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Ecology-Driven Real Options: An Investment Framework for Incorporating Uncertainties in the Context of the Natural Environment

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ABSTRACT. The role of uncertainty within an organization's environment features prominently in the business ethics and management literature, but how corporate investment decisions should proceed in the face of uncertainties relating to the natural environment is less discussed. From the perspective of ecological economics, the salience of ecology-induced issues challenges management to address new types of uncertainties. These pertain to constraints within the natural environment as well as to institutional action aimed at conserving the natural environment. We derive six areas of ecology-induced uncertainties and propose ecology-driven real options as a conceptual approach for systematically incorporating these uncertainties into strategic management. We combine our results in an integrative investment framework and illustrate its application with the case of carbon constraints.

KEY WORDS: ecological economics, uncertainty, natural environment, real options, investment planning

Introduction

In business ethics literature, there is a comprehensive debate of the role, extent, and necessity of ethical decision making in business (e.g., Donaldson and Dunfee, 1999; Jones, 1991; Knouse and Giacalone, 1992; Trevino, 1986). Ethical decision making in organizations is impacted by several content variables, namely individual variables, the job context, the organizational context, and the external environment[1] (McDevitt et al., 2007). With respect to the latter, external forces such as societal expectations, political institutions, or industry norms "can create environmental uncertainty" (McDevitt et al., 2007, p. 222) that is important to be addressed within internal management decisions. In this article, we investigate the role of emerging environmental uncertainties in such decisions. More specifically, we focus on uncertainties stemming from the natural environment for two reasons: first, ecological issues have not been of special emphasis in early work in business ethics (e.g., Garrett, 1966; Sharp and Fox, 1937) but are now of particular interest within the business ethics literature (e.g., Crane and Matten, 2007; Ferrell et al., 2002; Lawrence et al., 2005). Second, the issue of environmental uncertainty and its effects on organizations are very prominent in management literature (see Buchko, 1994; Miller and Shamsie, 1999 for reviews). However, what kinds of business-relevant uncertainties stem from the natural environment, what sort of risks these uncertainties pose for firms, and how these risks can be dealt with within strategic decision making, especially in corporate investment planning, are areas in which the discussion has been limited.[2]

We derive our main arguments from the literature on ecological economics and elucidate that new business-relevant issues stem from constraints within the natural environment and from institutional action aimed at conserving the natural environment. We refer to these issues as ecology-induced issues and suggest that they change the business environment and, consequently, constitute a new challenge for strategic management (Shrivastava, 1995). More specifically, we argue that strategic management has to attend to uncertainties stemming from these ecology-induced issues. We elucidate six areas of ecology-induced uncertainties and conclude that flexible adjustments in investment strategies as a response to these uncertainties are important. However, traditional financial assessment methods such as net present value (NPV) calculations fall short of capturing the value of these adjustments. In a similar context, Husted (2005) suggests that real options help to alleviate this shortcoming and provide a basis to better understand the strategic relevance of corporate social responsibility (CSR). He argues that real options are able to reflect managerial risks, and the value of such an option ''increases as perceived environmental uncertainty increases'' (Husted, 2005, p. 180). As such, real options facilitate strategic decisions in situations when a precise assessment of an investment's profitability is limited due to an uncertain business environment and when management is prompted to consider flexible adjustments to its original strategic plans.

We build on Husted's approach and investigate perceived uncertainties in the context of the natural environment. We take an instrumental perspective (Friedman, 1962; Garriga and Mele, 2004) by focusing on corporate profitability and suggest ecology-driven real options as a conceptual approach for investment planning under ecology-induced uncertainties. Based on this, we delineate an integrative investment framework and apply it to the case of carbon constraints.

Ecological economics and salience of ecology-induced issues

Firms are increasingly confronted with ethical decisions on the relationships formed between business and society (De Tienne and Lewis, 2005). Especially in the context of the natural environment, scholars have found that new issues emerge (e.g., Bansal and Roth, 2000) which constitute business-relevant topics (e.g., Starik, 1995) and can be interpreted as ''catalyst for a new round of creative destruction'' (Hart and Milstein, 1999). In this sense, the business environment in general goes through a transitional phase (Porter and van der Linde, 1995), and previous views that took certain business conditions for granted have to be challenged (Gladwin et al., 1995; King, 1995).

The interactions of a firm with the natural environment are discussed in two major streams of neoclassical economic literature: natural resource economics mainly considers the economy's extraction of resources from the natural environment, while environmental economics puts emphasis on the economy's material flows into the natural environment (Common and Stagl, 2005). The concept of ecological economics seeks to address both literature streams (Costanza et al., 1991) and emphasizes the role and impact of human activities with respect to the natural environment. Thus, ecological economics can be defined as ''the study of the human economy as part of nature's economy'' (Common and Stagl, 2005, p. 16). We base our initial arguments on this perspective and observe the salience of ecology-induced issues in two dimensions that influence the corporate business environment: constraints within the natural environment and institutional action aimed at conserving the natural environment.

In the first dimension, we refer to ecology-induced issues as constraints within the natural environment, which relate to the earth's endowment with natural resources and the carrying capacity of the natural environment. The natural resource endowment is determined by ecological limitations such as the finite reserves of natural resources within the ecosphere and the depletion of these resources. The carrying capacity addresses the ability of the ecosystem to absorb pollution discharges such as air emissions and delimits the critical flows of these substances from the anthroposphere to the ecosphere. Both the endowment of natural resources and the carrying capacity of the natural environment are normally considered stable business conditions, i.e., firms take a technocentric view and presume that the current status quo obtains within a given planning horizon (Gladwin et al., 1995). However, taking an ecological economics' perspective, the business conditions under which firms operate are increasingly changing under the growing impact of these ecology-induced issues.

In the second dimension, we refer to ecology-induced issues as institutional action aimed at conserving the natural environment. In general, institutional action refers to activities that become institutionalized over time (Scott, 2001) and tend to be enduring without further justification, socially accepted, and resistant to change (Oliver, 1992). In our context, we consider the interorganizational level of institutional theory (Oliver, 1997) and focus on ''both formal and informal pressures exerted on organizations by other organizations upon which they are dependent and by cultural expectations in the society within which organizations function'' (DiMaggio and Powell, 1983, p. 150). As such, we frame institutional action as human interventions and responses meant to protect the integrity of the natural environment. On the one hand, this action describes the contribution of governments, environmental activists, journalists, or scientists (Hannigan, 2006) to a changing institutional environment. On the other hand, informal social movements, interpreted as loosely organized collective actions, also shape the institutional environment (Benford and Snow, 2000; Polletta and Jasper, 2001). In short, the discussed institutional action is starting to fundamentally alter the institutional environment and, hence, the way business works within society. Therefore, conformity to such social expectations is important for firms as it ''contributes to organizational success and survival'' (Oliver, 1997, p. 699).

Uncertainties in the context of ecology-induced issues

In both dimensions, the ecology-induced issues constitute a new and salient driver of a changing business environment. However, they do not emerge in a continuous and predictable manner. Instead, the future availability of resources and the ecosystem's dynamics are uncertain (Chichilnisky and Heal, 1998; Heal, 1998; King, 1995), as is the process of interaction involved in institutional change (Lepoutre et al., 2007; McDevitt et al., 2007). Since environmental changes or corresponding uncertainties stimulate changes within organizations (Damanpour and Evan, 1984), firms need to specifically address emerging ecology-induced uncertainties. However, we argue that these uncertainties are in some respects fundamentally new and different compared to other uncertainties within the business environment, as they pertain to conditions that firms have taken for granted as enduring and stable. We see three interrelated reasons for this.

First, forecasting conditions in the natural environment such as ecological limitations or ecosystems' thresholds over the long term is difficult (King, 1995), as methodologies to appropriately deal with ''external shocks, non-linear responses, and discontinuous behavior'' (Clark, 1986, p. 31) are scarce and sufficient ex post data or long-term time series are often not available. These are needed for reliable predictions of future developments within the natural environment and related uncertainties. Similarly, institutional processes may appear stable for a certain time when in fact organizational fields and institutions co-evolve (Hoffman, 1999) and thus are rather not static (Greenwood et al., 2002). For example, stakeholder pressures on firms have increased dramatically (Dawkins and Lewis, 2003), and it is hard to predict how stakeholders' expectations and claims will develop in the future.

Second, understanding these uncertainties in a managerial context is difficult because of the problem of chaos and complexity (Clark, 1986; Prigogine and Stengers, 1984; Wheatley, 1999). It is a rule of ecology that everything is interconnected and each environmental insult will likely redound on society (King, 1995). Therefore, concerns about the global ecosystem ''lead to the generation of crude and difficult-to-operationalize axioms'' (Gladwin et al., 1995, p. 891). From an institutional point of view, the direction and pace of changes in the business environment vary across and within institutional sectors (Greenwood and Hinings, 1996). This offers strategic management a palette of response options but does not guarantee that any of them will meet societal expectations.

Third, the change in business conditions due to ecology-induced uncertainties can be rapid and massive. The overshoot of sustainable limits could cause a sudden environmental collapse (Meadows et al., 1972), which in organizational theory has been termed ecological surprise (King, 1995). Furthermore, natural disasters are not necessarily static, isolated phenomena (Hannigan, 2006) but constitute a threat of ''massive discontinuous ecological changes'' (Winn and Kirchgeorg, 2005, p. 233). From an institutional point of view, disruptive events such as the Rio Summit, catastrophes such as the Exxon Valdez oil spill, and legal or administrative activities like the release of environmental white papers (Hannigan, 2006) can result in sharp institutional changes (Hoffman, 1999).

Perception of ecology-induced uncertainties

It is a new challenge for firms to discard their prior 'taking-for-granted' view in the context of the natural environment and to analyze the relevance of corresponding uncertainties for strategic decisions. In this respect, a distinction can be made between perceived and objective uncertainties (Aragon-Correa and Sharma, 2003; Boyd et al., 1993). We build on the literature of perceived uncertainties for two reasons: first, knowledge, a precondition for assessing the future business environment, is determined more by perception than by objectivity (Hambrick et al., 2005; Smircich and Stubbart, 1985). Second, also ethical decision making stems from subjective (i.e., perception-based) assessments, with respect to both its behavioral choice component and its normative-effective component (Trevino and Youngblood, 1990).

Milliken (1987) defines uncertainty as an individual's perceived inability to predict a future condition accurately; such uncertainties pertain to general external events, cause–effect relationships between a firm and its environment, and management decision outcomes (Miller and Shamsie, 1999). Three types of uncertainty can be distinguished: environmental state uncertainty refers to the inability to forecast future industry or market developments. This results from conditions in the business environment or one of its components that all firms face, such as demand volatility, price increases, or regulatory pressure. Organizational effect uncertainty describes the inability to predict the impact of environmental events or changes on firms. It derives from a lack of knowledge and skills to understand the cause–effect relationship between environmental effects or changes and the individual corporate exposure. Decision response uncertainty represents the lack of knowledge concerning suitable response options and/or the inability to anticipate the consequences of individual decisions. We relate these three types of uncertainty to the previously discussed two dimensions of ecology-induced issues. As a consequence, we derive six areas of ecology-induced uncertainties that matter for corporate responsiveness to an ecology-induced change in the business environment (Table I).

With respect to constraints within the natural environment, management faces environmental state uncertainty regarding the general *extent and timing of ecological limitations* and their influence on the corporate business environment. Beyond that, management faces organizational effect uncertainty regarding the *magnitude and direction* of the influence of such ecological limitations: individual firms exhibit different exposures to ecology-induced constraints due to their unique position in industries, value chains, and geographies and resources, and capabilities to cope with these constraints are firm-specific. Anticipating likely constraints, firms are prompted to alter their strategy, notably in terms of investment decisions. To choose a successful response strategy, several firm-specific circumstances such as the general availability of technical alternatives have to be taken into account. Therefore, management faces decision response uncertainty regarding the firm's *own alternatives* for adequately reacting to and foreseeing the *consequences of coping* with ecology-induced constraints.

In light of institutional action aimed at conserving the natural environment, management faces

TABLE I

Six areas of ecology-induced uncertainties

Change of business environment due to	Environmental state uncertainty pertains to	Organizational effect uncertainty pertains to	Decision response uncertainty pertains to
Constraints within the natural environment	Extent and timing of ecological limitations	Magnitude and direction of ecology-induced constraints for the firm	Own alternatives for and consequences of coping with ecology-induced constraints
Institutional action aimed at conserving the natural environment	Scale and scope of human responses to ecological issues	Exposure to and relevance of ecology-induced institutional changes for the firm	Own alternatives for and consequences of adjusting to ecology-induced institutional changes

environmental state uncertainty vis-à-vis the general *scale and scope of human responses* to ecological issues and their influence on the corporate business environment. Moreover, the extent to which organizations exert formal and informal pressures and how social movements will affect individual firms is uncertain. Therefore, management faces organizational effect uncertainty regarding the *exposure to and relevance of* ecology-induced institutional changes. To choose a successful response strategy, several firm-specific characteristics are important, such as the firm's ability to reliably fulfill stakeholders' requirements and expectations. Therefore, management faces decision response uncertainty regarding the firm's *own alternatives* for adequately reacting to and foreseeing the *consequences of adjusting* to ecology-induced institutional changes.

In order to facilitate addressing these uncertainties in the managerial context, management has to understand the interplay between them. On the one hand, there is no primacy or dependence among the six areas: if a change in the business environment can be detected due to one specific issue, each of the areas can represent an independent source of uncertainty for a firm. The relevance of each uncertainty depends on the individual perception by management and the general business circumstances, such as the competitive landscape or the firm's technological possibilities. On the other hand, the six areas are interrelated over time: once management has solved decision response uncertainty by taking a certain action, this in turn feeds back to environmental state and organizational effect uncertainties. As such, some of the state and effect uncertainties might even be created by corporate responses to other ecology-induced issues.

Determining the profitability of investments

Generally, the anticipation of future developments in the business environment and their integration into the assessment of future cash flows constitute an important part of a firm's strategic management (Thompson, 1967). However, if these assessments face an uncertain business environment, an appropriate consideration of uncertainty is important for successful investment planning (Dixit and Pindyck, 1994). The economic consequence of a firm's exposure to uncertainties in the business environment is financial risk (Amram and Kulatilaka, 1999). For a comprehensive analysis of this risk in the context of ecology-induced issues, the six derived areas of uncertainties facilitate assessing the future profitability of investments. Standard methods for investment appraisal such as NPV calculations estimate and discount future cash flows but face two important limitations.

First, emerging ecology-induced issues may prompt management to alter its original plans. Consequently, firms need to reflect on different possible developments of the business environment and to determine the value of flexible adjustments in their investment strategy at a later stage, e.g., the value of switching, extending, or stopping the investment. However, the possibility of changing the investment strategy is not built into typical financial NPV models as they usually consider only one likely return stream of an entire project (Trigeorgis, 1988). Using NPV as an investment criterion is thus most suitable for firms operating in a fairly stable business environment.

Second, NPV logic usually applies a higher discount rate when returns appear to be more uncertain (Baecker and Hommel, 2004). As a result, the present value of the free cash flows decreases. Therefore, this valuation method captures the possibility that actual returns might be lower than expected, but the possibility that actual returns might be higher is not appropriately reflected in the valuation process (Cornelius et al., 2005). Hence, this inherent cognitive bias and risk-averse perspective of considering only possible negative effects might prompt managers to reject a project solely on the basis of a high level of uncertainty, thereby neglecting the opportunity perspective of ecology-induced investments.

The central challenge of a farsighted management is to adequately respond to unforeseen changes by incorporating flexibility into investment appraisals (Copeland and Antikarov, 2001). Available methods include Monte Carlo simulation (e.g., Clemen, 1996), dynamic programming (e.g., Cormen et al., 2001), and real options theory (e.g., Black and Scholes, 1973). For incorporating flexibility as a response to ecology-induced uncertainties, this article focuses on the last. In general, real options theory assumes an initial investment is to be made (Dixit and Pindyck, 1995); management must then decide whether to harvest or cultivate the initial investment (Adner and Levinthal, 2004). As such, ''real options can help decision makers assess the profitability of new projects and understand whether and when to proceed with the later phases of projects that have already been initiated. [...] Real options are especially valuable for projects that involve both a high level of uncertainty and opportunities to dispel it as new information becomes available'' (Copeland and Keenan, 1998, pp. 129–130). Following this logic, the result is an extended NPV, which consists of the standard NPV (without considering the value of flexibility) and the option value (Trigeorgis, 1995). The latter describes the value of flexible adjustments of the investment strategy.

When management intends to utilize real options, five parameters have to be determined: the present value of an investment's operating assets, the expenditure required to acquire the investment's assets, the considered time length, the time value of money, and underlying volatilities (Luehrman, 1998). Summarizing those parameters, Dixit and Pindyck (1994) name three determinants for incorporating flexibility into the process of assessing investments' profitability in an uncertain business environment: (a) analysis of the underlying investment conditions: what are the parameters of the project and what is the value of the investment under current conditions? (b) appraisal of volatilities: what is the likely distribution of future revenues? (c) assignment of a time to invest: when is the best time to invest?

In order to determine the option value in the context of ecology-induced issues, the orresponding uncertainties have to be translated into probabilities, i.e., interpreted as corporate risks. As one important assumption, the literature on real options differentiates between public and private risks (Borison, 2005), both in theoretical work (e.g., Dixit and Pindyck, 1994; Trigeorgis, 1988) and in managerial applications (Amram and Kulatilaka, 1999; Luehrman, 1998). Public risks are market risks, i.e., estimates for such risks can be observed on the market in alternative portfolios. These rather pertain to environmental state and organizational effect uncertainties. Private risks are firm-specific and require subjective estimates. As such, they can relate to all ecology-induced uncertainties in a similar manner. Both types of risk have to be considered when analyzing the three determinants of investments' profitability. As a result, management can consider the five types of real options delineated in Table II for practical application within investment decisions (Amram and Kulatilaka, 1999).

Ecology-driven real options

In the following, we exemplify the application of these five types of real options with a fictitious company which considers investing in a new environmentally sound production system. In order to develop the underlying technology, the company has already made R&D investments which represent an initial investment. The company now reflects on different ecology-induced uncertainties that could affect the future profitability of the production system once it is installed. In this situation, the application of ecology-driven real options is suitable: an option to defer could, for example, be built into the purchasing agreements of major components to allow postponing the start of the production system in case it turns out to be unprofitable under current market conditions. Conversely, if the new technology exceeds profitability forecasts a growth option can be realized to generate additional revenues through the increased sale of environmentally improved products. An option to extend could be created if the company is able to transfer the technology into related production systems in different fields, for example, with modularized technological components. Furthermore, the technology could be designed in such a way that an option to switch between different types of the environmentally sound system allows adjusting to changes in market conditions. Finally, management is able to create an option to abandon if some value of the production system can be retained even if its operation is discontinued at a later point in time. This can be the case, for example, if gained R&D insights can be used within other projects.

In light of the potential advantages outlined above, several scholars have started to use real options theory in order to address specific questions related to the natural environment. Table III illustrates some prominent examples. Most of these studies discuss the application of real options theory

TABLE II

Five types of real options within investment decisions

Types of option	Management flexibility	Description
Option to defer	Deferring the exercise date into the future	An option to defer allows the management to postpone the start of an investment. This applies to investments that are not profitable under current conditions but might become profitable at a later stage
Option to grow	Flexible adjustment of project's scope	Growth options can be adequate in situations where an initial investment turns out to be profitable. While building on this investment, further investments generate additional revenues at a later stage
Option to extend	Broadening the utilization of gained knowledge	Considering options to extend, firms are able to utilize an initial investment in related areas afterward if the conditions are favorable. Management is able to transfer technologies or knowledge gained to other projects
Option to switch	Flexible choice of path	Within a project's lifetime, management may have the option to move back and forth between different possibilities to utilize the initial investment, depending on each possibility's profitability
Option to abandon	Stop project	An option to abandon describes the possibility to stop a project at a later stage while retaining the ability to capture a remaining value of the initial investment. A reason for stopping a project could be a change in market conditions

Source: Extended from Amram and Kulatilaka (1999).

TABLE III

Applications of real option theory in the context of the natural environment

Authors	Areas of application	Types of real option
Blyth et al. (2007)	Investment decisions in the power sector under uncertain climate policy	Option to defer
Cortazar et al. (1998)	Investments in environmental technologies under varying output price levels	Option to defer, option to extend, and option to abandon
Laurikka and Koljonen (2006)	Investment decisions in the power sector in face of the EU ETS and fossil fuel prices	Option to defer, option to switch
Lin et al. (2007)	Timing of environmental pollution policy	Option to defer
Yang et al. (2008)	Investment decisions in the power sector in face of regulatory uncertainty	Option to defer

in the context of investment decisions in the power sector and consider the option to defer. A frequent conclusion is that due to uncertainties in climate policy management should pursue a waiting strategy and postpone investments.

Extending the basic idea of these studies, we devise a more general argument: on the one hand, we discussed that the salience of ecology-induced issues increases within the business environment. On the other hand, the underlying uncertainties exhibit specific characteristics which are not adequately treated in strategic management. Therefore, we propose a real options logic as a constitutive element of investment decisions in which managerial flexibility toward the derived six areas of ecology-induced uncertainties is required. This is of special relevance when assessing the profitability of investments with long lead and amortization times. With such a real options logic, management can reduce what Rugman and Verbeke (1998) call irreversible green mistakes: starting from a competitive advantage point of view, Rugman and Verbeke (1998) explain the importance of analyzing the flexibility of resource commitments as well as their leveraging potential for improving a firm's performance with respect to the natural environment. In the logic of their framework, the greater the flexibility and leveraging potential of resource commitments, the higher the utility of applying real options. In such business situations, it can be reasonable to consider one or several of the five types of real options mentioned above. Which option is most suitable depends on the characteristics of the required resource commitments (e.g., interchangeability of required resources), the firm-specific risk exposure (e.g., competitive landscape), the individual context of the investment decision (e.g., long-term amortization periods, path dependencies), the salience of ecology-induced issues, and the corresponding perception of uncertainties.

Based on these ideas, we derive an integrative investment framework that facilitates the incorporation of ecology-driven real options in investment decisions (Figure 1). This framework combines four steps under one conceptual umbrella. In the first step, ecology-induced changes in the business environment are analyzed that stem from constraints within the natural environment and related institutional action. In the second step, it is evaluated how these changes are likely to influence the general state of the business environment, to affect the organization, and to be relevant for decisions regarding how

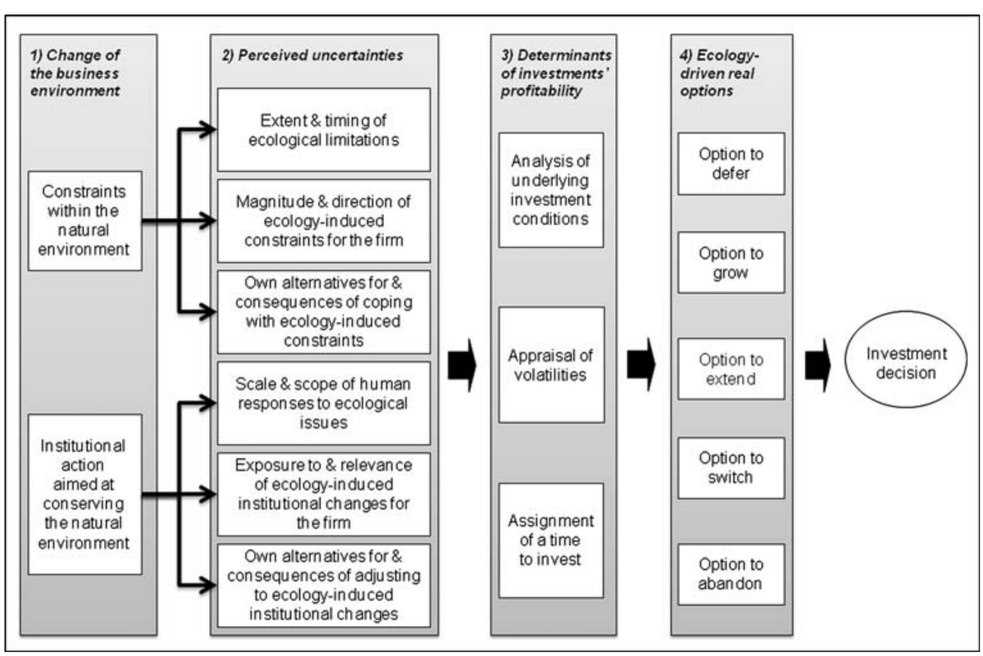

Figure 1. Integrative investment framework for ecology-driven real options.

to respond to these changes. Accordingly, one or more of the six areas of ecology-induced uncertainties might turn out to be important to focus on within an investment's planning process. In the third step, the consequences of these uncertainties for the determinants of investment profitability are assessed to offer a differentiated reflection from a risk perspective. In the fourth step, based on the effect of uncertainties on the determinants, one or more of the five real options can be considered. In this way, investment decisions in the face of ecology-induced uncertainties are facilitated.

Example: carbon constraints

We apply the investment framework by referring to carbon constraints. These relate on the one hand to the disposition of fossil fuels and on the other hand to direct and indirect climate change effects (Busch and Hoffmann, 2007). Carbon constraints can be considered a very prominent example for ecology-induced issues and uncertainties in the 21st century. As almost every industry is dependent on utilizing energy or fossil fuels, the steps below facilitate investment planning for firms independently of their industry affiliation. In the last step, we illustrate how individual firms have already implemented ecology-driven real-options-thinking.

Step 1: analyzing changes of the business environment

The availability of fossil fuels can be considered an emerging ecology-induced issue for firms: for example, rising oil prices and increasing price volatilities may be a first sign that markets are reacting to imminent concerns over the earth's endowment of fossil fuels (Hirsch et al., 2005). This *constraint within the natural environment* has macroeconomic implications for economies (Kuik, 2003) and, thus, influences the business environment. Furthermore, empirical data and findings of the IPCC (2007) prove that climate change has emerged as an ecology-induced issue, as greenhouse gas emissions are on the verge of exceeding the carrying capacity of the natural environment. Negative economic effects through adaptation and mitigation measures can be expected (Stern, 2006), which, in turn, will also change the business environment. Furthermore, climate change-related extreme weather events can destroy thriving business environments (Schwartz, 2007).

With respect to *institutional action*, a prevailing carbon constraint for firms is the European Emission Trading Scheme (EU ETS) that was launched in 2005.[3] The EU assigns amounts of CO_2 emission allowances to their member states which, in turn, grant these allowances to firms according to so-called National Allocation Plans. Firms can utilize them to fulfill their obligation to render allowances for their CO_2 emissions or trade them on the carbon market. From January to March 2008, the daily trading volumes centered around 10 million tonnes of CO_2 with an average price of 21 EUR per tonne of CO_2 (Point Carbon, 2008). Hence, changes in the natural environment lead to the implementation of this new regulatory framework, which constitutes an institutional change that influences the business environment (Hourcade et al., 2007).

Step 2: evaluating the perception of corresponding uncertainties

These previously described developments relate to all six areas of ecology-induced uncertainties. For example, firms face environmental state uncertainty regarding the future *extent and timing* of oil availability. This depends on a large number of factors, e.g., the discovery of new resource fields. Furthermore, price increases of crude oil affect corporate stock returns (Sadorsky, 1999), but the *magnitude and direction* of oil scarcity are difficult to anticipate, i.e., the effects for individual firms are subject to uncertainty. Some industries are dependent on utilizing oil and might bear price increase as long as they are able to pass them on to customers. However, it is uncertain when and to which extent disruptive technologies might offer customers competitive non-oil-based alternatives. In order to respond to these constraints, firms might consider their o*wn alternatives* in terms of investments in technologies that allow fossil fuel switching or efficiency increases. But each of these technologies will be accompanied by different market and price conditions and, thus, management faces uncertainty regarding the *consequences* of individual response options. Most importantly, this also implies that new environmental state and organizational effect uncertainties may need to be addressed. Similarly, the extent of climate change's alteration of the business environment and the resulting economic consequences are still debated (Clarkson and Deyes, 2002; Nordhaus, 2006; Tol, 2003). But how individual firms will be affected by temperature increases is hard to predict. For example, firms can adapt to climate change by relocating production facilities, but it remains uncertain whether such measures will be sufficient to avoid financial disadvantages.

Uncertainties also prevail with respect to institutional change. For example, the *scale and scope of human responses* in the context of the EU ETS are neither stable nor predictable for firms. This pertains to the future development of the EU ETS (e.g., the general amount of available emission allowances), stakeholder pressures on firms to improve their carbon performance and to be in compliance with the EU ETS (e.g., financial markets fostering initiatives such as the Carbon Disclosure Project), as well as the CO_2 allowance price (there is only a limited data basis for anticipating future CO_2 prices).[4] Furthermore, not all firms experience the same *exposure to and relevance* of the institutional change by the EU ETS. For example, for many energy utilities the system provided a positive monetary effect (Sijm et al., 2005); however, it is uncertain whether this will persist in the future. In order to respond to this institutional change, firms could consider carbon capture and storage (CCS) as their o*wn alternative* to reduce CO_2 emissions. However, the *consequences* are hard to predict especially if underground reservoirs for CO_2 storage leak over time. In addition, it is unclear whether CCS will be acknowledged by the EU ETS and what the consequences of potential leakages on a firm's image would be. Therefore, a CCS investment would be accompanied by new environmental state and organizational effect uncertainties.

Step 3: assessing the consequences for the determinants of investments' profitability

In order to determine the profitability of investments in light of carbon constraints, it is important to assess the relevance of each of the above-derived uncertainties and interpret them in terms of probabilities. Depending on their severity, some uncertainties might require a stronger incorporation in terms of future flexible adjustments of the initial investment plan. In analyzing the *underlying investment conditions*, it is important for management to consider all parameters of the project and the value of the investment under current conditions. For instance, uncertainty regarding the general state of oil availability is important for strategic decisions such as whether to invest in oil-based or carbon-free technologies. Uncertainty about the effects of higher oil prices on the firm's future cash flows impedes the accurate analysis of an investment's revenues. Therefore, the likely distribution of future revenue can be determined by the *appraisal of volatilities*. For crude oil, ex post volatilities or those on future markets can be considered. Finally, management has to assign, based on the results of the previous analysis, an optimal *time to invest*.

Step 4: deriving ecology-driven real options

We now provide empirical examples where firms considered ecology-driven real options under carbon constraint-related uncertainties. The technology firm Choren Industries considered an *option to defer* regarding an investment in a gasification technology for biomass and carbon-containing residues. The investment was subject to several uncertainties, notably regarding the technology's general feasibility and competitiveness with fuel-based technologies (response uncertainty pertaining to its own alternatives for and consequences of coping with ecology-induced constraints). Nevertheless, the firm patented a specialized gasification process in 1995 (Choren, 2006). With this initial investment, the firm obtained the option to bring this new technology to market once it proved able to compete with traditional processes. Based on the patent, at present Choren builds large-scale industrial plants.

The oil firm Shell incorporated an *option to grow* regarding investments in hydrogen technology. As a response to carbon constraints, the firm assumes that substantial markets for hydrogen-powered vehicles will develop (Shell, 2006). However, these assumptions depend on a range of uncertain factors, one important being the future price of gasoline (state uncertainty pertaining to the extent and timing of ecological limitations). Nevertheless, Shell set up

Shell Hydrogen in 1999 with an initial investment dedicated to investigating business opportunities related to hydrogen and fuel cells as an alternative energy source. By continuously investing in R&D projects and growing Shell Hydrogen, Shell retrains the option to participate in the growing hydrogen market at a later stage.

The chemical firm BASF pursued an *option to extend* by investing in its eco-efficiency analysis tool (Saling, 2002). The tool assesses life cycle-wide impacts of products and processes, including the firm's CO_2 emissions and fossil fuel consumption. The motivation behind this initiative can be partly explained as the fulfillment of stakeholder expectations, since the chemical industry is usually considered high polluting. However, it was unclear if stakeholders would consider this approach appropriate and sufficient (decision response regarding their own alternatives for and consequences of adjusting to ecology-induced institutional changes). Nevertheless, BASF started to develop the methodology as an initial investment and later decided to transfer it to other products and processes. Up to 250 analyses have been completed. Furthermore, the method is being offered to other firms through a consultancy service.

The firm Chief Industries embedded an *option to switch* in the case of investing in an ethanol production facility (Nilles, 2006). The facility required a boiler, and management faced the question which fuel would be most cost-effective in the future given emerging carbon constraints (effect uncertainty regarding the magnitude and direction of ecology-induced constraints for the firm). The initial investment was a coal-fired boiler. However, the firm was later able to utilize a dual-fuel system capable of burning coal or natural gas. Depending on current fuel price developments, Chief Industries uses the option to switch between fuels. As a result, this decreases production costs.

The automotive firm Volkswagen utilized an *option to abandon* when it withdrew from the production of the Lupo car (Reed, 2007). Like the automotive industry in general, the firm faces issues in the context of carbon constraints, one of them being consumer preferences about car-specific fuel consumption (effect uncertainty regarding the exposure to and relevance of ecology-induced institutional changes for the firm). The Lupo was produced with the intention of being the world's first car in series consuming as little as 3 l of gasoline/100 km. However, the demand for the car turned out to be rather low and Volkswagen stopped production in 2005. Instead, the firm utilizes the knowledge it acquired to pursue a more successful strategy and introduced the Blue Motion line.

Discussion and conclusions

Within the continuously evolving field of business ethics, managers ''confront dilemmas of increasing complexity in a climate of uncertainty and change'' (Nicholson, 1994, p. 593). Ecology-induced issues are a prime example for such a change, as they pertain to business conditions that were previously taken for granted. Furthermore, constraints within the natural environment are accompanied by new uncertainties that need to be addressed in a systematic manner. One prominent example is climate change, which is already seen as the most important risk factor for insurance companies (Ernst & Young and Oxford Analytica, 2008). Similarly, institutional action aimed at conserving the natural environment represents another source of new uncertainties that needs to be addressed within corporate risk management. For instance, legislation such as the EU ETS has to be regarded as a critical source of uncertainty with far-reaching strategic implications for firms (compare Hillman and Hitt, 1999). In order to grasp these uncertainties, this article classifies six areas of ecology-induced uncertainties, which challenge strategic management and, notably, corporate investment planning.

For firms to respond to this challenge, we suggest the concept of ecology-driven real options and derive an integrative investment framework. The framework enables the systematic consideration of ecology-induced uncertainties and facilitates the incorporation of flexibility when assessing the profitability of investments. From a competitive advantage point of view, real-options-thinking helps management to re-conceptualize the relevance that issues in the natural environment hold for the business environment. Specifically, it fosters a market-related understanding of emerging uncertainties with respect to issues that currently do not seem market-related and, thus, it supports the self-interest of firms to understand and reduce business risk.

From a business ethics perspective, it contributes to a more sustainable society by enabling management to more quickly and adequately address issues related to the natural environment.

We built our arguments from an ecological economics' point of view and explicitly took an instrumental perspective on firms' responses to a changing natural environment. However, in the context of sustainable development also social issues and voluntary activities of firms influence the corporate business environment (Garriga and Mele, 2004; Husted and Allen, 2007). Voluntary activities in addressing social and environmental issues beyond compliance can be ascribed to CSR (Lo and Sheu, 2007; van Marrewijk and Werre, 2003). However, as with ecology-induced issues, substantial uncertainties emerge, which need to be addressed when governing CSR policies (Lepoutre et al., 2007). One prominent example is the Nike case in which the firm was publicly confronted with child labor practices in its supply chain (De Tienne and Lewis, 2005; Zadek, 2004) and illustrated that strategic management also faces the challenge of ethical decision making (McDevitt et al., 2007). As such, sustainable development with all its different facets increasingly emerges as a business topic (Hart, 1995; Hart and Milstein, 1999; Shrivastava, 1995). Therefore, future research might extend our concept to 'sustainability-driven real options.' However, research has to address notable differences between environmental and social issues (Hannigan, 2006) when analyzing corresponding uncertainties within the business environment.

While we highlight the advantages of adopting a real options logic, the literature also discusses limitations of its practical application. Mostly, real option calculations assume that the underlying asset is similar to a so-called European option, i.e., the option can only be exercised on the expiration day. However, in real life, options are exercised whenever it seems most suitable. Hence, many real options rather resemble American options, which do not require a pre-defined time to invest (Luehrman, 1998), but which are more difficult to calculate. Furthermore, it is also important to be aware that the calculation of real options is based on certain assumptions for probability distributions (Brach, 2003; Copeland and Antikarov, 2001) and for public and private risks (Borison, 2005). Thus, overall it appears to be challenging to empirically calculate all different real options in an exact manner. Nevertheless, due to the increasing salience of ecology-induced issues and the characteristics of the underlying uncertainties, we stress the importance of at least implementing ecology-driven real-options-*thinking* within investment planning. Notably, accelerating climate change and the current consumption rates of fossil fuel urgently need countervailing forces, as emerging carbon constraints constitute a serious issue for society. As such, climate change rightly has to be considered as an ethical issue (e.g., Atkisson, 2007; Le Menestrel et al., 2002). Real-options-thinking can point the way forward, as management might consider investments in low-carbon and low-energy technologies even if these appear not to be profitable under current market conditions.

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Notes

[1] We use the terms *environment* or *business environment* to refer to the general environment of firms. When referring to the ecological dimension of this environment, we use the term *natural environment*.

[2] It could be argued that these questions are less relevant in times of large-scale economic changes caused by the subprime crisis and the ensuing global financial crisis that have started to unfold in 2008. These changes bear the risk of superseding areas of ethical concern in business decisions. However, due to the increasing ecological challenges that will affect the business environment, it is important to investigate firms' changing comprehension of and motivation to address ecological issues while ascertaining that their behavior can be considered to be "acceptable and appropriate" (Stanwick and Stanwick, 2009, p. 3).

[3] The EU ETS covers over 11,500 energy-intensive installations across the EU and represents almost half of

Europe's CO_2 emissions. Installations included are combustion plants, oil refineries, coke ovens, iron and steel plants, and factories making cement, glass, lime, brick, ceramics, pulp, and paper. The first trading period ended in 2007; the second one will last until 2012. For further information, see http://ec.europa.eu/environment/climat/emission.htm.

[4] The theoretical price should reflect the marginal abatement costs (Bailey, 1998). However, in reality, CO_2 prices have been determined by a large variety of factors, such as fuel prices, weather conditions, and availability of production capacities (Sijm et al., 2005).

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