales for cooperation between firms and states within an emerging radical innovation. In: Avadikyan, A., Cohendet, P., Héraud, J. (Eds.), The Economic Dynamics of Fuel Cell Technologies. Springer, New York, pp. 79–114.
Breakthrough Technologies Institute, 2003a. Fuel cells at the crossroads: attitudes regarding the investment climate for the U.S. fuel cell industry and a protection of industry job creation potential. Breakthrough Technologies Institute, Inc., Report No. ANL/OF-00405/300.
Breakthrough Technologies Institute, 2003b. Fuel Cells for Portable Power: Markets, Manufacture and Costs. Breakthrough Technologies Institute, Inc. Retrieved on May 22, 2005 from www.fuelcells.org.
Breschi, S., Malerba, F., 1997. Sectoral innovation systems: technological regimes, Schumpeterian dynamics and spatial boundaries. In: Edquist, C. (Ed.), Systems of Innovation: Technologies, Institutions and Organizations. Pinter, London, pp. 130–155.
CAFCP, 2005.California Fuel Cell Partnership. Retrieved on May 20, 2005 from http://www.fuelcellpartnership.org/contact.html.
Cantwell, J., 1995. The globalization of technology: what remains of the product cycle model? Cambridge Journal of Economics 19 (1), 155–174.
Carlsson, B., 2006. Internationalization of innovation systems: a survey of the literature. Research Policy 35, 56–67.
Casper, S., 2001. The legal framework for corporate governance: the influence of contract law on company strategies in Germany and the United States. In: Hall, P.A., Soskice, D. (Eds.), Varieties of Capitalism: The Institutional Foundations of Comparative Advantage. Oxford University Press, Oxford, Great Britain.
Casper, S., Matraves, C., 2003. Institutional frameworks and innovation in the German and UK pharmaceutical industry. Research Policy 32, 1865–1879.
Casper, S., Whitely, R., 2004. Managing competencies in entrepreneurial technology firms: a comparative institutional analysis of Germany, Sweden and the UK. Research Policy 33, 89–106.
Cawson, A. (Ed.), 1985. Organized Interests and the State. Sage Publishers, London, U.K..
Chesnais, F., 1993. The French national system of innovation. In: Nelson, R.R. (Ed.), National Innovation Systems: A Comparative Analysis. Oxford University Press, New York, pp. 192–229.
Crouch, C., Streeck, W., 1997. Political Economy of Modern Capitalism: Mapping Convergence and Diversity. Sage Publications, Newbury Park, CA.
Dacin, M., Oliver, C., Roy, J., 2007. The legitimacy of strategic alliances: an institutional perspective. Strategic Management Journal 28 (2), 169–187.
d'Aubert, F., 2004. Research in France Today. Cordis, French Research and Technology Service. Retrieved November 6, 2004 from http://www.cordis.lu/france/home.html.
D'Aveni, R.A., Gunther, R.E., 1994. Hypercompetition: Managing the Dynamics of Strategic Maneuvering. Free Press, New York.
Dobbin, F., 1994. Forging Industrial Policy. Cambridge University Press, Cambridge.
Dyson, K.H.F., 1980. The State Tradition in Western Europe: A Study of an Idea and Institution. Oxford University Press, New York.
Edquist, C., 2004. Reflections on the systems of innovation approach. Science and Public Policy 31, 485–489.
Eisenhardt, K.M., 1989. Building theories from case study research. Academy of Management Review 14 (4), 532–550.
Eisenhardt, K.M., Graebner, M.E., 2007. Theory building from case: opportunities and challenges. Academy of Management Journal 50 (1), 25–32.
Enova, 2005. Activities and Programmes. Retrieved on May 20, 2005 from http://www.enova.no/.
Ergas, H., 1987. Does technology policy matter? In: Guile, B.R., Brooks, H. (Eds.), Technology and Global Industry: Companies and Nations in the World Economy. The National Academies of Sciences, Washington, DC.
Fligstein, N., 1991. The structural transformation of American industry: an institutional account of the causes of diversification in the largest firms, 1919–1979. In: Powell, W.W., DiMaggio, P.J. (Eds.), The New Institutionalism in Organizational Analysis. University of Chicago Press, Chicago, IL, pp. 311–336.
Fligstein, N., 2001. The Architecture of Markets: An Economic Sociology of Twenty-First Century Capitalist Societies. Princeton University Press, Princeton, NJ.
Garud, R., Jain, S., Kumaraswamy, A., 2002. Institutional entrepreneurship in the sponsorship of common technological standards: the case of Sun Microsystems and Java. Academy of Management Journal 45 (1), 196–214.
Garud, R., Karnoe, P., 2003. Bricolage and breakthrough: disrupted and embedded agency in technology entrepreneurship. Research Policy 32, 277–300.
Godoe, H., Nygaard, S., 2006. System failure, innovation policy and patents: fuel cells and related hydrogen technology in Norway 1990–2002. Energy Policy 34, 1697–1708.
Graebner, M.E., Eisenhardt, M.E., 2004. The seller's side of the story: acquisition as courtship and governance as syndicate in entrepreneurial firms. Administrative Science Quarterly 49, 366–403.
Guillen, M., 2001. Is globalization civilizing, destructive or feeble? A critique of five key debates in the social science literature. Annual Review of Sociology 27, 235–260.
Hall, P.A., Soskice, D., 2001. Varieties of Capitalism: The Institutional Foundations of Comparative Advantage. Oxford University Press, Oxford, Great Britain.
Hart, J.A., 1992. Rival Capitalists: International Competitiveness in the United States, Japan and Western Europe. Cornell University Press, Ithaca, New York.
Hicks, A., Kenworthy, L., 1998. Cooperation and political economic performance in affluent democratic capitalism. American Journal of Sociology 103 (6), 1631–1672.
IEA, 2004. Hydrogen and Fuel Cell Activities in France. IEA Hydrogen Coordination Group. Retrieved November 7, 2004 from www.usea.org/IPHE/2-19-04/France%20Country%20Paper.doc.
IEC, 2004. The Current International Status of Codes and International Standards Development in Fuel Cell Technology. Retrieved on May 20, 2005 from www.jrc.nl/fctestnet/Workshop%20Leysin.
International Finance Corporation, 2001. Market Prospects and Attendant Intervention Strategies to Accelerate the Deployment of Fuel Cells in Distributed Power Generation for Developing Countries. International Finance Corporation, Washington, DC.
Jankowski, R., 1989. Preference aggregation in firms and corporatist organizations: the enterprise group as a cellular encompassing organization. American Journal of Political Science 33 (4), 973–996.
Jepperson, R., 2002. Political modernities: disentangling two underlying dimensions of institutional differentiation. Sociological Theory 20 (1), 61–85.
Katzenstein, P.J. (Ed.), 1978. Between Power and Plenty: Foreign Economic Policies of Advanced Industrial States. University of Wisconsin Press, Madison, Wisconsin.
Kenworth, L., 2003. Quantitative indicators of corporatism. International Journal of Sociology 33 (3), 10–44.
Kogut, B., Zander, U., 1992. Knowledge of the firm, combinative capabilities, and the replication of technology. Organization Science 3 (3), 383–397.
Kostova, T., Roth, K., Dacin, M., 2008. Institutional theory in the study of multinational corporations: a critique and new directions. Academy of Management Review 33 (4), 994–1006.
Lundvall, B., 1998. Why study national systems and national styles of innovation? Technology Analysis and Strategic Management 10 (4), 407–421.
Macher, J.T., Mowery, D.C., Di Minin, A., 2007. The "non-globalization" of innovation in the semiconductor industry. California Management Review 50 (1), 217–242.
Maeda, A., 2003. Innovation in Fuel Cell Technologies in Japan: Development and Commercialization of Polymer Electrolyte Fuel Cells. Retrieved on May 20, 2005 from http://www.oecd.org/dataoecd/12/28/31968247.pdf.
Malerba, F., Orsenigo, L., 1993. Technological regimes and firm behaviour. Industrial and Corporate Change 2, 45–71.
Malerba, F., 2002. Sectoral systems of innovation and production. Research Policy 31, 247–264.
March, J.G., 1991. Exploration and exploitation in organizational learning. Organization Science 2 (1), 71–87.
Mezias, S.J., Kuperman, J.C., 2001. The community dynamics of entrepreneurship: the birth of the American film industry, 1895–1929. Journal of Business Venturing 16 (3), 209–233.
Mima, S., Criqui, P., 2003. The future of fuel cells in a long-term inter-technology competition framework. In: Avadikyan, A., Cohendet, P., Héraud, J. (Eds.), The Economic Dynamics of Fuel Cell Technologies. Springer, New York, pp. 43–78.
Morris-Suzuki, T., 1994. The Technological Transformation of Japan: From the Seventeenth to the Twenty-first Century. Cambridge University Press, Cambridge, UK.
Mowery, D., Nelson, R.R., 1999. The Sources of Industrial Leadership. Cambridge University Press, Cambridge.
Murmann, J.P., 2004. Knowledge and Competitive Advantage: The Coevolution of Firms, Technologies and National Institutions. Cambridge University Press, Cambridge.
Murtha, T.P., 1991. Surviving industrial targeting: state credibility and public policy contingencies in multinational subcontracting. Journal of Law Economics and Organization 7 (1), 117–143.
Murtha, T.P., Lenway, S.A., 1994. Country capabilities and the strategic state: how national political institutions affect multinational corporations' strategies. Strategic Management Journal 15, 113–129.
Nail, J.M., Anderson, G., Caesar, G., Hansen, C.J., 2005. The Evolution of PEM Stationary Fuel in the U.S. Innovation System. Retrieved on May 20, 2005 from http://www.oecd.org/dataoecd/12/30/31967874.pdf.
Nelson, R.R., 1990. Capitalism and engine of progress. Research Policy 19, 193–214.
Nettl, J.P., 1968. The state as a conceptual variable. World Politics 20 (4), 559–592.
Nygaard, S., 2004. Patents, Innovation and Policy: Fuel Cells and Related Hydrogen Technologies in Norway 1990–2002. Retrieved on May 20, 2005 from www.innovation.lth.se/files/Stian/chumpeter%202004%20paper%20by%20Stian%20Nygaard.pdf.
OECD, 2007. Science Technology and Industry Scoreboard: Innovation and Performance in the Global Economy. Organization for Economic Cooperation and Development, Paris.

Patel, P., Pavitt, K., 1991. Large firms in the production of the world's technology-an important case of non-globalization. Journal of International Business Studies 22 (1), 1–21.

Pavitt, K., Patel, P., 1999. Global corporations and national systems of innovation: who dominates whom? In: Archibugi, D., Howells, J., Michie, J. (Eds.), Innovation Policy in a Global Economy. Cambridge University Press, Cambridge, pp. 94–119.

Penner-Hahn, J., Shaver, J.M., 2005. Does international research and development increase patent output? An analysis of Japanese pharmaceutical firms. Strategic Management Journal 26 (2), 121–140.

Porter, M.E., 1990. The Competitive Advantage of Nations. Free Press, New York.

Riis, T.U., Midtsundstad, E., 2005. National Hydrogen Activities in Norway. Retrieved on May 20, 2005 from www.iphe.net/1-3-05/Norwegian%20Country%20Statment%20-%20desember%202004.pdf.

Royo, S., 2002. A New Century of Corporatism? Corporatism in Southern Europe-Spain and Portugal in Comparative Perspective. Praeger Publishers, Westport, CT.

Ruttan, V.W., 2006. Is War Necessary for Economic Growth? Military Procurement and Technology Development. Oxford University Press, New York.

Schmitter, P.C., 1974. Still the century of corporatism? In: Pike, F.B., Stritch, T. (Eds.), The New Corporatism: Social-Political Structures in the Iberian World. University of Notre Dame Press, Notre Dame, pp. 85–131.

Seymour, R., 2004. Fuel Cell Market Survey: Patents, A Rich Vein of Knowledge. Retrieved November 7, 2004 from http://www.fuelcelltoday.org/FuelCellToday/IndustryInformation.

Skocpol, T., 1985. Bringing the state back in: strategies of analysis in current research. In: Evans, P.B., Reuschemeyer, D., Skocpol, T. (Eds.), Bringing the State Back In. Cambridge University Press, Cambridge, UK, pp. 3–43.

Soskice, D., 1999. Divergent production regimes: coordinated and uncoordinated market economies in the 1980s and 1990s. In: Kitschelt, H., et al. (Eds.), Continuity and Change in Contemporary Capitalism. Cambridge University Press, Cambridge.

Spencer, J.W., Murtha, T.P., Lenway, S.A., 2005. How governments matter to new industry creation. Academy of Management Review 30 (2), 321–337.

Swaminathan, A., Wade, J.B., 2001. Social movement theory and the evolution of new organizational forms. In: Schoonhoven, C.B., Romanelli, E. (Eds.), The Entrepreneurship Dynamic: Origins of Entrepreneurship and the Evolution of Industries. Stanford University Press, Stanford, CA.

Teece, D.J., Pisano, G., Shuen, A., 1997. Dynamic capabilities and strategic management. Strategic Management Journal 18 (7), 509–533.

USDOE, 2004. Fuel Cells Program Overview. Retrieved on May 20, 2005 from http://www.eere.energy.gov/hydrogenandfuelcells/h2_fc_coord_mtg.html.

Van de Ven, A.H., Garud, R., 1989. A framework for understanding the emergence of new Industries. In: Rosenbloom, R.S., Burgelman, R. (Eds.), Research on Technological Innovation, Management and Policy. JAI Press, Greenwhich, CT.

Van de Ven, A.H., 2004. The context-specific nature of competence and corporate development. Asia Pacific Journal of Management 21, 123–147.

Vitols, S., 2001. Varieties of corporate governance: comparing Germany and the U.K. In: Hall, P.A., Soskice, D. (Eds.), Varieties of Capitalism: The Institutional Foundations of Comparative Advantage. Oxford University Press, Oxford, Great Britain.

Whitley, R., 2000. The institutional structuring of innovation strategies: business systems, firm types and patterns of technical change in different market economies. Organization Studies 21 (5), 855–886.

Williamson, P.J., 1989. Corporatism in Perspective. Sage Publications, London.

Winter, S.G., 1987. Knowledge and competence as strategic assets. In: Teece, D. (Ed.), The Competitive Challenge: Strategies for Industrial Innovation and Renewal. Ballinger, Cambridge.

Wright, M., 1988. Policy community, policy network and comparative industrial policies. Political Studies 36, 593–612.

Zahra, S.A., George, G., 2002. Absorptive capacity: a review, reconceptualization and extension. Academy of Management Review 27, 185–203.

Zander, U., Kogut, B., 1995. Knowledge and the speed of transfer and imitation of organization capabilities: an empirical test. Organization Science 6, 76–92.