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Challenges and Trade-Offs in Corporate Innovation for Climate Change

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ABSTRACT
The international debate on addressing global climate change increasingly points to the role that companies can play by using their innovative capacity. However, up till now companies have been rather cautious in taking decisive steps in facilitating an innovation-based transition towards a low-carbon economy. This paper conceptually explores some key challenges related to innovating for climate change, in the broader context of technological change, complementary capability development and sociotechnical systems, to point to trade-offs to be made by companies. We adopt a firm-level perspective to discuss (a) how companies strike a balance between further development and deployment of emissions-reducing technologies, in view of the fact that there is no 'silver bullet' solution for climate change yet, (b) how and in what way low-carbon solutions are brought to the market, by targeting consumers in either mainstream markets or niche markets, and (c) to what extent the success or failure of climate change innovations depends on companies' bargaining power and willingness to cooperate with others. The paper shows how several industry- and firm-specific factors – technological dynamism, complementarity between new technologies and existing assets, and ownership of specialized assets for commercialization – influence how companies strike a balance between the different trade-offs and deal with the uncertainty created by the current 'climate policy deadlock'. Copyright © 2010 John Wiley & Sons, Ltd and ERP Environment.

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Introduction

The international debate on addressing global climate change and the concomitant reduction of greenhouse gases (GHGs) increasingly points to the role that business can (and/or should) play. Most attention has focused so far on carbon trading (also labelled compensatory approaches to climate change, Kolk and Pinkse, 2005), also due to the start of the European Union Emissions Trading Scheme (EU ETS) and a range of voluntary carbon markets, for example in the US and Australia (see for example a special issue of *European Management Journal* in December 2007). However, creating a mature (global) carbon market is only the first step to a more fundamental corporate contribution to GHG emission reductions. Even if a carbon market

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functioned as intended, it would still only be an incentive to take the price of carbon into account when making investments and other types of corporate decision. Then there would be a stimulus for underlying innovation that realizes such emission reductions at the lowest cost, and furthers the search for low-carbon solutions.

In the current situation this is not really the case (yet), and technological innovation related to climate change is much more novel and in its early stages compared with compensation via trading and offsetting. This even applies to those companies that are significant emitters and thus most confronted with the problem – and also crucial in helping find (technological) solutions. While there are some early movers that have seized the opportunity, perhaps to gain a strategic advantage over their rivals, overall companies have been rather cautious in taking decisive steps in facilitating what has been indicated as the market transition needed to address climate change (cf. Hoffman, 2005). This may have to do with the fact that particularly large international companies have been facing a complex context of continuously changing climate policies in various regions/countries, and thus a high level of uncertainty (Kolk and Pinkse, 2008; Pinkse and Kolk, 2009). Moreover, a complete integration of climate change and a move towards a low-carbon economy ultimately asks for a competitive reconfiguration (or replacement) of several of the most powerful industries, namely those that supply fossil fuels and/or have products that demand massive amounts of fossil fuels (Holdren, 2006).

As a result, companies seem to fear making what have been called 'irreversible green mistakes' and to doubt the flexibility of climate-induced investments (Rugman and Verbeke, 1998). The reason is that technological innovation depends strongly on long-term investments in research and development (R&D): a process where the outcome is always uncertain. Moreover, low-carbon technologies will only become a success when companies possess the capabilities to bring these technologies to the market in the form of products and services and serve global mainstream markets instead of local niche markets only (Gallagher *et al.*, 2006; Wellington *et al.*, 2007). Furthermore, to effectively tackle climate change it appears necessary that companies move away from existing technologies and build new, unrelated capabilities. Finally, all of this has to take place in a setting where viable markets and concomitant infrastructure are (as yet) absent, and with uncertainty about technological possibilities – incremental or radical, based on existing technologies or ones that still need to be developed.

Hence, innovating for climate change presents companies with key challenges, which in themselves are subject to different managerial perceptions and interpretations of inter alia technological and market potential, regulatory constraints and firm-specific capabilities (Kolk and Levy, 2004; Sharma, 2000), and trade-offs have to be made. This paper adopts a firm-level perspective to explore some of the key issues related to technological innovation for climate change, using different lenses on technological trajectories, markets and capabilities, and relying on illustrative examples from various sources, particularly from those sectors most affected by the issue. The three trade-offs discussed are first, technology development or deployment (i.e. whether to search for a 'silver bullet' or aiming to 'scale up'), second, niche development or hybridization (i.e. whether to aim for a carbon-free end-point or a low-carbon transition technology), and third, cooperation or competition (i.e. how to balance working together on a more systemic solution with the competitive implications including the threat of new entrants). Before exploring these aspects, however, we shall first briefly pay some attention to the broader setting that affects decisions on these trade-offs, as outlined in Figure 1. This involves the role of technological change in relation to companies' (perceived) capabilities, and the broader sociotechnical system.

Exploring the Boundaries: Technological Change, Complementary Capabilities and the Sociotechnical System

A change in technology is seen as one of the most important means for tackling the climate change problem.[1] Because the current carbon-intensive energy system lies at the heart of the problem, an energy transition seems necessary to lower dependence on fossil fuels. Therefore, the literature has discussed many alternative technologies that might potentially replace fossil fuels as our main source of energy (Hoffert *et al.*, 1998, 2002; Pacala and Socolow, 2004). Technological change is, however, often seen as an exogenous event (Lavie, 2006), while

[1] The other main option to reduce the impact of humans on the climate is a behavioral change towards consuming less energy, an activity in which companies can also play an active role.

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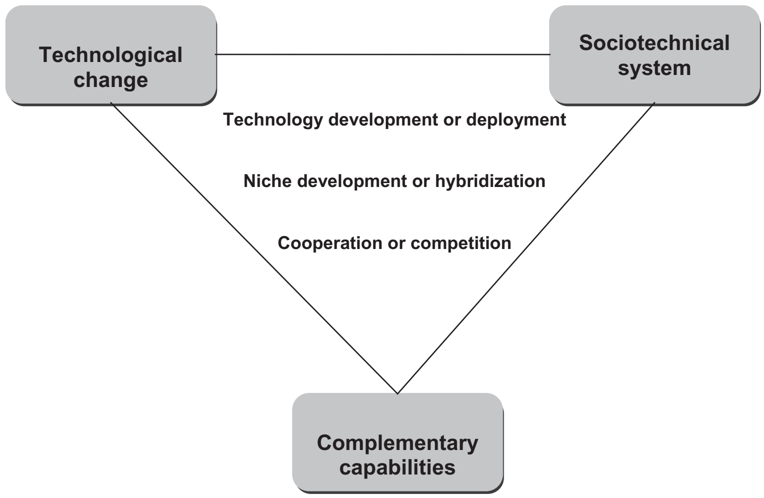

Figure 1. Main issues faced by companies in the transition towards a low-carbon economy

companies can in effect have a clear influence on the specific trajectory that technological change follows (Kemp *et al.*, 1998). Through R&D and technological capabilities companies can invent technologies that help reduce emissions. However, potentially more important even is their role in the whole innovation process, which means not only inventing a technology, but also commercializing it by bringing usable products to the market. This involves a wide array of capabilities such as integrating technological capabilities into product design and the manufacturing process, being responsive to market needs, optimizing the time it takes to bring a product to the market and maintaining flexibility (Rothwell, 1994). What distinguishes the corporate innovation process for *climate change* is that the role of government is crucial. By setting goals for reduction of GHGs, governments put pressure on companies to speed up the innovation process to even go beyond compliance in anticipation of upcoming climate policies (Marcus and Geffen, 1998).

Hence, how companies affect technological change is related to the specific complementary assets and capabilities (in e.g. manufacturing, marketing *and* lobbying policy makers) that they employ in the innovation process to commercialize a new technology, because these determine whether companies can profit from the innovation process (Teece, 1986). Thus, whether companies will push for, or fight against, technological change induced by climate change policy depends largely on how they perceive the impact on the value of their complementary assets and capabilities that form the basis of their competitive advantage (Tripsas, 1997). Companies that possess specialized assets that are required for commercializing certain types of innovation can benefit from technological change because they form the bottleneck in the value chain; however, those companies that merely own generic assets stand to lose their competitive advantage as the innovation will make these assets obsolete (Jacobides *et al.*, 2006; Rothaermel and Hill, 2005; Tripsas, 1997).

The choice that companies have in responding to technological change is therefore trying either to influence the technological trajectory in such a way that it will most likely be competence enhancing or to change firm-specific capabilities to be able to deal with a competence-destroying change instead (Tushman and Anderson, 1986). If companies push for competence-enhancing change they can still rely on existing complementary capabilities, while a competence-destroying change means that they will need to realize a complete modification of these capabilities within the company and/or the acquisition of new capabilities from outside (Gatignon *et al.*, 2002; Lavie, 2006).

What further complicates innovation for climate change is that it calls for a change not only in a company's assets or capabilities, but often also in the entire sociotechnical system. A sociotechnical system 'is not only characterized by a set of rules that guide technical design, but also by rules that shape market development (e.g. user preferences) and rules for regulating these markets' (Schot and Geels, 2007, p. 608). The notion of the

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sociotechnical system considers the role of technology in fulfilling a specific function in society, such as mobility and energy supply, and takes into account that a range of actors including companies, consumers and governments can influence the way in which this function is fulfilled (Geels, 2004). The fact that the nature of the sociotechnical system depends on many different actors means that a change cannot be realized by companies on a unilateral basis. For example, technologies need to be in line with consumer preferences, and regulators may have to adjust rules by offering subsidies and tax breaks in a way favourable to the technology. The regulatory regime that governments will put in place to curb GHG emissions currently seems to form a barrier because of the continuously changing climate policies in various regions/countries and the lack of global agreement for a post-2012 follow-up to the Kyoto Protocol. Companies thus face a considerable degree of uncertainty, which might impede the innovation process (Raven, 2007). This is the context in which the analysis of this paper is embedded.

Hence, and as indicated in Figure 1, technological change, complementary capabilities and the sociotechnical system are main elements to be considered in innovating for climate change, and in the trade-offs that companies will have to make. Innovating for climate change is likely to require a move away from carbon-intensive technologies towards technologies that lower the human impact on the climate. However, a change in technology does not mean that it will also be successful in the market, because dominant companies may fear it will be competence destroying, and negatively affect their competitive position, and thus stand in the way of market introduction, particularly into mainstream markets. Moreover, even if companies favour a specific technology and take part in its market introduction, in the end consumers generate demand and governments support certain technologies. Thus, it is the wider sociotechnical system that acts as a selection environment for the success of specific technologies (Schot and Geels, 2007). Generally speaking, a transition to a low-carbon economy seems only possible when all three elements work in the same direction. The specific interaction of the three, however, differs for the various dimensions of the multi-faceted and complex climate problem. The remainder of the paper will explore this for three key trade-offs related to innovating for climate change and specifically addresses the way in which the level of uncertainty and complementary assets affect this process in high-salience industries.

Trade-Offs in Innovating for Climate Change

Picking Winners: Technology Development or Technology Deployment

One of the major challenges for climate change innovation is that a real reduction of GHG emissions requires a lower dependence on fossil fuels. Although energy-efficiency improvements could play an important role in stabilizing carbon dioxide (CO_2) emissions on a global level, it will not be enough to completely ward off that dangerous CO_2 concentration levels might be reached. To move into safer waters a much greater deployment of low-carbon or carbon-free alternatives is deemed necessary (Hoffert *et al.*, 1998). However, for high-salience sectors such as power generation and transportation it is not at all clear what should replace the prevailing fossil-fuel-based technologies. There is no technological 'silver bullet' solution at the moment. Although non-fossil-fuel-based alternatives might lead to a lower climatic impact, it is typically the case that they have other limitations, liabilities and uncertainties (Holdren, 2006; Kemp *et al.*, 1998) that particularly come to the surface when their deployment is scaled up (Grubb, 2004).

Climate change experts have different views on the most desirable technological trajectories to reach a solution for climate change (Grubb, 2004; Hoffert, 2006). On the one hand, it has been argued that a major investment in (government-led) R&D programmes and international cooperation are necessary because all possible alternatives to the current fossil-fuel-based energy infrastructure require large investments in fundamental and applied research (Hoffert *et al.*, 1998, 2002). The main idea is that whatever technological trajectory is chosen for power generation (be it continued use of coal or natural gas combined with carbon capture and storage, nuclear, or renewables), this will in all cases call for a radical departure from the existing energy infrastructure and require further research, if these options are to help in significantly reducing carbon emissions.

On the other hand, it is stated that there has been too much focus on developing new fundamental scientific, technical and industrial expertise in search of radical solutions, while a significant reduction could also be achieved by scaling up technologies based on existing know-how (Pacala and Socolow, 2004). This approach, which has

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become known as the 'stabilization wedges', argues that there will not be one single carbon-free technology that is sufficient to solve the climate change problem on its own; instead, it is a portfolio of less ambitious options that will do the job jointly. These options (or wedges) include energy efficiency and conservation measures (e.g. more efficient and reduced use of vehicles, efficient buildings, efficient coal-based power plants); fuel switching (e.g. from coal to natural gas); carbon capture and storage; nuclear power; renewable electricity and fuels (e.g. wind and solar power, and the use of hydrogen and biomass as transportation fuels) and forest and agricultural management (Pacala and Socolow, 2004).

What is remarkable is that both approaches basically call for further development and deployment of the same collection of technologies for energy supply and transportation. However, they diverge in that one puts more emphasis on development and the other on deployment. This difference is important because it has implications for the technological trajectories that companies follow. Translated to the corporate level, this debate on climate change technology comes down to a trade-off between further exploring new technological possibilities and more fully exploiting existing ones (cf. March, 1991). Companies are facing a dilemma of whether to search for solutions that still require huge amounts of R&D or choose to scale up existing technologies that have proven themselves (at least in a demonstration phase) (Wellington *et al.*, 2007). Such a shift in focus on development or deployment means that companies would differ in not only their technological trajectory process-wise, but also in which technological options they will invest to start with. The main difficulty for companies in this regard is usually the timing of R&D investments in emission-reducing technology, as this affects the possibility for creating a first-mover advantage based on the new technology (Nehrt, 1996). Before a company will be able to create returns from the accumulation of technological assets, it must maintain a stable rate of R&D spending over a considerable time period instead of investing a huge amount of R&D at once, because developing the essential know-how takes time (due to time compression diseconomies) (Dierickx and Cool, 1989). Only a company that focuses on technology development reflected by early timing of R&D investments will be able to develop a first-mover advantage from climate change innovation in the longer run (Nehrt, 1996).

This implies that, even when companies currently do not feel a pressure to deal with climate change, uncertainty about the outcomes of global climate policy negotiations creates a scenario that technology development cannot be postponed until stringent climate policies will be implemented – they have to act much earlier than that. If companies wait until climate policies come into effect, they risk having to implement quick-fix measures, which are relatively disruptive for the production process (Christmann, 2000). On the other hand, in a situation of uncertainty about climate policy, which implies that specific standards for GHG emissions have not been set yet, companies have more influence on decision-making on the type of technology that will be best for complying with upcoming policies; this may stimulate their corporate innovation process (Aragón-Correa and Sharma, 2003; Marcus and Geffen, 1998).

An important factor in this respect is the level of technological dynamism in the industry (Uotila *et al.*, 2009). In industries with a high level of technological dynamism, companies tend to take greater risks because there are better opportunities to benefit from innovation (Aragón-Correa and Sharma, 2003). A company that merely relies on deployment of existing assets runs the risk of its technologies becoming obsolete, as they might be substituted rather abruptly by technological innovations developed by others (Uotila *et al.*, 2009). However, if an industry exhibits slow technological change, a company may gamble that competitors will not be able to change their technological assets promptly and thus focus on deployment of existing technologies and only improve them through incremental changes.

The difference in R&D patterns between the power generation industry and the automotive industry clearly illustrates this industry specificity. R&D intensity in power generation has been notoriously low (Margolis and Kammen, 1999), which can be explained from the fact that technological innovation in this industry involves massive capital investments combined with limited opportunities for product differentiation (Grubb, 2004). Car companies, on the other hand, operate in a much more dynamic technological environment and therefore face greater pressure to develop alternative drive-train technologies, such as hybrids, electric vehicles and fuel cell vehicles (Dyerson and Pilkington, 2005; Van den Hoed and Vergragt, 2004).

We therefore expect industry technological dynamism to moderate how the level of uncertainty from climate policy affects companies in striking a balance between technology development and deployment, as summarized in the following proposition.

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Proposition 1. Under conditions of high uncertainty from climate change policy, firms will invest more in technology development than deployment if they operate in technologically dynamic industries.

Commercializing Technologies: Niche Market or Mainstream Market

Another challenge with regard to the corporate climate change innovation process is the issue of commercialization – how to develop new markets. As discussed above, commercialization involves the integration of new technology in the design and manufacturing process, responsiveness to market needs, speed of time-to-market, flexibility and getting ahead of regulatory activity on climate change (Rothwell, 1994). Hence, whether a company succeeds in commercializing the innovation depends not only on its technical attributes, but also on creating consumer acceptance of the technology, establishing a low-carbon brand reputation and anticipating government regulation (Schot and Geels, 2007). Since the market for climate-induced innovations is relatively novel, companies run the risk of making irreversible green mistakes and, as a consequence, will prefer an approach by which they maintain flexibility in their resource commitments (Rugman and Verbeke, 1998). Companies would like to have the option to pull out of the market without putting too many resources at risk if the innovation turns out not to deliver the expected rate of return. Uncertainty about the outcomes of current climate policy negotiations aggravates this risk. In the long run, the ideal scenario would be an energy and transportation infrastructure that does not rely at all on fossil fuels. To reach this end-point, companies can follow two trajectories in developing new markets for low-carbon products, while safeguarding their flexibility: a market niche or a mainstream market approach.

The first option is that companies aim for a trajectory of commercializing carbon-free technologies, where the low-carbon aspect forms the unique selling point. As heavy dependence on fossil fuels is the rule rather than the exception, this means a radical departure from existing markets and systems. One way of achieving this is to let a new technology first develop in a market niche and then gradually progress through several other niches. Such a strategy of 'market niche development' leads to the creation of institutions (e.g. safety rules), adjustment of consumer preferences and improvement of the fit between the new technology and the market (Kemp *et al.*, 1998; Raven, 2007). The main advantage of first targeting niche markets is that it enables a company to experiment with several new technologies in parallel and thus helps in coping with uncertainty as several options are kept open. However, a market niche approach also has several drawbacks. It has proven difficult for companies to move their innovation beyond the market niche into mainstream markets. Moreover, developing a sequence of market niches requires many resources, and if an insufficient rate of return is reached further investments will come to a halt (Raven, 2007). To illustrate, the fact that the fuel cell vehicle was long predestined as the ultimate solution was partly because it followed the route of market niche development. Since the 1960s, fuel cells have been used in several market niches, such as space travel and the US army and navy. However, fuel cell technology has still not managed to leave niche markets (Raven, 2007).

The second option is a trajectory of commercializing low-carbon technologies via incremental changes of existing products, where the low-carbon aspect just forms an extra element to other main selling points. This has been called 'hybridization' because innovation is commercialized as an add-on element to existing products, thus appealing to mainstream markets more swiftly (Raven, 2007). This trajectory is a reflection of the phenomenon that companies, when confronted with technological change, generally do not fully discard their existing key capabilities, but build on them instead (Unruh, 2000). For example, recent evidence shows that US utilities with high levels of coal-based power generation were less likely to invest in renewable generation, as this would be a departure from capabilities in running large, centralized coal-fired power plants (Delmas *et al.*, 2007). There is thus a certain level of inertia in the way in which companies adjust their capabilities in response to technological change (Leonard-Barton, 1992). As a consequence, a climate-induced market shift takes place through transition technologies (Hekkert and Van den Hoed, 2004), which often means that companies commercialize technologies which may be less carbon intensive, but not carbon free. One of the issues then is whether low-carbon products that seem to be of a transitory nature at first will not become dominant themselves, thus standing in the way of further market entry of more radical end-point solutions. For example, the recent success of hybrid cars such as the Toyota Prius might have serious consequences for the marketability of the fuel cell vehicle. The fuel cell's main advantage compared to the internal combustion engine – that it performs much better in terms of emissions –

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almost completely fades away compared with hybrids and may not weigh up to the much higher costs of bringing the fuel cell vehicle to the market (Hekkert and Van den Hoed, 2004). Because resources tend to be scarce, there is a trade-off between developing carbon-efficient transition technologies for mainstream markets and developing carbon-free end-points for niche markets.

To what extent companies' perceived uncertainty about the outcomes of climate policy will drive companies to decide on targeting niche markets or mainstream markets will depend on the complementarity of their investments in the innovation process with existing assets. A company will create more returns from accumulating assets if it already possesses a considerable stock of these assets, because this can lead to asset mass efficiencies (Dierickx and Cool, 1989). The higher historical investments in developing and commercializing emissions-reducing technology have been, the more likely it is that a company will be able to reach the critical mass necessary for market penetration of low-carbon products in mainstream markets (Nehrt, 1996). Important sources of asset mass efficiencies for commercializing emissions-reducing technologies are the usefulness of an existing infrastructure, e.g. for the transportation of fuel and electricity, and the benefits of existing product and brand reputation in mainstream markets (Raven, 2007; Dierickx and Cool, 1989). However, such asset mass efficiencies will only materialize if the innovation has a considerable degree of complementarity with the existing asset stock; otherwise, these existing assets will not be relevant at all (Dierickx and Cool, 1989; Jacobides *et al.*, 2006). For example, a utility that has historically invested in coal-based power generation will have difficulty establishing a 'green' reputation, because the sincerity of the intention of becoming climate friendly will be doubted by prospective customers (Delmas *et al.*, 2007). If this complementarity is lacking, companies will face a situation similar to having low initial levels of relevant know-how, which would drive them towards building this critical mass by investing in market niches to let the innovation thrive first in a relatively protected environment.

An example of an attempt to relate to existing assets with the intention to target mainstream markets is the emergence of carbon capture and storage (CCS). CCS is a particularly attractive route for oil companies because it enables them to continue supplying fossil fuels in a way that is relatively low carbon. Oil companies can use much of their existing know-how, as capture technology has already been developed for other purposes in oil refining and gas processing. They know how to transport CO_2 through pipelines and inject it into underground reservoirs, as this has been used in the US for many years to help with oil production from declining wells (Stephens, 2006). Nevertheless, this does not mean that oil companies have not become involved in niche market development. For example, BP and Shell have both invested in the development of market niches in alternative energy, including solar, wind, hydrogen and biofuels. BP's investments in alternative energy increased to 7% of total capital spending in 2008 – although it formed only 3% of the company's value in terms of market capitalization in that year (Crooks, 2008). An interesting example is Shell, which decided, in March 2009, to discontinue investments in the market niches for solar, wind and hydrogen to merely focus on biofuels, because they have a better fit with its oil and gas operations (Bergin, 2009).

Hence, we expect the level of complementarity between new and existing asset stocks to moderate how the level of uncertainty from climate policy affects companies in striking a balance between hybridization and niche development, as summarized in the following proposition.

> Proposition 2. Under conditions of high uncertainty from climate change policy, firms are more likely to pursue a hybridization approach instead of niche development if they expect high complementarity between the new technology and their existing assets.

Choosing Organizational Scope: Cooperation or Competition

One reason why climate change innovation is complex for companies is that they often need to cooperate with others to some extent (Unruh, 2000). As argued above, the challenge is not only in adapting technology and firm-specific capabilities, but also the entire sociotechnical system. Changing the sociotechnical system is simply too all encompassing for single players (Raven, 2007), as companies depend on complementary technologies and capabilities from others in the supply chain – be it upstream or downstream – as well as favourable government regulations and consumer acceptance of low-carbon technologies (Kemp *et al.*, 1998). Many climate change innovations aim for a more systemic solution, which one company cannot deliver single-handedly. This raises the

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question how far companies are willing to go in taking responsibility for climate change when they need responses from others to achieve a positive outcome, and also how they deal with the competitive dimensions involved. Hence, there is a trade-off between choosing an optimal level (and mode) of cooperation and safeguarding future competitiveness through appropriation of the products of climate change innovation.

Companies will have different incentives for cooperation and depending on the incentive they will choose specific types of partner. On the one hand, a clear incentive for cooperation is to seek knowledge elsewhere. Large multinationals can do this by tapping into their vast global networks – not all technologies still have to be developed, as many have already emerged in niches throughout the world. On the other hand, perceived uncertainty about the outcomes of climate policy also drives companies to cooperate for reasons of risk-sharing and avoiding putting too many resources at risk. For example, many car and oil manufacturers work together with companies that own a specific technology: usually small local niche players. To develop biofuels both Daimler and Volkswagen cooperated with Choren industries, a German firm specialized in gasification technology for the production of energy from biomass. Likewise, Ford and Daimler both partnered with Canadian niche player Ballard, which developed the fuel cell technology to further improve the fuel cell for use in cars. However, a drawback of cooperating with a close competitor in this way is that it hinders building a firm-specific capability, as it is inevitable that at least one competitor will own the same technology as well.

In this sense, cooperation with companies from other industries offers more opportunities to create a firm-specific capability, because both partners can then use the ensuing technology quite differently in their activities. Dow Chemical and General Motors, for example, work together on the development of fuel cells, each for a different purpose. Still, inter-industry cooperation is definitely not always successful either. With regard to plug-in hybrids, for example, for which growth expectations are currently high, there is the question of whether electricity networks could meet such (peak) demands to charge the vehicles. For these types of car, the car industry thus needs some sort of cooperation with utilities. Some resentment of becoming (too) dependent on utilities has been expressed already, for example by the CEO of GM Europe (Oude Weernink, 2008). Nevertheless, two such partnerships – between Toyota and EDF, and Daimler and RWE, respectively – have been announced recently, both with the aim to develop a recharging infrastructure in selected locations (Reed, 2008).

The fact that developing a low-carbon economy calls for a change in the sociotechnical system is thus not necessarily leading to a cooperative stance from all actors involved. Especially in the case of large powerful multinationals, there is a looming 'danger' that they can also create barriers to a more successful market penetration of low-carbon technologies in specific cases beyond their own supply chains. When they cooperate with others in further stimulating climate change innovation, the main question for powerful incumbents is a matter of value appropriation: to what extent will the innovation contribute to their competitive advantage and not to those of others (Jacobides *et al.*, 2006)? Multinationals have the power to use their strength in the value chain to leverage some of their existing capabilities to enter new markets in clean technology. However, they can simultaneously act as main barriers to a more successful market penetration of low-carbon technologies.

To illustrate, in the attempt to commercialize the fuel cell vehicle, the car industry is relying on chemical and oil industries to supply the hydrogen necessary to attract prospective customers. This necessitates a major breakthrough in the production and distribution of hydrogen, which has not occurred yet because it can be a competence-destroying change for fossil-fuel suppliers. As the car industry will not be able to supply the hydrogen itself, it thus faces a major barrier in bringing the fuel cell vehicle to the market. It is basically a 'chicken-and-egg' problem: oil companies will not scale up their hydrogen activities until car companies come with more affordable fuel cell vehicles, while car companies will only launch such models if there is a hydrogen infrastructure (Romm, 2006). Resistance to cooperation may also occur if these technologies do not originate from incumbents but from new entrants. New entrants could initiate a change of the sociotechnical system, which will be difficult for incumbents to accommodate because existing capabilities cannot be leveraged, thus leading to attempts to obstruct such a change (Tripsas, 1997).

What this implies is that the nature of firm-specific complementary assets and capabilities will affect how companies balance cooperation and competition. Companies with specialized complementary assets for the commercialization of an innovation will be affected less by the uncertainty from climate policy, because whatever technology prevails they will be buffered from the entailing technological change as commercialization depends on their specialized assets (Tripsas, 1997). As a consequence, they have no incentive to cooperate, as this may only

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be the first step in initiating an unfavorable market transition. However, if their complementary assets are generic, companies somehow need to ensure appropriation of the innovation and engage in strategic alliances or other forms of collaboration, because this will be the only way to preserve their position in the industry (Jacobides *et al.*, 2006).

A case in point of the influence of specialized complementary assets is the power generation industry's vast grip on the infrastructure for the transmission and distribution of electricity. The system for supply of electricity clearly suffers from a 'carbon lock-in', as technological and market systems surrounding electricity favour generation from fossil fuels (Sandén and Azar, 2005; Unruh, 2000), which hinders scaling up the use of renewables for electricity generation. Technologically speaking, renewables involve intermittent generation instead of the constant generation that characterizes coal- or gas-fired power plants. This creates a barrier because existing transmission networks cannot handle intermittent sources of electricity very well, due to the fact that power stations would need more back-up and storage capacity (Neuhoff, 2005). To reach a mainstream market of electricity consumers, renewable energy suppliers thus rely on cooperation with incumbent utilities. However, the barrier lies in that adjusting the transmission network to enhance access of renewables is not to the benefit of these utilities, because the transmission network is specialized towards working with large conventional power plants, which they generally own themselves. Adapting the network would thus open the door to new entrants at the cost of profitability of their own power plants (Neuhoff, 2005).

Hence, we expect ownership of specialized complementary assets to moderate how the level of uncertainty from climate policy affects companies in striking a balance between cooperation and competition, as summarized in the following proposition.

> Proposition 3. Under conditions of high uncertainty from climate change policy, firms are more likely to embrace competition and refrain from cooperation if their complementary assets are specialized.

Discussion on Implications and Further Trade-Offs

This paper has used different lenses to explore some key trade-offs related to innovating for climate change from the company perspective, in the broader context of technological change, complementary capability development and sociotechnical systems. It has discussed the scaling up of existing technologies, in view of the fact that there is no 'silver bullet' solution yet, and how the balance between further technological development and deployment of the existing collection of technologies are best to be found. A related issue is how and in what way low-carbon solutions are commercialized, targeting consumers in either mainstream markets or niche markets. This is all the more important as choices have to be made on technological trajectories in a market transition towards a low-carbon economy, which may entail incremental or more radical innovations. The success or failure of such innovations also depends on companies' bargaining power and whether they rely on specialized assets for commercialization owned by others in their supply chain or (potential) competitors, and their ability and willingness to cooperate with these other companies. Although presented separately, there are clear overlaps between the three trade-offs. For example, scaling up low-carbon technologies is not only a technological issue. It also involves being able to target mainstream markets, which often depends on cooperation with powerful players in focal markets. Similarly, low-carbon technologies that need large amounts of R&D are in general first commercialized on a small scale in niche markets.

It is important to note that managerial perceptions and interpretations of the problem and its solution(s) may differ considerably (Kolk and Levy, 2004; Sharma, 2000). These sometimes divergent perspectives particularly stem from the considerable uncertainty and complexity in view of the diversity of contexts and policy responses, which means that capabilities developed in response to this 'moving target' will need constant rejuvenation. Perceptions also influence which positions companies take vis-à-vis the various trade-offs (Kolk and Pinkse, 2008). We have explained how several industry- and firm-specific factors – technological dynamism, complementarity between new technologies and existing assets, and ownership of specialized assets for commercialization – influence how companies strike a balance between the different trade-offs and deal with the uncertainty created by the current 'climate policy deadlock'. Of course, this list of factors is not exhaustive, and considering how other

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contingencies might influence these trade-offs deserves further study. This also applies to further empirical explorations and more systematic data collection to test the propositions put forward. While the paper has approached the topic from a firm-level perspective, there are also some broader issues that need to be taken into account in the discussion on future solutions and approaches to address climate change, and in follow-up research. This is particularly important because current compensatory approaches via trading and offsetting are still emerging, but do not seem to be able, even in the situation of a mature carbon market, to realize innovation and a market transition towards a low-carbon economy on their own.

For a profitable and sustained transition towards more environmentally friendly and less carbon-intensive technologies that foster innovation, in the absence of viable markets and concomitant infrastructure, decisive policy steps are needed as well as behavioral changes. Systemic climate solutions that require cooperation between private and public partners, both profit and non-profit, appear necessary. There is a large 'chicken-and-egg' problem though, with parties waiting for one another, and calls to break the deadlock but without clear ideas as to the how (Pinkse and Kolk, 2009). Hardly anyone is taking decisive steps even though quite a few companies and governments have the ability to do so. Moreover, the role of consumers in tackling climate change should become clearer as well. Companies often state they do not supply low-carbon products because they do not sense demand from consumers; at the same time, however, consumers will not buy more low-carbon alternatives if their choice is still limited. Therefore, another dilemma for companies is how to convince consumers to buy climate-friendly products and services. It now seems that the marketing of 'green products' is not taken to its full potential because many companies expect a low (or no) demand for such products (Ginsberg and Bloom, 2004). If companies strive for serving mainstream markets with climate change innovations, more insight into consumer behaviour, and how emerging awareness on the topic translates into buying decisions (or not) is necessary.

It may be that attempts to address the economic crisis could have implications for climate change innovation as well; these have also made some of the connections between the two ('green' new deal) and the trade-offs involved more visible (Kolk and Pinkse, 2009). For example, bail-out plans have aimed to scrap old, energy-inefficient cars and boost demand for more efficient ones, but whether this has a net environmental benefit can be doubted; it is also unclear whether government spending stimulates new ventures or instead favours established companies that struggle to remain innovative and/or to survive at all. The economic slow-down has highlighted some contradictions in terms of climate impacts as well: for example, that a recession may be helpful for meeting Kyoto targets, but not for attracting investments in renewable energy and energy-saving activities. Implications of lower oil/petrol prices have also come to the fore. These have included the reduction of driving activity and car sales (and a diminution of the trend towards smaller, more energy-efficient cars in the US), and a sharp decline in the interest in biofuels; the latter has (temporarily) ended the heated debate about the upward effect of biofuels on food prices.

These are just some of the broader dimensions of innovation and climate change that may need further consideration for a better insight into the dynamics and drivers. In a sense, the economic crisis as well as growing awareness of a climate crisis that also needs attention offers the opportunity to follow in more detail what the effects are of particular measures taken globally, regionally (e.g. EU), nationally and/or locally (e.g. at the level of states in the US or Germany). Especially when looked at from the perspective of multinational enterprises, which are located in multiple countries with a variety of policy approaches and involving a multitude of actors, some of the trade-offs in the field of climate-related innovation will emerge (Kolk and Pinkse, 2008). This has to do with the fact that not only stakeholder and political circumstances but also geographical and infrastructural conditions differ considerably in different locations, so climate change can be an opportunity at one location, but a threat at another. More detailed studies on how different policy approaches, covering multiple levels, work out for corporate innovation within one organizational framework, and how trade-offs and uncertainty are being dealt with, will be very worthwhile to shed more light on the ideas and propositions put forward in this paper.

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