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The option to abandon: Stimulating innovative groundwater remediation technologies characterized by technological uncertainty ☆

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HIGHLIGHTS

- The adoption of a new groundwater remediation strategy under uncertainty is studied.
- The ex ante decision and the ex post evaluation of the investment are considered.
- Contrary to the standard real option effect, an option value stimulates investment.
- If performance indicators provide correct information investment is justified.
- Authorities should allow for flexibility within the remediation project.

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ABSTRACT

Many studies on technology adoption demonstrate that uncertainty leads to a postponement of investments by integrating a wait option in the economic analysis. The aim of this study however is to demonstrate how the investment in new technologies can be stimulated by integrating an option to abandon. Furthermore, this real option analysis not only considers the ex ante decision analysis of the investment in a new technology under uncertainty, but also allows for an ex post evaluation of the investment. Based on a case study regarding the adoption of an innovative groundwater remediation strategy, it is demonstrated that when the option to abandon the innovative technology is taken into account, the decision maker decides to invest in this technology, while at the same time it determines an optimal timing to abandon the technology if its operation proves to be inefficient. To reduce uncertainty about the effectiveness of groundwater remediation technologies, samples are taken. Our analysis shows that when the initial belief in an effective innovative technology is low, it is important that these samples provide correct information in order to justify the adoption of the innovative technology.

1. Introduction

In this introduction, we first review the parts of the real option theory that are relevant for our study. We focus on technology adoption and the role of technical uncertainty. Because groundwater remediation is the case study subject, we also introduce the groundwater remediation techniques considered. We further explain how this case study relates to previously performed studies.

1.1. Real option theory

Concerning the economic evaluation of investment projects one has become more aware that discounted cash flow (DCF) methods are inadequate to deal with issues like uncertainty, the irreversibility of an investment decision, and the flexibility of the decision process (Diederen et al., 2003; Fernandes et al., 2011; Boomsma et al., 2012). Dixit and Pindyck (1994) developed the basic theory of irreversible investment under uncertainty, emphasizing the option-like characteristics of investment opportunities. The option theory takes into account the possibility to integrate flexibility in the decision making process and these authors illustrate that under uncertainty, the opportunity cost of not being flexible, rather than keeping the option open to rethink a project, is a significant component of the firm's investment decision.

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Also in the field of sustainable development, it is widely demonstrated that the real option approach gives a better insight into the management of natural resources (Murillas and Chamorro, 2006; Guthrie and Kumareswaran, 2009) and into the adoption of pollution control and renewable energy systems, including the evaluation of policy support (Wirl, 2006; Fuss and Szolgayová, 2010; Heydari et al., 2012; Reuter et al., 2012). For a more comprehensive literature review on real option theories, we refer to Dixit and Pindyck (1994), Trigeorgis (1996), and De Neufville and Scholtes (2011).

The literature on technology adoption mostly considers the ex ante adoption problem under technological uncertainty taking into account the value of waiting (Hart, 2009). Dosi and Moretto (1997) explore the relationships between the design of public incentives and a firm that faces uncertain benefits from the abandonment of a polluting technology. These authors point out that the green investments' irreversibility and uncertainty about related benefits might delay environmental innovations. Farzin et al. (1998) investigate the optimal timing of technology adoption by a competitive firm that faces a stochastic innovation process with uncertainties about the speed of the arrival and the degree of improvement of new technologies. They demonstrate that investments in new technologies slow down when firms are already at the forefront of technological efficiency. When the pace at which technological improvements arrive is fast, the optimal timing of adoption is delayed. Also Fuss and Szolgayová (2010) find that uncertainty associated with technological progress leads to a postponement of investment, which can enforce the lock-in of currently applied systems.

Kline (2001) states that policy response to lock-in should pursue the encouragement of experimentation with alternative technical and institutional approaches to environmental management. A broad range of technology options should be surveyed without considering what the market outcomes might produce. Both learning by doing and learning by using can result in increased technology improvements and the growth of technology demand (Rosenberg, 1982; Mukoyama, 2006). Rosenberg (1982) emphasizes the importance of learning through the utilization of the new technology. An early experience with a new technology not only leads to a better understanding of the relationship between specific design characteristics and performance, it can also result in new practices that increase the productivity of the project. Also Grübler and Messner (1998) state that technological change is a result from R&D, technology demonstration, and investments. Without short-term investments, long-term technology improvements will not materialize.

Aim of this study is to show that integrating the option to abandon can result in a decision to invest in a new technology of which the technical performance is uncertain. In this way, this study relates to current literature in the field of design engineering that shows how integrating flexibility in system design increases the value of these systems. Deng et al. (2013) and Zhang and Babovic (2012) also show the impact of the option value on the ex ante investment decision. In addition, this study demonstrates how the evaluation of the technical performance can be integrated in the management of applied technology and how technical uncertainty is resolved after the ex ante decision to invest is made. This evaluation is referred to as the ex post analysis. Groundwater samples taken provide information regarding the effectiveness of the bioremediation strategy and based on these samples, the belief in an efficient bioremediation strategy is updated as well as the expected value of the bioremediation strategy. The firm then decides whether or not to abandon the bioremediation strategy and adopt pump & treat.

Based on a case study, it is demonstrated that without this option, the decision maker does not invest in the new technology. If the option to redirect the decision is taken into account, the decision maker invests in the new technology (ex ante) and the optimal timing to stop the operation if the new technology proves to be inefficient is determined (ex post). Regarding the ex post evaluation, the model is constructed based on the theoretical framework developed by Thijssen et al. (2004) and which integrates the real option theory. Regarding the ex ante decision, a decision tree analysis is applied in which the ex post evaluation is integrated when the option to abandon is considered. An alternative for the continuous time approach adopted in this study is to apply binomial lattice (Trigeorgis, 1996).

1.2. Groundwater remediation

Groundwater is an essential resource that should be protected and managed properly. However, fuel storage tank leakages, accidental spills, and the excessive use of pesticides are only a few of the many sources contaminating groundwater. If groundwater contamination occurs, it is important to remediate or at least contain the contamination in order to prevent transport to lakes and rivers by natural discharge (Hardisty and Özdemiroglu, 2005). When the market for groundwater remediation is considered, there is one technique dominating: pump & treat (USEPA, 2010). Pump & treat involves the extraction of contaminated groundwater which is then treated above ground (USEPA, 1996). More gentle remediation techniques like bioremediation are not widely accepted and only applied to a limited extent. Stakeholders and policy makers who are not familiar with these kinds of remediation techniques, still need to be convinced of its merits (Vangronsveld et al., 2009; Compernolle et al., 2012).

Bioremediation involves the extraction of groundwater, but unlike the pump & treat technology, the extracted groundwater is enriched with nutrients and injected in a recharge well. The nutrients then activate the bacteria present in the groundwater, which results in the degradation of the contamination (Juwarkar et al., 2010). The technological uncertainty addressed in this paper stems from the variability inherent to bioremediation processes. Factors such as low temperature, anaerobic conditions, low levels of nutrients and co-substrates, the presence of toxic substances, and the physiological potential of microorganisms can limit the efficiency of microbial degradation (Megharaj et al., 2011). It relates to the physical difficulty to achieve certain goals: it is not known beforehand how much time, effort and materials will ultimately be required to meet the objectives set.

This kind of uncertainty does not induce a value to wait, it can only be resolved by undertaking the project (Pindyck, 1993). One then observes how actual costs, or the actual efficiency of the technology in our case, unfold as the project proceeds. In this study, a firm has the opportunity to invest in a bioremediation technology of which the contaminant mass removal efficiency is uncertain. After having invested, the firm faces the decision to continue the operation or to redirect it and adopt pump & treat, a technology it is more familiar with. It is not known beforehand how effective bioremediation will be. However, from the moment bioremediation is started, the contaminant mass removal efficiency is evaluated by taking groundwater quality samples, indicating bioremediation to perform either good or bad.

This type of problem closely relates to the studies performed by Jensen (1982) and Thijssen et al. (2004). Jensen (1982) describes a decision problem in which an innovation is introduced but the firm does not know whether the adoption will be profitable or not. By waiting and gathering information, this uncertainty can be resolved. This decision problem is formalized as an optimal stopping problem in which the firm can either invest, i.e. adopt the innovative project and receive the expected return, or wait, learn from the observations and receive the expected value of this information. The firm starts with an initial belief concerning the profitability of the innovation, which it updates each time it receives new information. The firm's learning behavior is assumed to be Bayesian: the belief is a conditional probability based on past information. While Jensen (1982) only showed existence of a critical value of the belief in a good project at which investing is optimal, Thijssen et al. (2004) extend this study and develop a framework in which an explicit expression is provided for this critical value.

Our study uses the theoretical framework of Thijssen et al. (2004) to find the critical value of the belief in bioremediation at which the firm decides to stop its operation and adopt pump & treat. Unlike the study