Institut für Wirtschaftsforschung Halle
Halle Institute for Economic Research

Towards a Theory of Climate Innovation - A Model Framework for Analyzing Drivers and Determinants

Wilfried Ehrenfeld

January 2012 No. 1

IWH-Diskussionspapiere
IWH Discussion Papers

Author: *Wilfried Ehrenfeld*
Department of Structural Change
E-mail: wilfried.ehrenfeld@iwh-halle.de
Phone: +49 345 7753 832

The responsibility for discussion papers lies solely with the individual authors. The views expressed herein do not necessarily represent those of the IWH. The papers represent preliminary work and are circulated to encourage discussion with the authors. Citation of the discussion papers should account for their provisional character; a revised version may be available directly from the authors.

Comments and suggestions on the methods and results presented are welcome.

IWH Discussion Papers are indexed in RePEC-Econpapers and in ECONIS.

Editor:
HALLE INSTITUTE FOR ECONOMIC RESEARCH - IWH
The IWH is a member of the Leibniz Association.

Address: Kleine Maerkerstrasse 8, D-06108 Halle (Saale), Germany
Postal Address: P.O. Box 11 03 61, D-06017 Halle (Saale), Germany
Phone: +49 345 7753 60
Fax: +49 345 7753 820
Internet: http://www.iwh-halle.de

ISSN 1860-5303 (Print)
ISSN 2194-2188 (Online)

Towards a Theory of Climate Innovation - A Model Framework for Analyzing Drivers and Determinants

Abstract

Climate change, including its possible causes and consequences, is one of the most controversial and intensely discussed topics of our time. However, European businesses nowadays are less affected by the direct effects of climate change than by its indirect consequences. One central issue that arises in this context is the change in demands imposed by the enterprises' operational environment.

This article contributes to environmental innovation literature by providing a comprehensive framework which allows an analysis of the drivers, determinants and outcomes of climate innovations implemented by companies. In this context, the prime issue is how the perception of climate change affects corporate innovation processes. Firstly, the new demands imposed on the company by its stakeholders are considered. Secondly, the innovative reactions to these impulses are captured. Finally, the functions and relevance of certain internal and external determinants in the innovative process are highlighted.

Keywords: climate change, evolutionary economics, innovation, research framework

JEL Classification: O31, Q54, O33, O38, Q55

Klimainnovationen - ein evolutorischer Modellrahmen zur Untersuchung von Treibern und Determinanten

Zusammenfassung

Der Klimawandel - einschließlich seiner möglichen Ursachen und Folgen - ist eines derjenigen Themen, die derzeit am intensivsten und kontroversesten diskutiert werden. Unternehmen in Europa sind heute allerdings weniger durch die direkten Auswirkungen des Klimawandels betroffen als vielmehr durch dessen indirekte Konsequenzen. Dazu gehört vor allem die Veränderung von Ansprüchen an sie, welche seitens ihres betrieblichen Umfeldes gestellt werden.

Ziel dieses Artikels ist es, ein umfassendes theoretisches Rahmenwerk zur Analyse von Treibern, Determinanten und Ergebnissen betrieblicher Klimainnovationen zu entwickeln. Hier steht primär die Frage im Vordergrund, wie die Wahrnehmung des Klimawandels betriebliche Innovationsprozesse beeinflusst. Zum einen werden die neuen Forderungen berücksichtigt, die seitens betrieblicher Anspruchsgruppen an Unternehmen gestellt werden. Zum anderen werden die Innovationen erfasst, mit denen Unternehmen auf diese Impulse reagieren. Schließlich wird untersucht, welchen externen und internen Determinanten bei diesen Prozessen welche Funktion und Relevanz zukommt.

Schlagwörter: Klimawandel, evolutorische Ökonomik, Innovation, Modell

JEL-Klassifikation: O31, Q54, O33, O38, Q55

1 Introduction

At least since the introduction of the European Union Emission Trading System (EU ETS) in the year 2005 and the publication of the fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC 2007), the topic "Climate Change" has become one of the most controversial and intensely discussed issues of our times. One thing is indisputable, however: innovation is considered essential in tackling the problem of climate change (see, e. g., Montgomery and Smith 2007:331).

Nowadays, European businesses are less affected by the direct effects of climate change, such as extreme weather events, than by its indirect consequences. These arise mainly from society's perceptions of climate change and include the change in demands made on companies by their operating environment. Corporations could react with innovative activities in adapting to these changes. Depending on the group making the demands and the business objectives and factors, the resulting innovations may differ.

The main focus in this context is to answer the question of how the perception of climate change can affect corporate innovation processes. This question can be divided into three sub-questions. Firstly, how do the demands of company stakeholders, motivated by their perceptions of climate change, affect companies? Secondly, how do companies react innovatively to these impulses? In order to do so, different kinds of innovations and their sources must be distinguished. Furthermore, the possible economic consequences of these innovations on the corporate entities should be considered. Finally, which external and internal determinants are particularly important in these processes and which have what function and relevance?

The literature on environmental innovation is extensive (for overviews see, e. g., del Río González 2009; Oltra 2008; and González-Benito and González-Benito 2006 as well as the literature cited therein). Earlier research has covered various aspects of environmental innovation such as overviews and discussions of the determinants of such innovations (see, e. g., González-Benito and González-Benito 2010; del Río González 2009; and González-Benito and González-Benito 2006) and numerous empirical studies in various sectors and countries (see, e. g., Fraj-Andrés, Martínez-Salinas, and Matute-Vallejo 2009; Horbach 2008; del Río González 2005; and Brunnermeier and Cohen 2003). As far as climate change is concerned, apart from the physical science literature, most papers concentrate on the EU ETS (see, e. g., Pinkse 2007), its competitive effects (see, e. g., Oberndorfer and Rennings 2007) or the pass-through of its costs (see, e. g., Zachmann and Hirschhausen 2008). Very little of this literature deals with the impact of the EU ETS on innovation (see, e. g., Rogge, Schneider, and Hoffmann 2011 and Gagelmann and Frondel 2005).

However, there is no all-encompassing framework dedicated to analyzing climate innovation at the corporate level in the existing literature.[1] The aim of this article is therefore to develop a comprehensive theoretical framework for the analysis of the operational drivers, determinants and outcomes of climate innovations. In so doing, various elements from the literature on environmental innovation are combined.

2 Theoretical fundamentals

2.1 Foundations of evolutionary economics

The process of innovation cannot be represented adequately by using neoclassical theory (Suurs 2009:19; Hanhoff genannt Stemping 2003:32ff.). The criticism in this context concerns central assumptions of neoclassical theory which may here prove too restrictive. These include perfect and complete markets with elements such as complete information, full rationality, profit-maximizing behavior of the actors and the existence of a static equilibrium. In accepting these assumptions, many factors of human behavior are ignored and reality is greatly reduced. In the case of the analysis of innovative behavior, this is a hindrance. In terms of technological innovations there are, for example, uncertainties that should not be ignored.

As a framework for the consideration of innovations and their development processes, evolutionary economics (see Dosi and Marengo 2007; Dosi 1997; Nelson 1995; Freeman 1994; Nelson and Winter 1982) appears much more suitable because of its explicitly dynamic conception. In addition, this strand of theory allows a consideration of exogenous as well as endogenous drivers of evolutionary change. Its concern is to understand the processes that lead to currently observable phenomena and the selection of future development paths (Dosi 1997:1544; Nelson 1995:48). How

[1] In the initial stages of writing this article, a systematic literature search of Ebsco's Business Source Complete Database was conducted using various combinations of the keywords determin*, factor*, clima*, klima*, environ*, innovat* and technolog* chang*.

innovations emerge and how selection processes take place in the market are of particular interest (Dosi 1997:1531). In the next section, the basic principles of this theoretical concept are explained. For an overview of recent developments and trends in evolutionary economics see Dolfsma and Leydesdorff (2010), Witt (2008a) and Dopfer (2005).

Basically, evolutionary theory uses some analogies from evolutionary biology and Darwin's theories to describe the development process in companies and industries (Witt 2008b:548ff.; Witt and Cordes 2007; Nelson 2006). Terms such as diversity, (natural) selection and development are adopted and specifically interpreted. But in these models, companies are the main actors, not human individuals (Metcalfe 2005:392; Nelson 1995:68). For example, the behavioral patterns of companies are described as an analogy of the genotypes in biology. They are the subject of the selection process (Witt 2008b:557; Nelson and Winter 1982:17). The analogous applicability of biological concepts to economic issues is, however, regarded as rather controversial (see, e. g., Bünstorf 2002:22ff.).

In evolutionary economics, all regular and predictable patterns of behavior are described by the concept of the "routine" (Ruttan 2002:19; Nelson and Winter 1982:14ff.). This concept determines characteristics and possible behavior, which range from well-defined technical routines of production, procedures of staff development and investment behavior to research and development (Nelson 1995:69). Routines may change over time and define the entrepreneurial activity as a function of external variables (e. g. market conditions) and internal state variables (e. g. stock of machinery and capital stock). Finally, in this concept companies follow routines that change various aspects of their operating characteristics. These include the possession of market analysis tools and research and development units within the company.

According to the theory, firms possess specific capabilities which underlie their routines, enabling them to exercise and to sustain a specific set of these practices (Nelson and Winter 1982:142). Just as in the case of routines, capabilities are dynamic and subject to changes over time. These include, in particular, "technological knowledge" as well as the "decision rules" applied by a company (Nelson and Winter 1982:62; 68).

2.2 Time variable routines and capabilities

The current routines and capabilities of a company are aligned to the circumstances in which the company usually operates. However, when new or unexpected situations arise these may prove inadequate (Nelson and Winter 1982:165). One possible reason for this is exogenously altered market conditions. These could occur, for example, in the form of changes in relative prices or purchase and sales conditions (Dosi 1997:1534ff.), or in the form of governmental regulations or impulses from competitors. Pressure is exerted on the company to respond to changes in its market conditions. This could cause companies to rethink their current strategies, resulting in a different way of working (Jaffe, Newell, and Stavins 2002:45).[2]

Subsequently, by means of search processes, new routines or possible changes to existing routines are found (Nelson and Winter 1982:18). Due to changing market conditions, the relative search effort towards certain technologies or products could shift. Furthermore, even the selection of a (stochastic) outcome of a search process could change the direction of technical change. Finally, the ability to respond will depend on a company's ability to invest in new production facilities (Dosi 1997:1536f.).

Routines and skills are viewed as a legacy of the entrepreneurial past and thus path-dependent. They determine the scope and direction of technological progress in both product and process technologies. Dosi (1982; 1988a:1128ff.) uses the notion "trajectory" to describe this issue. Path dependencies can result, for example, from the cumulative nature of technology (Nelson 1995:74): today's technology builds on yesterday's and tomorrow's technology builds on today's. An often-cited example of this is the layout of the U.S. typewriter keyboard, named "QWERTY", which was later used for computer keyboards (see David 1985).

Other factors influencing path dependencies are network externalities and the nature of information and knowledge (Dosi 1997:1538): the cost of gathering information arises only in the process of acquisition. After that, the information can be used in the production process at any time and it is not exhausted. On the contrary, through learning effects in the application, information instead increases. However, it can be

[2] The effect of firms responding to changes in their operational environment with actions that are "outside the range of existing practice" was described by Schumpeter (1947:150) and named "creative response".

passed on and is non-rival in its use. That means it can be employed by multiple users simultaneously without excluding any of them. Successful paths, however, can also lead to a so-called “lock-in”, because the technology of this path is invested in again and again (Arthur 1989:116f.). This is a kind of captivity within the current technology trajectory and may prove a hindrance in the future when adapting to changing conditions (Nelson 1995:78; Dosi 1988a:1147).

In reality, companies do not have complete information regarding their production processes (Rahmeyer 2007:167). Also, the rationality of decision makers is “limited” in the sense that real life decision problems are too complex to be captured completely, which leads ultimately to an incomplete understanding (Simon 2005:93). For this reason, companies cannot “maximize” over all possible alternatives. This is why the assumption of optimality is rejected by representatives of evolutionary theory (Rahmeyer 2007:167). Instead, decisions are made on the basis of relatively simple decision rules and procedures, but due to the limited rationality these decisions cannot be optimal (Selten 2002:16). This component of evolutionary economics goes back to the work of Herbert Simon (1955).

In this context, Simon (1959:262) used the term “satisficing” - derived from the terms “satisfying” and “suffice”. According to this concept, the search for profitable alternatives will continue until a satisfactory solution, not necessarily the optimal solution, is found. If a satisfactory solution can be found relatively easily, the “aspiration level” is increased. If the search is relatively difficult, the aspiration level is lowered. These search processes require both time and attention from the company, and the decision makers may differ in terms of their aspiration levels and their cognitive abilities (Gigerenzer and Selten 2002:5; Selten 2002:14).

As a consequence of bounded rationality and path dependent learning the routines and capabilities of various companies may also vary. The (incomplete) adaptation to changing market conditions and the differences in the discovery of new alternatives generates diversity among firms. So, the market actors are heterogeneous (Dosi and Marengo 2007:492; Nelson 1995:76; Barney 1991). This is the case even if identical information exists and the agents face the same opportunities (Dosi 1997:1531).

2.3 Dynamic competition and innovation

A central element of evolutionary theory is the concept of dynamic competition, which draws heavily on the work of Joseph Schumpeter (1934; 1950). Thus, this strand of evolutionary theory which is primarily concerned with competition, innovation, technology and routines of businesses is labeled “neo-Schumpeterian” (Fagerberg and Verspagen 2009:226ff.; Witt 2008b:554ff.). According to Schumpeter (1950:83ff.), it is the qualitatively new which determines the critical cost and quality advantages in competition and which is the fundamental impulse of the economy. He describes the innovative process, using biological terminology, as a kind of “industrial mutation” that constantly destroys old structures and creates new ones, calling this process of qualitative change “creative destruction”. In processes of change and development, especially in technological advances, the endogenous nature of these processes is emphasized (Nelson 1995:68). By the term “development” Schumpeter (1934:63) meant only those economic changes that arise endogenously in the economy, “from within”.

Together with the exogenous supply and demand conditions of the market, the decisions of different firms determine the market prices of input and output goods (Nelson and Winter 1982:19). These routines, decisions and characteristics determine companies’ profitability and thus their economic success and expansion. The market here exercises the function of a selection mechanism. Those companies whose decision rules are profitable under current market conditions expand and are therefore relatively “fit”. Unprofitable companies shrink and are eventually forced out of business (Dosi 1997:1531; 1542f.).

Schumpeter (1934:66f.) identified the “carrying out of new combinations” as the core of the development process (see also Fagerberg 2005:14). In a competitive economy the implementation of new combinations means the competitive destruction of the old ones (the abovementioned creative destruction). A characteristic of evolutionary theory is the existence of a permanent disequilibrium in the market, which is caused by perpetual innovation. Innovation at the market level is created by the search processes of an existing company or by the entry of new firms which follow new routines (Nelson and Winter 1982:142). At company level, however, Nelson and Winter (1982:41) refer to Schumpeter’s view and describe innovation as a “deviation from routine behavior”.

2.4 Defining climate innovation

Basically, innovation means “something new” (from the Latin *innovare* = renew), which is more than just a gradual improvement. Closely associated with “innovation” is “invention” (from the Latin *inventio* = discover). Colloquially, these terms are not always strictly separated. An idea or a discovery alone does not make an innovation. In order to move from invention to innovation one must find application (Fagerberg 2005:4ff.). The innovation process therefore includes the process of idea generation, the implementation of these ideas in practice and their dissemination. Dosi’s (1988b:222) description of the innovation process makes this clear: “In an essential sense, innovation concerns the search for, and the discovery, experimentation, development, imitation, and adoption of new products, new production processes and new organisational set-ups.” However, in the literature there are various definitions of the term “innovation” which emphasize different aspects of the concept. Tidd and Bessant (2009:15ff.), as well as Hauschildt and Salomo (2010:5ff.), provide an overview of these various definitions.

For the purpose of this work, the term “innovation” is used as it is in the OECD’s “Oslo Manual”: “implementing something new or significantly improved” (OECD 2005:46ff.). In doing so, the improvement must go beyond a routine or periodic change. Consequently, the term “climate innovation” refers to all innovations which result in the direct or indirect avoidance of greenhouse gases (especially carbon dioxide emissions).[3] It is irrelevant at this point whether or not the avoidance of greenhouse gases (GHGs) was the primary goal of innovation. Furthermore, this is a business-oriented perspective as the focus of this theoretical framework is the individual company. So, the innovation must be new to individual companies, but not necessarily to specific sectors, regions or markets (cf. OECD 2005:46).

In the framework presented, special attention is given to aspects that are particularly relevant to the innovative reaction of companies in the context of climate change. On the one hand, changing market conditions in the form of claims from certain groups (the stakeholders) are of importance. The exercise of such claims is here referred to as the “driver”. Secondly, the properties of certain internal and external operational variables (the “determinants”) receive special attention. These have a steering,

[3] As a working basis for this definition, the terms “eco-innovation” in Rennings (2000:322) and “environmental innovation” in Klemmer, Lehr, and Löbbe (1999:25) were used.

obstructive or conducive influence on the innovation process and are important for the change in entrepreneurial skills and routines in this context. Furthermore, the different forms of innovations, their sources and economic impact on the company are captured. Figure 1 illustrates the structure of the framework in graphic form. In the following section the various elements of the framework are explained in detail.

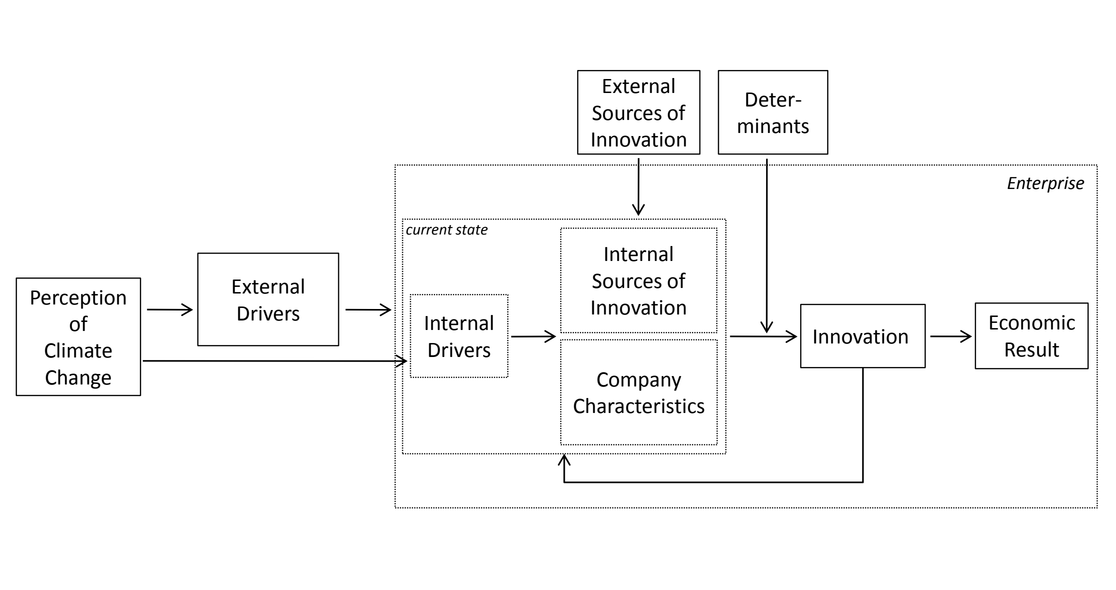

Figure 1: Schematic structure of the framework: The company in context.
Source: Author's own illustration.

3 Drivers of climate innovation

3.1 Classification of stakeholders

Following Freeman (1984:46; 2004:229), a company's stakeholders are defined as individuals or groups that affect the company's performance or are affected by the company's actions. They can be differentiated into primary and secondary stakeholders (Clarkson 1995:105ff.): without the continuing participation of the primary stakeholders a company cannot survive as a functioning entity. This primary group typically includes customers and suppliers, shareholders and investors as well as employees and the so-called public stakeholders - governments and communities. In contrast, secondary stakeholders are not essential for the survival of the company as they are not engaged in transactions with the corporation. Typical examples are therefore the media, special interest groups such as non-governmental organizations (NGOs), but also domestic and international competitors and the civil society (cf. Fassin 2009:120).

Furthermore, primary stakeholders can be categorized as internal or external (Buysse and Verbeke 2003:462ff.). While internal primary stakeholders are employees, shareholders and financial institutions, external primary stakeholders are, for instance, suppliers and customers. In addition, in this article governmental or regulative entities are regarded as primary external stakeholders. In the following section the focus will be set on those stakeholders, which are considered most important for European industrial companies in the context of climate change.

3.2 Governmental intervention: Regulation

Perhaps the most obvious form of pressure exerted by stakeholders on corporate environmental actions is regulation stemming from governmental bodies. Traditionally, regulation is regarded as a main force not only for environmental innovation (cf. Carrión-Flores and Innes 2010:27) but also for innovation in general. In this context, a number of studies have concentrated on the question, which environmental policy instrument to choose in order to provide maximum incentive for a company's innovation (cf. Jaffe, Newell, and Stavins 2002:41ff.). Regarding this incentive to innovate, marked-based systems have been shown to deliver a stronger stimulus than command and control type regulations such as standards, because the former provide more flexibility to derive the given aim (cf. Jaffe, Newell, and Stavins 2004:35; Brunnermeier and Cohen 2003:280).

Besides the selection of instruments, regulatory stringency has an impact on the effectiveness of regulation (Taylor, Rubin, and Hounshell 2005:350). In this regard, the so-called Porter hypothesis (see Porter and van der Linde 1995a; 1995b) recommends rather stringent regulation to spur innovation. Based on the view that economically and ecologically favorable innovations are not implemented because of incomplete information and other aspects of limited rationality (cf. p. 5), Porter and van der Linde (1995b:100ff.) argue that "properly crafted" environmental regulation may induce firms to innovate. As a result, not only is pollution reduced, but resource efficiency of firms is increased, reducing the costs of compliance (the "innovation offsets"). Furthermore, early mover advantages may be induced for regulated firms by environmental policy and this may in turn lead to higher profits in the future.

This hypothesis has often been criticized by traditional economists who have argued that regulation would reduce productivity, create uncertainty about future regulatory demands and delay investment (see, e. g., Gray and Shadbegian 1995:4). Others support the argument of forcing environmental innovation but doubt that such efforts would offset the opportunity costs and, if they did, this would only in rare cases (see, e. g., Jaffe, Newell, and Stavins 2002:45ff.). Empirical evidence for the Porter-hypothesis is ambivalent today, regarding both the impact of environmental regulation on productivity and the offset of compliance costs (see, e. g., Rennings and Rammer 2010; Kriechel and Ziesemer 2009; Lanoie, Patry, and Lajeunesse 2008).

Frondel, Horbach, and Rennings (2007) conducted a study of cleaner production technologies in seven OECD countries and found that the stringency of policy measures was even more important than the choice of policy instrument - more precisely, it is the perceived stringency that matters. This corresponds with Delmas and Toffel's (2004:210) observation: it is not only the existence of the regulation itself that matters, but how the regulation is perceived by the firm's management. Furthermore, rapidly changing regulatory conditions can lead to uncertainty among investors and so hinder investment in environmental technology (del Río González 2009:869). In fact, recent studies argue that the design of regulation is a key factor in corporate innovative reaction, especially in flexibility, stringency and in limiting uncertainty (see, e. g., Oltra 2008:7).

The best known governmental intervention related to climate change is probably the introduction of the European Emissions Trading System (EU ETS) in 2005 (see, e. g., Pinkse 2007). In addition to the reduction of greenhouse gas emissions (cf. Pinkse and Kolk 2010:264), an aim of the system was to spur innovation (Hoffmann 2007:465). As a market based instrument, emissions trading is supposed to be more efficient than a command and control (CaC) type instrument, for instance. Imposing costs on CO_2-emissions creates monetary incentives for firms to introduce more energy- and carbon-efficient technologies (Schleich, Rogge, and Betz 2009:38; Fischer and Newell 2008:160). Together with this comes the risk contained in the uncertain price development of CO_2-allowances, creating an incentive for firms to manage or avoid this risk (see, e. g., Dannenberg and Ehrenfeld 2011b).

Based on evidence from US trading schemes (see, e. g., the overview in Hansjürgens 2006) prior to its introduction, the innovation potential of the EU ETS was expected to be low to moderate in its early phases (see Gagelmann and Frondel 2005 and the overview of simulation studies in Oberndorfer and Rennings 2007). First empirical investigations of the German electricity sector confirmed this expectation in part as the innovation impact works, but has indeed been rather limited so far (Rogge, Schneider, and Hoffmann 2011; Rogge and Hoffmann 2010; Hoffmann 2007). One limiting factor in this connection is the persistent regulatory uncertainty caused by the rather short trading periods; another is the rather low stringency of the system in the early periods (Schleich, Rogge, and Betz 2009:39; Oberndorfer and Rennings 2007:13). Furthermore, the generous supply of emission allowances led to a price decline in the first trading period (see, e. g., Dannenberg and Ehrenfeld 2011a:150ff.).

3.3 Market factors

In the empirical literature, competitive motivation is seen as a very important incentive for environmental strategy (see, e. g., Ren 2009). Indeed, besides governmental regulation, the achievement of cost savings is claimed to be the most important driver in the environmental innovation literature (Fischer and Newell 2008:143; Oltra and Saint Jean 2005:154; Jaffe, Newell, and Stavins 2003:463ff.). Based on the insight that a relatively high resource consumption is a sign of an inefficient production process, this motivation includes the reduction of input costs as well as the improvement of the company's productivity, leading to the improvement of production processes (Frondel, Horbach, and Rennings 2007:573ff.). The advanced aim is to gain thereby comparative advantage over competitors and consequently to increase market shares (Klemmer, Lehr, and Löbbe 1999:62ff.). In the context of climate change these considerations are especially true for energy resources in energy utilities but also for energy intensive branches of industry. In the case of the latter, added to these is the passing-on of the carbon allowance costs from the energy suppliers in the form of rising energy prices, as became clear in the first trading period of the EU ETS (see, e. g., Alexeeva-Talebi 2010; Zachmann and Hirschhausen 2008).

Regarding general innovations, two factors are dominant in the discussion of the supply and demand sides of the market: technology-push and demand-pull. Technology-push results from the autonomous provision of company innovation, stemming usually from research and development (R&D) efforts (Pavitt 1984:365) or coming as a by-product of scientific advances (Dosi 1988a:1141). New technological opportunities are assumed as the main driving force in this case (Rosenberg 1974:95), and the technological capabilities of the company are emphasized (Rehfeld, Rennings, and Ziegler 2007:92). These include the firm's capital stock, both technology and knowledge. In this connection an innovation is only rational for the firm if the returns of the innovative activity can be reaped (Horbach 2008:164).

The demand-pull hypothesis goes back to the work of Schmookler (1966) and states that demand from customers, other firms or the government has a strong influence on innovation activity. This is especially true for product innovations. Regarding consumer's demand for environmentally friendly products, Fraj-Andrés, Martínez-Salinas, and Matute-Vallejo (2009:502ff.) see a change in recent purchase behavior, but also an increased sensitivity among economic agents to sustainable issues in general. The environmental consciousness of consumers and firms is an important factor underlying this demand (Horbach 2008:165; del Río González 2005:25). In addition, creating customer benefits in the form of cost and energy savings or improved product quality, for instance, can deliver added value to the customer and therefore help the company to increase the demand for its product (Kammerer 2009:2287). Also, companies which act at a later stage of the value chain could demand products or solutions which help them to save resources. In the discussion about climate change, the most important resource is energy. These companies' demands could in turn be driven by duty from emissions trading or likewise by cost considerations.

On the other hand, Rehfeld, Rennings, and Ziegler (2007:94) see impediments in the way of the introduction of environmental products in the form of higher costs which have been experienced as well as quality issues, but also in the form of some perception bias in this direction. In addition, the empirical evidence to support the argument that consumer demand drives environmental innovations in general is divided (see, e. g., Bergh 2008 and Wong, Turner, and Stoneman 1996, but, e. g., Doonan, Lanoie, and Laplante 2005). For successful innovation, both technology push and demand pull are necessary (Pavitt 1984:365). Today, there appears to be consensus that technology push factors are especially important during the initial stages of the life cycle of an innovation whereas demand factors are more relevant at later stages, i. e. during diffusion (Rehfeld, Rennings, and Ziegler 2007:92).

3.4 Pressure of civil society and management commitment

According to DiMaggio and Powell (1983:149), organizations not only compete for "economic fitness", e. g. resources and customers, but also for political power and institutional "legitimacy" for their "social" fitness. Suchman (1995:574) defines legitimacy as "a generalized perception or assumption that the actions of an entity are desirable, proper, or appropriate within some socially constructed system of norms, values, beliefs, and definitions". Based on this set of values and (informal) norms, civil society expects certain behavior from firms, consistent with these cultural expectations. In order to remain legitimate, firms should communicate credible compliance with these values and avoid negative interference with them. Regarding environmental responsibility in general, stakeholders generally demand integrity and transparency (see Waddock, Bodwell, and Graves 2002:145).

On a very pragmatic level, a positive corporate image can "make it easier" to operate (Bansal and Roth 2000:725) in terms of employee morale, public relations and goodwill (Paulraj 2009:456). Furthermore, legitimate organizations are perceived as "more worthy", "more meaningful" and "more trustworthy", or are described as "desirable", "proper" and "appropriate" (Suchman 1995:574f.). This can be of particular importance for the supply of resources, especially when accessing financial resources (Schwartz 2009:195), or when lessening the delegitimizing effect of single, isolated failures (Suchman 1995:579).

On the other hand, social pressure can be exerted by the media or special interest groups such as NGOs, as well as by local communities and scientific institutions in interaction with the media. By creating adverse publicity around the breach in socially accepted values, the media can create a negative image of the firm, damaging its reputation and eventually influencing public opinion (Buysse and Verbeke 2003:461). Because consumers and regulatory decision makers (both on a legislative and a community level) are also members of civil society and consumers of media, a negative bias in their perception of the company could result. The consequence could be a decreased demand for the firms' goods, declining shareholder value or an unpleasant development in the regulatory environment for these firms. Secondary stakeholder groups, even though they are not essential for the survival of the company, can as Clarkson (1995:107) states "cause significant damage to a corporation".

A vivid illustration of how individual or direct social pressure can be exercised and eventually find its way into a company is the "myth" of the influence of a Swedish CEO's 13-year-old daughter, told in Strannegård (2000:166). She is said to have asked her father at breakfast what his company did for the environment. She said she did not want him to work for a firm that destroyed the environment. This is believed to have made her father think seriously about environmental issues.

As greenhouse-gas emissions or energy consumption are usually not visible, unlike water pollution, for instance, and act on a more global level, the pressure from local community leaders is believed to be less substantial in this case. Instead, as climate change is a global problem, the interest in the subject is also global and so is the public perception. One channel to communicate a firm's pro-active climate behavior on an international level is offered by the so-called Carbon Disclosure Project (CDP). Once a year this organization surveys the world's largest 500 public companies (according to the FTSE Global Equity Index Series) and how they have responded to issues such as greenhouse gas emissions, risks and opportunities, as well as the actions they have taken regarding climate change. The results are then published in an annual report (CDP 2010:7). Finally, to create some perceived public pressure in addition to a monetary fine, one component of the sanctioning mechanism of the EU ETS is the publication of the operator's name in cases where the firm did not surrender sufficient allowances (European Parliament and Council 2003:Art. 16.2).

Mirroring the social norms and values of society, managerial commitment to the environment and the corporate vision in general can also act as significant drivers of climate innovation (cf. Fraj-Andrés, Martínez-Salinas, and Matute-Vallejo 2009:504). Whereas the drivers described above are external to the firm, this motivation of management can be seen as intrinsic. Of course, since managers themselves are also members of society, they are in turn influenced by social values. They act, because for them it is "the right thing to do" (Bansal and Roth 2000:718). It is often the initiative from one (powerful) individual in a firm that triggers ecological responses based on his/her or the organization's values (Bansal and Roth 2000:728).

4 Sources and outcomes of the innovation process

4.1 Sources of innovations

Innovation can come from various sources (see OECD 2005:78ff.). In principle, these sources can be distinguished as developments which are originally created "in-house", either alone or in cooperation with external partners, and as developments which were created outside the firm, in other firms or institutions. In the case of the former, the best known source is research and development (R&D). R&D is defined by the OECD (2002:30) as the "creative work undertaken on a systematic basis in order to increase the stock of knowledge ... and the use of this stock of knowledge to devise new applications" and includes basic research as well as applied research and experimental development. R&D has a determined aim, e. g. the solution to a technological problem, and requires a well defined, methodical approach to reach this goal. In addition, other internal innovative activities, such as learning effects from experience ("learning-by-doing"), can extend the capabilities of a firm, leading eventually to innovation (see, e. g., Taylor, Rubin, and Hounshell 2005:366f.).

When developing new knowledge and technologies, the company may also cooperate with other firms or research organizations. Such cooperation is characterized by every party taking an active part in the work in a joint innovation project, for instance. In doing so, firms can gain access to certain knowledge or capabilities that they might not have been able achieve on their own (del Río González 2005:25). Furthermore, because the partners learn from each other, there is great potential for synergy. In this context, Pittaway, Robertson, et al. (2004) stress the importance of business networking for innovativeness.

Firms do not have to develop new knowledge and technology themselves or in cooperation, but can obtain these by transfer from other firms or public research organizations (the process of diffusion). This term denotes the way in which innovations spread from their first application to others through "market or non-market channels" (OECD 2005:77f.). In this process, the original innovation can change considerably. After the pure adoption, the firm reflects the technology or knowledge, learns from it and builds upon it. Through this process, feedback may even be provided to the original innovator. One way of obtaining external technology and knowledge is by purchasing without active cooperation. In many cases this knowledge materializes in new equipment or is manifested in patents, software and licenses. Another way of obtaining knowledge from outside the firm is by hiring a competent employee or making use of consulting services.

4.2 Types of innovation

In principle, the typology of innovation goes back to Schumpeter's (1934:67) classification of cases for "carrying out new combinations". Here, the following four types of innovation are distinguished (see OECD 2005:29; 47-52). In this connection, it should be noted that an innovation is not necessarily a change in one major step ("radical" innovation), but may consist of multiple smaller changes or continuous advance ("incremental" innovation). A product innovation is called the introduction of new goods (or services) to the market. This refers to the nature of this product, its function and its intended use and includes improvements in technical specifications, components, materials and function. A process innovation is the implementation of a new production method by the firm. Such innovations include changes in production techniques, equipment and software, the use of new skills and may also include changes in the purchase activity of an industrial company. This holds true not only for the production process itself, but also for production logistics. The purpose of this innovation type is usually to reduce unit costs or to improve product quality.

Organizational innovation is known as the introduction of new organizational methods in business practices, workplace organization or external relations of the company. These include the reorganization of the firm's workflow routines as well as procedures for internal knowledge processing. Such innovations aim at the reduction of transaction costs and costs of equipment. The redistribution of responsibilities and the modification of decision making processes in the firm as well as the establishment of new collaborations are also regarded as organizational innovations. Lastly, the introduction of a new marketing method is called marketing innovation. This includes changes in the (functionally irrelevant) product design, its packaging, distribution channels, advertising or pricing.

In relation to climate change, product innovations would help a firm's customers to save energy or limit GHG emissions by using the new product. This could be a new intermediate product requested by industrial customers who act at a later stage of the established value chain and have a new incentive because of the EU ETS. Another example would be new synthetic insulating materials for buildings offered to final customers or to the building sector. As there is still no viable industry-scale end-of-pipe technology for filtering GHG out of the exhaust, the only solution to decreasing GHG in production processes is the modification of the production technology itself. Aside from the direct effect on GHG, process innovations are intended to lower energy consumption and therefore (indirectly) to reduce the GHG outcome caused by the firm. This can be achieved through, for example, the acquisition of new equipment that requires less energy for the same output, or new processes that produce less GHG in manufacturing the same product. The use of true "green IT", i. e. information technology constructed to be relatively energy efficient, in information processing corporations would be such a case.

The introduction of an environmental management system (EMS) including GHG, or the (implemented) change in the company's vision towards its climate change strategy would be an organizational innovation referring to climate change. The integration of GHG in an existing EMS would be if at all classified as incremental innovation. Another example would be the migration of European companies to non-European countries because of the rising costs introduced by the EU ETS. This phenomenon is called "carbon leakage". Finally, the new orientation of the firm's marketing towards a "climate friendly" perception is a marketing innovation in this context. An example of this would be the indication on the packaging that a product was produced using 10 percent less energy than another, comparable product and emphasizing this in advertisements.

4.3 Classes of climate innovation

Based on the consistency of aim and result, three classes of climate innovation can be distinguished: congruent, unintended and insubstantial (see figure 2). An innovation or innovation strategy is "congruent" if the underlying incentive is the reduction of greenhouse gases, if the innovation really performs this task and if this connection is intended. An example is the modification of production processes in a company to save GHG emissions. "Unintended" climate innovations are not driven by any aspect of climate change whether direct or indirect. The result is indeed a climate innovation, but the incentive was something completely different. Typical examples are investments in energy efficiency which are driven only by

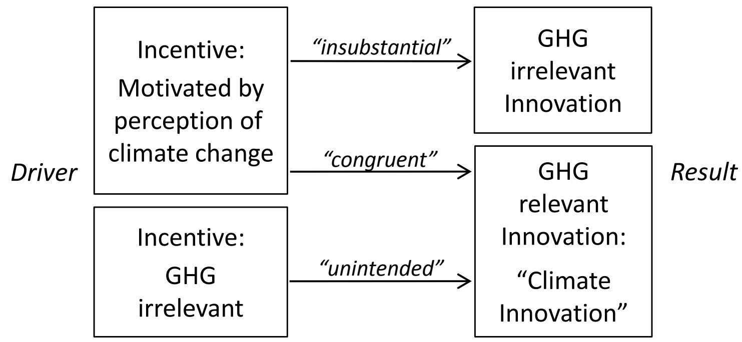

Figure 2: Classes of Climate Innovation.
Source: Author's own illustration.

cost considerations and are undertaken in companies otherwise uninterested in the environment. Some innovations are "insubstantial" in the sense that they have no function in the reduction of greenhouse gases, but the trigger for the innovation was indeed an understanding of the subject of climate change. This may have led to the consideration that it would be socially desirable or beneficial for the firm's image to simply do something about climate change. Such innovations are also called "greenwashing" activities (see, e. g., Ramus and Montiel 2005; Laufer 2003).

4.4 Economic results

Finally, every innovation will have an economic impact on the implementing company. With the introduction of new products and processes, the product portfolio, production technology and organization of the company will change, thereby modifying the market position and likewise the possible future development path of the company. In most cases there should be at the very least a basic cost-benefit estimation before the introduction of an innovation. After a time, there will probably be an evaluation of the results of the innovation. So, the corporation will determine whether the outcome matches the intention, e. g. whether the energy consumption or GHG emissions were indeed noticeably reduced and the attendant costs, whether the product was accepted by the market, whether the image of the company improved, or whether the new organizational elements proved efficient. All these positive outcomes could lead to increased competitiveness sooner or later. This holds true for environmental innovations in general (Cortez and Cudia 2011; Chang 2011). Based on the experience of the innovation, feedback for future innovative activities by the corporation is provided. Good experiences can lead to a greater involvement in climate innovation in the future, and may also influence the perception and commitment of the management, fostering this topic in the company.

5 Determinants of the climate innovation process

5.1 Internal determinants of the firm

There are a number of determinants in the innovation process which have a steering, obstructive or beneficial effect. In contrast to drivers, they do not have any incentive to direct the firm towards any climate innovation. However, because of their pure existence and their properties, they have an influence on the firm's innovative behavior. First, the present technological portfolio and knowledge base of the firm will have a distinct effect on the implementation of new innovation, independent of source and driver. If a new development, either technological or in terms of stakeholder demand, fits well with the current technology portfolio, it is much easier for the firm to implement the innovation. Owing to differences in technology and knowledge portfolios, the technological premises of firms related to innovation differ notably. Furthermore, the current physical technology portfolio of a firm will determine whether the firm is subject to the EU ETS.

As stated above (see p. 4), capabilities and the technology portfolio of the firm are considered to be path dependent. In other words, the feedback from the economic outcome of earlier innovations determines the position for the future development of the firm, financially and technologically. The positive aspect of this is that "innovation breeds innovation", as Baumol (2002:284) puts it. Innovations in the past build the basis for present and future innovations. Also, a market barrier to future potential competitors can be established because of technological protrusion (Jaffe, Newell, and Stavins 2003:493; Christensen and Rosenbloom 1995:234). The disadvantage is that innovative path dependencies can lead to a "lock-in" caused by the firm's specialization being reinforced by its history.

This situation occurs because firms invest in the same, to date successful technologies time after time (Dosi and Marengo 2007:496). If new developments are to be implemented, the firm faces serious switching costs in diverging from its trajectory (Jaffe, Newell, and Stavins 2003:491f.; Ruttan 1997:1523). The existence of sunk costs further reinforces the lock-in because of irreversible investments (David 2000). So, firms may be very reluctant to integrate new technologies into the existing processes, even if current technology proves to be less than optimal. Closely related to this issue is organizational inertia in general, and the "not invented here" syndrome specifically (see, e. g., Fagerberg 2005:11). This is a well known feature in firms of all sizes and leads to a certain inertia in the corporate system itself towards new developments which come from outside.

One of the most important determinants in the innovation literature is the "absorptive capacity" of a corporation (Cohen and Levinthal 1990; Cohen and Levinthal 1989). This is the ability to gain access to external knowledge and to absorb and deploy this knowledge to the advantage of the company. Besides the capacity to assimilate existing knowledge, the development of problem solving skills is crucial to achieving this aim. To a large extent this ability is dependent on the firm's level of prior knowledge related to the new information and results as a side effect either of the firm's R&D or in the course of the firm's manufacturing operations. Of course, the absorptive capacity of an organization will depend on the absorptive capacities of its individual members. Therefore, a direct way for an organization to gain absorptive capacity is to send its personnel for technical training. In this context, knowledge is understood to be embedded not only in a non-material way in members of organizations, but also in a material form in technical equipment and machinery (Dosi and Marengo 2007:495).

The influence of firm size on environmental innovation is not entirely conclusive. In general, large companies are found to be more active in environmental patenting (as a measure of innovation) than smaller firms (Wagner 2007:1596). Consistent with this view, Brunnermeier and Cohen (2003:285) find that at the industry level firm size (measured as value of shipments) has a positive nexus to patent activity. One explanation could therefore be that larger corporations are better suited to bear fixed costs and the risks of R&D simply because of their size and associated capital stock. Türpitz (2004) conducted a case study analysis of environmental product innovations and found that larger firms are more likely to conduct mass production of environmentally friendly products whereas smaller firms tend to produce specialized products for market niches. As far as environmental innovation is concerned, one factor in this context is considered to be the higher visibility and the interest of the media in larger companies and their dealing with environmental issues (as emphasized by Wagner 2011:944 and Bansal 2005:209).

Investigating the differences between environmental and other innovations, Horbach (2008:169) finds a positive link between firm size and environmental innovation in an innovation survey study but no statistically significant differences between environmental innovation activity and other innovators. Frondel, Horbach, and Rennings (2007) compare factors for end-of-pipe and cleaner production innovation decisions and find no significant influence of firm size on the implementation of end-of-pipe technologies and only a slightly significant influence on cleaner production. Mazzanti and Zoboli (2006) conduct a survey study in northern Italy and find an inverted U shape relation between energy related innovation and size. Output innovations in general do not experience a clear size effect.

The position in the value chain can also influence a firm's environmental innovation behavior (González-Benito and González-Benito 2010:17f.; Taylor 2008; Pavitt 1984). Proximity to the end consumer might have a positive influence on the firm's overall environmental activity. This is because the pressure to deal with environmental issues imposed by the end consumer is more crucial to the company in this case.

Another determinant derived from the literature of environmental innovation is the organizational form of the corporation or the corporate group (del Río González 2009:863). In a large or multinational group of companies, the organizational structure is typically characterized by a higher degree of technological competency. This can act as a source of innovation for individual firms, allowing a transfer of knowledge between companies. These structures may also exert pressure on firms, fostering environmental innovation if intended by the corporate head office.

This indicates the importance of the attitude of management towards climate issues (González-Benito and González-Benito 2010:171f.). In larger groups of companies particularly, the role of top level management is crucial for environmental issues of all types as most of the main decisions are enforced from the top down. Strategic decisions are based on the perceptions, expectations, beliefs and opinions of the managers. Furthermore, the selection of environmental practices or strategies depends on whether the managers see environmental issues as opportunities or threats; the same environmental pressures exerted by stakeholders may be perceived completely differently by different managers.

The presence of an environmental management system can in this context be regarded as a sign of a certain awareness of environmental aspects within a firm. At the forefront of the introduction of environmental innovations such as energy and cost saving cleaner technologies, EMS are especially useful in gathering information within a firm (Rennings, Ziegler, et al. 2006:53). In their conception, EMS are quite similar to quality management systems (e. g. certified after ISO 9001) and include a number of core activities of a firm such as an initial environmental review and the publication of certain policy and report documents (see, e. g., Wagner 2007:1588). In addition, firms can conduct external audits and implement strategies for a continuous improvement process in order to receive a certificate for their EMS based on the ISO 14001 standard or the EU Eco-Management and Auditing Scheme (EMAS) guidelines. These are intended to help a firm in making a further signal to their customers. Empirical studies (Wagner 2008; Mazzanti and Zoboli 2006; Rehfeld, Rennings, and Ziegler 2007; Wagner 2007) show a positive correlation between organizational innovations and environmental product or process innovations.

5.2 Properties of innovations

As in the case of any innovation, climate innovations always contain an element of uncertainty (see, e. g., Dosi 1988b:222). Without a doubt, uncertainties have a hampering effect on the introduction of innovations but are inevitable in any innovation process. In principle, the decision in favor of new, expensive technology is harder to make than for lower-priced ones, and cost and benefit reflections about new technology are critical to the outcome. But, as in every innovative planning process, actual costs of innovation can exceed the planned costs or may not deliver the expected success. The origins of uncertainty in this case are manifold and arise from various sources: sales markets, buying markets, investment volume, payback period and many more. In the case of resource saving technology, there is an additional source of uncertainty (Jaffe, Newell, and Stavins 2003:496ff.): the economic value of such an innovation depends on future resource prices. These are themselves subject in turn to an uncertain development. Furthermore, continuing technical progress adds an element of timing uncertainty to the innovative process.

Specific to environmental innovations in general is, in addition to the beneficial environmental effect, what Rennings (2000:325) calls the “double externality” problem. In general, two types of positive externalities are created by this kind of innovation. Firstly, the regular externalities typical of R&D efforts or technological knowledge with their possibility of spillover and difficulty in preventing others from using or copying these in the research and innovation phase. Instruments such as patenting can make a contribution to reducing spillover (Rennings 2005:23), but cannot prevent it. Secondly, in the later phase of diffusion these externalities have a positive impact on the environment, making this kind of innovation socially desirable.

While the spread of these innovations is beneficial for the society as a whole they establish an impediment for firms which wish to invest and innovate. This is because the private return on research and development in environmental technology is less than its social return. Altogether, this situation leads to an overall underinvestment in environmental technologies. This “tale of two market failures” (Jaffe, Newell, and Stavins 2005) justifies the introduction of environmental policy instruments to create a “regulatory push/pull effect” (Rennings 2000:326) in order to spur on innovation. In doing so, environmental policy should help to internalize external costs from competing products or services which are ecologically more harmful in the diffusion phase.

5.3 External contextual factors

Complementary to regulation, governments can encourage innovation by funding (Jaffe, Newell, and Stavins 2003:474). In contrast to regulation, funding is not seen here as an independent driver for certain innovations but rather as an instrument to encourage their introduction. Just like regulation, this is an expression of political will with the difference that funding is seen as a “softer” instrument. Funding for R&D or innovation in general can be obtained in the form of a tax-based subsidy for R&D programs or investments, for instance (see, e. g., Hall and Van Reenen 2000). Because they leave the choice of how to implement R&D to the firm, tax incentives are a very flexible instrument. The drawback of this instrument is perhaps its inefficiency as the response elasticity is rather low.

Another way of obtaining innovation funding from the government is via direct subsidies or grants for R&D activities or certain innovations (see, e. g., Klette, Møen, and Griliches 2000). This instrument is typically used to support commercial R&D projects with great potential for social benefit but with insufficient expected returns for private investors. Another reason for the use of this instrument is the speculation that temporary R&D grants will have a more sustainable effect on private R&D even after the end of the program. Again, as opposed to regulation, this kind of funding is not regarded here as an independent driver for certain innovations but rather as an instrument to encourage their introduction.

Furthermore, cooperation and "networking" activities are considered determinants of the strengths of a firm's innovative environmental behavior (Reniers, Dullaert, and Visser 2010:1590; Mazzanti and Zoboli 2006:7). Networks can act as knowledge transfer mechanisms and can on the one hand serve as a source of information for the individual firm while on the other they can reduce the risks related to the adoption of new innovations. In addition, the interaction between the participants in the network influences the decisions adopted by each. The inclusion in networks is also intended to increase the possibility of cooperation between the participants. Cooperation spreads the risks of common research and development or innovative activities among the participants therefore reducing the risk for the single firm, leading in addition to a reduction in transaction costs (Osborn and Hagedoorn 1997; Hagedoorn 1993).

In this connection, the literature on localized knowledge spillovers stresses the importance of physical distance for the "facilitation of other agents' innovation efforts", be it intended or unintended (Breschi and Lissoni 2001:975). According to this strand of literature, spatial proximity to important knowledge sources assists companies in accessing knowledge spillovers and therefore in introducing innovations (see, e. g., Audretsch 1998; Audretsch and Feldman 1996). However, the localized knowledge spillover theory is not without controversy because the mechanisms of knowledge spillovers are considered much more complex and dependent on other forms of proximity, for example social or organizational proximity (see, e. g., Boschma 2005 and Breschi and Lissoni 2001:978ff.).

Finally, the structure of markets is a determinant of a firm's innovation activity. In principal, a larger sales market has greater uptake potential for innovations. On the other hand, monopolistic market structures help large firms to appropriate the returns of their innovative activities. However, firms in a monopolistic market holding large market shares have less incentive to innovate than smaller firms which are forced to be better than their competitors in order to survive (Horbach 2008:165). Furthermore, there are great sectoral differences in terms of innovation processes, rate of technological change and access to knowledge. This is also true for organizational structures and institutional factors (Malerba 2005; OECD 2005:37).

6 Summary and outlook

Motivated by the perception of climate change, new claims are being imposed on companies. In this article, a comprehensive evolutionary model framework was developed for studying the factors which motivate and control the introduction of climate related innovation in firms. In this innovative process, different internal and external determinants have different functions and relevance that can be examined in empirical research by using this analytical framework.

The effects of climate change and its influence on markets, government and civil society as well as the resulting innovative responses by companies have only been scarcely empirically tested yet. Those studies which have dealt with this situation are limited to the European emissions trading system and its effect on the energy sector. The analysis of other industries has barely been addressed in the literature at this point. There is still great scope for further research in this field in the future. This research framework appears particularly useful for such in-depth studies of climate innovations in energy intensive industry branches.

References

Alexeeva-Talebi, V. (2010): Cost Pass-Through in Strategic Oligopoly: Sectoral Evidence for the EU ETS. ZEW Discussion Paper No. 10-056.

Arthur, W. B. (1989): Competing technologies, increasing returns, and lock-in by historical events. In: *Economic Journal* 99, pp. 116–131.

Audretsch, D. B. (1998): Agglomeration and the Location of Innovative Activity. In: *Oxford Review of Economic Policy* 14.2, pp. 18–29.

Audretsch, D. B. and M. P. Feldman (1996): R&D spillovers and the geography of innovation and production. In: *The American Economic Review* 86.3, pp. 630–640.

Bansal, P. (2005): Evolving Sustainably: A Longitudinal Study of Corporate Sustainable Development. In: *Strategic Management Journal* 26.3, pp. 197–218.

Bansal, P. and K. Roth (2000): Why companies go green: a model of ecological responsiveness. In: *Academy of Management Journal* 43.4, pp. 717–736.

Barney, J. (1991): Firm Resources and Sustained Competitive Advantage. In: *Journal of Management* 17.1, pp. 99–120.

Baumol, W. J. (2002): The Free-Market Innovation Machine - analyzing the Growth Miracle of Capitalism. New Jersey: Princeton University Press.

Bergh, J. C. van den (2008): Environmental regulation of households: An empirical review of economic and psychological factors. In: *Ecological Economics* 66, pp. 559–574.

Boschma, R. A. (2005): Proximity and innovation. A critical assessment. In: *Regional Studies* 39.1, pp. 61–74.

Breschi, S. and F. Lissoni (2001): Knowledge Spillovers and Local Innovation Systems: A Critical Survey. In: *Industrial and Corporate Change* 10.4, pp. 975–1005.

Brunnermeier, S. B. and M. A. Cohen (2003): Determinants of environmental innovation in US manufacturing industries. In: *Journal of Environmental Economics and Management* 45, pp. 278–293.

Bünstorf, G. (2002): “Perspektiven des Wandels und Perspektiven Evolutorischer Ökonomik.” In: Perspektiven des Wandels. Evolutorische Ökonomik in der Anwendung. Ed. by M. Lehmann-Waffenschmidt. Marburg: Metropolis, pp. 17–36.

Buysse, K. and A. Verbeke (2003): Proactive Environmental Strategies: A Stakeholder Management Perspective. In: *Strategic Management Journal* 24, pp. 453–470.

Carbon Disclosure Project (CDP) (2010): Carbon Disclosure Project 2010 - Global 500 Report. Carbon Disclosure Project.

Carrión-Flores, C. E. and R. Innes (2010): Environmental innovation and environmental performance. In: *Journal of Environmental Economics and Management* 59, pp. 27–42.

Chang, C.-H. (2011): The Influence of Corporate Environmental Ethics on Competitive Advantage: The Mediation Role of Green Innovation. In: *Journal of Business Ethics* 104.3, pp. 361–370.

Christensen, C. M. and R. S. Rosenbloom (1995): Explaining the attackers advantage - technological paradigms, organizational dynamics, and the value network. In: *Research Policy* 24, pp. 233–257.

Clarkson, M. B. E. (1995): A Stakeholder Framework For Analyzing And Evaluating Corporate Social Performance. In: *Academy of Management Review* 20.1, pp. 92–117.

Cohen, W. M. and D. Levinthal (1989): Learning and innovation: the two faces of R&D. In: *Economic Journal* 99, pp. 569–596.

Cohen, W. M. and D. Levinthal (1990): Absorptive capacity - A new perspective on learning and innovation. In: *Administrative Science Quarterly* 35.1, pp. 128–152.

Cortez, M. A. A. and C. P. Cudia (2011): The Virtuous Cycles Between Environmental Innovations and Financial Performance: Case Study of Japanese

Automotive and Electronics Companies. In: *Academy of Accounting and Financial Studies Journal* 15.2, pp. 31–43.

Dannenberg, H. and W. Ehrenfeld (2011a): “A Model for the Valuation of Carbon Price Risk.” In: Emissions Trading - Institutional Design, Decision Making and Corporate Strategies (Second Edition). Ed. by R. Antes, B. Hansjürgens, P. Letmathe, and S. Pickl. Heidelberg; Dordrecht; London; New York: Springer, pp. 141–161.

Dannenberg, H. and W. Ehrenfeld (2011b): Stochastic income statement planning as a basis for risk assessment in the context of emissions trading. In: *Greenhouse Gas Measurement and Management* 1.1, pp. 64–72.

David, P. A. (1985): Clio and the economics of QWERTY. In: *American Economic Review* 75, pp. 332–337.

David, P. A. (2000): Path Dependence, Its Critics and the Quest for 'Historical Economics'. Working Paper. Department of Economics. Stanford University.

Delmas, M. and M. W. Toffel (2004): Stakeholders and Environmental Management Practices: An Institutional Framework. In: *Business Strategy and the Environment* 13, pp. 209–222.

del Río González, P. (2005): Analysing the Factors Influencing Clean Technology Adoption: A Study of the Spanish Pulp and Paper Industry. In: *Business Strategy and the Environment* 14, pp. 20–37.

del Río González, P. (2009): The empirical analysis of the determinants for environmental technological change: A research agenda. In: *Ecological Economics* 68, pp. 861–878.

DiMaggio, P. J. and W. W. Powell (1983): The Iron Cage Revisited: Institutional Isomorphism and Collective Rationality in Organizational Fields. In: *American Sociological Review* 48.2, pp. 147–160.

Dolfsma, W. and L. Leydesdorff (2010): The citation field of evolutionary economics. In: *Journal of Evolutionary Economics* 20, pp. 645–664.

Doonan, J., P. Lanoie, and B. Laplante (2005): Determinants of environmental performance in the Canadian pulp and paper industry: An assessment from inside the industry. In: *Ecological Economics* 55, pp. 73–84.

Dopfer, K. (2005): The Evolutionary Foundations of Economics. Cambridge University Press.

Dosi, G. (1982): Technological Paradigms and Trajectories: A Suggested Interpretation of the Determinants and Directions of Technical Change. In: *Research Policy* 11, pp. 147–162.

Dosi, G. (1988a): Sources, procedures, and microeconomic effects of innovation. In: *Journal of Economic Literature* 26.3, pp. 1120–1171.

Dosi, G. (1988b): "The nature of the innovative process." In: Technical Change and Economic Theory. Ed. by G. Dosi, C. Freeman, R. Nelson, G. Silverberg, and L. Soethe. London; New York, pp. 221–238.

Dosi, G. (1997): Opportunities, Incentives and the Collective Patterns of Technological Change. In: *The Economic Journal* 107, pp. 1530–1547.

Dosi, G. and L. Marengo (2007): On the Evolutionary and Behavioral Theories of Organizations: A Tentative Roadmap. In: *Organization Science* 18.3, pp. 491–502.

European Parliament and Council (2003): Directive 2003/87/EC of the European Parliament and of the council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC.

Fagerberg, J. (2005): "Innovation. A Guide to the Literature." In: The Oxford Handbook of Innovation. Ed. by J. Fagerberg, D. C. Mowery, and R. R. Nelson. Oxford: Oxford University Press, pp. 1–26.

Fagerberg, J. and B. Verspagen (2009): Innovation studies - The emerging structure of a new scientific field. In: *Research Policy* 38, pp. 218–233.

Fassin, Y. (2009): The Stakeholder Model Refined. In: *Journal of Business Ethics* 84, pp. 113–135.

Fischer, C. and R. G. Newell (2008): Environmental and technology policies for climate mitigation. In: *Journal of Environmental Economics and Management* 55, pp. 142–162.

Fraj-Andrés, E., E. Martínez-Salinas, and J. Matute-Vallejo (2009): Factors Affecting Corporate Environmental Strategy in Spanish Industrial Firms. In: *Business Strategy and the Environment* 18, pp. 500–514.

Freeman, C. (1994): The economics of technical change. In: *Cambridge Journal of Economic* 18, pp. 463–514.

Freeman, R. E. (1984): Strategic Management: A Stakeholder Approach. Boston: Pitman-Ballinger.

Freeman, R. E. (2004): The Stakeholder Approach Revisited. In: *Zeitschrift für Wirtschafts- und Unternehmensethik (zfwu)* 5/3, pp. 228–241.

Frondel, M., J. Horbach, and K. Rennings (2007): End-of-Pipe or Cleaner Production? An Empirical Comparison of Environmental Innovation Decisions Across OECD Countries. In: *Business Strategy and the Environment* 16, pp. 571–584.

Gagelmann, F. and M. Frondel (2005): The Impact of Emission Trading on Innovation - Science Fiction or Reality? In: *European Environment* 15, pp. 203–211.

Gigerenzer, G. and R. Selten (2002): "Rethinking Rationality." In: Bounded Rationality: The Adaptive Toolbox. Ed. by G. Gigerenzer and R. Selten. MIT Press, pp. 1–12.

González-Benito, J. and Ó. González-Benito (2006): A Review of Determinant Factors of Environmental Proactivity. In: *Business Strategy and the Environment* 15, pp. 87–102.

González-Benito, J. and Ó. González-Benito (2010): A Study of Determinant Factors of Stakeholder Environmental Pressure Perceived by Industrial Companies. In: *Business Strategy and the Environment* 19, pp. 164–181.

Gray, W. B. and R. J. Shadbegian (1995): Pollution Abatement Costs, Regulation, and Plant-Level Productivity. NBER Working Paper No. 4994.

Hagedoorn, J. (1993): Understanding The Rationale of Strategic Technology Partnering: Interorganizational Modes of Cooperation and Sectoral Differences. In: *Strategic Management Journal* 14.5, pp. 371–385.

Hall, B. and J. Van Reenen (2000): How effective are fiscal incentives for R & D? A review of the evidence. In: *Research Policy* 29, pp. 449–469.

Hanhoff genannt Stemping, I. (2003): Charakteristika und Bestimmungsgründe im Umweltinnovationsprozess: Analyse am Beispiel der europäischen PVC-Industrie. Dissertation. Technische Universität Berlin. Berlin: Mensch & Buch.

Hansjürgens, B. (2006): Emissions Trading for Climate Policy – U.S. and European Perspectives. Cambridge: Cambridge University Press.

Hauschildt, J. and S. Salomo (2010): Innovationsmanagement. 5th ed. Vahlen.

Hoffmann, V. H. (2007): EU ETS and Investment Decisions: The Case of the German Electricity Industry. In: *European Management Journal* 25.6, pp. 464–474.

Horbach, J. (2008): Determinants of environmental innovation - New evidence from German panel data sources. In: *Research Policy* 37, pp. 163–173.

IPCC (2007): IPCC Fourth Assessment Report: Climate Change 2007 (AR4). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Jaffe, A. B., R. G. Newell, and R. N. Stavins (2002): Environmental Policy and Technological Change. In: *Environmental and Resource Economics* 22, pp. 41–69.

Jaffe, A. B., R. G. Newell, and R. N. Stavins (2003): "Technological change and the environment." In: Handbook of Environmental Economics. Ed. by K.-G. Mäler and J. R. Vincent. Elsevier Science B. V. Chap. 11, pp. 462 –516.

Jaffe, A. B., R. G. Newell, and R. N. Stavins (2004): Technology Policy for Energy and the Environment. In: *Innovation Policy and the Economy* 4, pp. 35–68.

Jaffe, A. B., R. G. Newell, and R. N. Stavins (2005): A tale of two market failures: Technology and environmental policy. In: *Ecological Economics* 54, pp. 164–174.

Kammerer, D. (2009): The effects of customer benefit and regulation on environmental product innovation. Empirical evidence from appliance manufacturers in Germany. In: *Ecological Economics* 68, pp. 2285–2295.

Klemmer, P., U. Lehr, and K. Löbbe (1999): Environmental Innovation: Incentives and Barriers. Berlin: Analytica.

Klette, T. J., J. Møen, and Z. Griliches (2000): Do subsidies to commercial R & D reduce market failures? Microeconometric evaluation studies. In: *Research Policy* 29, pp. 471–495.

Kriechel, B. and T. Ziesemer (2009): The environmental Porter hypothesis: theory, evidence, and a model of timing of adoption. In: *Economics of Innovation and New Technology* 18.3, pp. 267–294.

Lanoie, P., M. Patry, and R. Lajeunesse (2008): Environmental regulation and productivity: testing the porter hypothesis. In: *Journal of Productivity Analysis* 30, pp. 121–128.

Laufer, W. S. (2003): Social Accountability and Corporate Greenwashing. In: *Journal of Business Ethics* 43.3, pp. 253–261.

Malerba, F. (2005): "Sectoral Systems: How and Why Innovation Differs Across Sectors." In: Fagerberg, J., D. Mowery, and R. R. Nelson. The Oxford Handbook of Innovation. Oxford: Oxford University Press. Chap. 14, pp. 380–406.

Mazzanti, M. and R. Zoboli (2006): Examining the Factors Influencing Environmental Innovations. Nota di Lavoro 20.2006. Fondazione Eni Enrico Mattei.

Metcalfe, J. S. (2005): "Evolutionary concepts in relation to evolutionary economics." In: The Evolutionary Foundations of Economics. Ed. by K. Dopfer. Cambridge University Press, pp. 391–430.

Montgomery, W. D. and A. E. Smith (2007): "Price, quantity, and technology strategies for climate change policy." In: Human-induced Climate Change: An Interdisciplinary Assessment. Ed. by M. Schlesinger, H. Kheshgi, J. Smith,

F. de la Chesnaye, J. M. Reilly, T. Wilson, and C. Kolstad. Cambridge University Press. Chap. 27, pp. 328–342.

Nelson, R. R. (1995): Recent Evolutionary Theorizing About Economic Change. In: *Journal of Economic Literature* 33.1, pp. 48–90.

Nelson, R. R. (2006): Evolutionary social science and universal Darwinism. In: *Journal of Evolutionary Economics* 16, pp. 491–510.

Nelson, R. R. and S. G. Winter (1982): An Evolutionary Theory of Economic Change. Cambridge, Mass; London: Belknap Press of Harvard Univ. Press.

Oberndorfer, U. and K. Rennings (2007): Costs and Competitiveness Effects of the European Union Emissions Trading Scheme. In: *European Environment* 17.1, pp. 1–17.

OECD (2002): Frascati Manual: Proposed Standard Practice for Surveys on Research and Experimental Development. Paris: OECD Publishing.

OECD (2005): Oslo Manual: Guidelines for Collecting and Interpreting Innovation Data. 3rd ed. Paris: OECD Publishing.

Oltra, V. (2008): Environmental innovation and industrial dynamics: the contributions of evolutionary economics. Working Papers of GREThA, n° 2008-28.

Oltra, V. and M. Saint Jean (2005): Environmental innovation and clean technology: an evolutionary framework. In: *International Journal of Sustainable Development* 8.3, pp. 153–172.

Osborn, R. N. and J. Hagedoorn (1997): The Institutionalization and Evolutionary Dynamics of lnterorganizational Alliances and Networks. In: *The Academy of Management Journal* 40.2, pp. 261–278.

Paulraj, A. (2009): Environmental Motivations: a Classification Scheme and its Impact on Environmental Strategies and Practices. In: *Business Strategy and the Environment* 18, pp. 453–468.

Pavitt, K. (1984): Sectoral patterns of technical change: Towards a taxonomy and a theory. In: *Research Policy* 13, pp. 343–373.

Pinkse, J. (2007): Corporate Intentions to Participate in Emission Trading. In: *Business Strategy and the Environment* 16, pp. 12–25.

Pinkse, J. and A. Kolk (2010): Challenges and Trade-Offs in Corporate Innovation for Climate Change. In: *Business Strategy and the Environment* 19, pp. 261–272.

Pittaway, L., M. Robertson, K. Munir, D. Denyer, and A. Neely (2004): Networking and innovation: a systematic review of the evidence. In: *International Journal of Management Reviews* 5/6.3&4, pp. 137–168.

Porter, M. E. and C. van der Linde (1995a): Green and Competitive: Ending the Stalemate. In: *Harvard Business Review* September-October 1995, pp. 119–134.

Porter, M. E. and C. van der Linde (1995b): Toward a New Conception of the Environment-Competitiveness Relationship. In: *Journal of Economic Perspectives* 9.4, pp. 97–118.

Rahmeyer, F. (2007): "From a routine-based to a knowledge-based view: towards an evolutionary theory of the firm." In: Elgar Companion to Neo-Schumpeterian Economics. Ed. by H. Hanusch and A. Pyka. Cheltenham, Northampton: Edward Elgar Publishing Ltd. Chap. 10, pp. 159–181.

Ramus, C. A. and I. Montiel (2005): When Are Corporate Environmental Policies a Form of Greenwashing? In: *Business & Society* 44.4, pp. 377–414.

Rehfeld, K.-M., K. Rennings, and A. Ziegler (2007): Integrated product policy and environmental product innovations: An empirical analysis. In: *Ecological Economics* 61, pp. 91–100.

Reniers, G., W. Dullaert, and L. Visser (2010): Empirically based develop ment of a framework for advancing and stimulating collaboration in the chemic al industry (ASC): creating sustainable chemical industrial parks. In: *Journal of Cleaner Production* 18, pp. 1587–1597.

Rennings, K. (2005): "Umweltinnovationen und neoklassische Umweltökonomik." In: Beckenbach, F. et al. Innovationen und Nachhaltigkeit, Jahrbuch Ökologische Ökonomik Band 4. Ed. by F. Beckenbach et al. Marburg: Metropolis Verlag, pp. 15–39.

Rennings, K. (2000): Redefining Innovation - Eco-Innovation Research and the Contribution from Ecological Economics. In: *Ecological Economics* 32, pp. 319–332.

Rennings, K. and C. Rammer (2010): The Impact of Regulation-driven Environmental Innovation on Innovation Success and Firm Performance. ZEW Discussion Paper No. 10-065.

Rennings, K., A. Ziegler, K. Ankele, and E. Hoffmann (2006): The influence of different characteristics of the EU environmental management and auditing scheme on technical environmental innovations and economic performance. In: *Ecological Economics* 57, pp. 45–59.

Ren, T. (2009): Barriers and drivers for process innovation in the petrochemical industry: A case study. In: *Journal of Engineering and Technology Management* 26, pp. 285–304.

Rogge, K. S. and V. H. Hoffmann (2010): The impact of the EU ETS on the sectoral innovation system for power generation technologies - Findings for Germany. In: *Energy Policy* 38, pp. 7639–7652.

Rogge, K. S., M. Schneider, and V. H. Hoffmann (2011): The innovation impact of the EU Emission Trading System - Findings of company case studies in the German power sector. In: *Ecological Economics* 70, pp. 513–523.

Rosenberg, N. (1974): Science, Invention and Economic Growth. In: *Economic Journal* 84.333, pp. 90–108.

Ruttan, V. W. (2002): "Sources of Technological Change: Induced Innovation, Evolutionary Theory, and Path Dependence." In: Grübler, A., N. Nakicenovic, and W. D. Nordhaus. Technological Change and the Environment. Washington, DC: Resources for the Future. Chap. 2, pp. 9–39.

Ruttan, V. W. (1997): Induced innovation, evolutionary theory and path dependence: Sources oftechnical change. In: *Economic Journal* 107, pp. 1520–1529.

Schleich, J., K. Rogge, and R. Betz (2009): Incentives for energy efficiency in the EU Emissions Trading Scheme. In: *Energy Efficiency* 2.1, pp. 37–67.

Schmookler, J. (1966): Invention and Economic Growth. Cambridge, MA: Harvard University Press.

Schumpeter, J. A. (1934): The Theory of Economic Development: An Inquiry Into Profits, Capital, Credit, Interest, and the Business Cycle. Reprint (1983). Transaction Publishers.

Schumpeter, J. A. (1947): The Creative Response in Economic History. In: *The Journal of Economic History* 7.2, pp. 149–159.

Schumpeter, J. A. (1950): Capitalism, Socialism, and Democracy. 3rd ed. Harper Perennial Modern Classics.

Schwartz, B. (2009): Environmental Strategies as Automorphic Patterns of Behaviour. In: *Business Strategy and the Environment* 18, pp. 192–206.

Selten, R. (2002): "What Is Bounded Rationality?" In: Bounded Rationality: The Adaptive Toolbox. Ed. by G. Gigerenzer and R. Selten. MIT Press, pp. 13–36.

Simon, H. A. (1955): A Behavioral Model of Rational Choice. In: *Quarterly Journal of Economics* 69, pp. 99–118.

Simon, H. A. (1959): Theories of Decision Making in Economics. In: *American Economic Review* 49, pp. 253–283.

Simon, H. A. (2005): "Darwinism, altruism and economics." In: The Evolutionary Foundations of Economics. Ed. by K. Dopfer. Cambridge University Press, pp. 89–104.

Strannegård, L. (2000): Flexible Couplings: Combining Business Goals And Environmental Concern. In: *Business Strategy and the Environment* 9.3, pp. 163–174.

Suchman, M. C. (1995): Managing Legitimacy: Strategic and Institutional Approaches. In: *Academy o/ Management Review* 20.3, pp. 571–610.

Suurs, R. A. A. (2009): Motors of sustainable innovation - Towards a theory on the dynamics of technological innovation systems. Dissertation. Utrecht: Utrecht University. (Visited on 05/19/2010).

Taylor, M. (2008): Beyond technology-push and demand-pull: Lessons from California's solar policy. In: *Energy Economics* 30, pp. 2829–2854.

Taylor, M. R., E. S. Rubin, and D. A. Hounshell (2005): Regulation as the Mother of Innovation: The Case of SO_2 Control. In: *Law & Policy* 27.2, pp. 348–378.

Tidd, J. and J. Bessant (2009): Managing Innovation: Integrating Technological, Market and Organizational Change. 4th ed. John Wiley & Sonsox.

Türpitz, K.-M. (2004): The Determinants and Effects of Environmental Product Innovations - An Analysis on the Basis of Case Studies. ZEW Discussion Paper No. 04-02.

Waddock, S. A., C. Bodwell, and S. B. Graves (2002): Responsibility: The new business illlperative. In: *Academy of Management Executive* 16.2, pp. 132–148.

Wagner, M. (2007): On the relationship between environmental management, environmental innovation and patenting: Evidence from German manufacturing firms. In: *Research Policy* 36, pp. 1587–1602.

Wagner, M. (2008): Empirical influence of environmental management on innovation: Evidence from Europe. In: *Ecological Economics* 66, pp. 392–402.

Wagner, M. (2011): Corporate performance implications of extended stakeholder management: New insights on mediation and moderation effects. In: *Ecological Economics* 70, pp. 942–950.

Witt, U. and C. Cordes (2007): "Selection, learning and Schumpeterian dynamics: a conceptual debate." In: Elgar Companion to Neo-Schumpeterian Economics. Ed. by H. Hanusch and A. Pyka. Cheltenham, Northampton: Edward Elgar Publishing Ltd. Chap. 20, pp. 316–328.

Witt, U. (2008a): Recent Developments in Evolutionary Economics. Edward Elgar Publishing.

Witt, U. (2008b): What is specific about evolutionary economics? In: *Journal of Evolutionary Economics* 18, pp. 547–575.

Wong, V., W. Turner, and P. Stoneman (1996): Marketing Strategies and Market Prospects for Environmentally-Friendly Consumer Products. In: *British Journal of Management* 7, pp. 263–281.

Zachmann, G. and C. von Hirschhausen (2008): First evidence of asymmetric cost pass-through of EU emissions allowances: Examining wholesale electricity prices in Germany. In: *Economics Letters* 99.3, pp. 465–469.