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Carbon capture and storage—Investment strategies for the future?

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ABSTRACT

The following article deals with real options modeling for investing into carbon capture and storage technologies. Herein, we derive two separate models. The first model incorporates a constant convenience yield and dividend for the investment project. In the second model, the convenience yield is allowed to follow a mean reverting process which seems to be more realistic, but also increases the model's complexity. Both frameworks are to be solved numerically. Therefore, we calibrate our model with respect to empirical data and provide insights into the models' sensitivity toward the chosen parameter values. We found that given the recently observable prices for carbon dioxide, an investment into C O2-storage facilities is not profitable.

1. Motivation

Following the Kyoto protocol, adopted on the 11th of December in 1997, the European Union decided to reduce emissions of carbon dioxide by 20% (in comparison to the amount of emissions in 1990). Carbon dioxide emissions, mainly caused by humans, increased from 21 to 38 giga tons per year since 1970 (see IPCC, 2007). Following a report of the European Commission (EC, 2007), in Europe, 33% of these emissions result from traffic, agriculture and waste and are hardly avoid- or absorbable. The remaining 67% are composed of 12% pollution resulting from industrial productions, while the residual 88% are caused by the energy sector (heating, cooling or power stations). Due to these facts, the energy sector lies in the center of recent developments for reducing CO_2-pollution. Consequently, this implies research in the area of energy extraction and renewable energy sources as well as the improvement of operating efficiency of the energy sector in general. However, the situation leads to the common opinion that the targets of the Kyoto protocol cannot be reached without an additional interim solution. In this context, one possibility is given by the development of carbon capture and storage technologies (CCS), which means storing CO_2 in aquifers, exploited oil and gas fields, coal seams and other mineral formations.[2] The overall holding capacity for carbon dioxide storage is estimated to reach between 2000 and 11,000 giga tons, worldwide (see IPCC, 2005).

Nevertheless, capturing CO_2 is not a trivial task as it requires the consideration of certain technical aspects.[3]

The following article deals with investment decisions into carbon capture and storage facility, as one of the above mentioned

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[2] Other possible interim solutions are given by temporary storage solutions, Kyoto goal revisions, or delayed reduction. For a deeper insight into these topics see Simpson et al. (2007).

[3] As the technical details of CCS technologies are not in the center of the following research, these are summarized in this footnote. Post-combustion capture systems can be seen as an add on to conventional fossil fuel combustion systems in which CO_2 is captured from flue gases which are produced by combusting fossil fuels with air (IPCC, 2005). Herein, several techniques can be used, as, for example: absorption based on chemical solvents, absorption by membranes or solid sorbents. Since flue gas is usually at atmospheric pressure, the partial pressure of CO_2 is low. As a consequence, currently only absorption by chemical solvents is able to meet the requirements in terms of capture-efficiency and costs. In order to remove CO_2 before combustion (precombustion), fossil fuels can be gasified and shifted. Hence, most of the initial energy content of fossil fuels is switched to pure hydrogen and can be combusted using air without issuing CO_2, as mentioned in IPCC (2005). This process is called Integrated Gasification Combined Cycle (IGCC). Fossil fuel is normally gasified by pure oxygen and steam which leads to a syn gas mixture of carbon monoxide (CO) and hydrogen (H_2). Following Ogriseck (2006), the remaining energy content in carbon monoxide is shifted with steam to hydrogen and CO_2. Following Goettlicher (1999), both previously mentioned combustion processes lower plant efficiency by 10–15%. A third way for removing CO_2 is combusting fuels with pure oxygen in order to get a flue gas stream of nearly 100% CO_2 (see IPCC, 2005). Oxy fuel technology is widely based on currently used fossil fuel boilers which are a major advantage for forecasting reliability and costs in comparison to IGCC. Herein, nitrogen is removed prior to combustion in the air separation unit to get pure oxygen. For getting similar conditions like in air fired fossil fuel combustion systems, nitrogen is substituted by recirculated flue gas (mainly CO_2) (see Kather, 2007). After removing water from the flue gas, the (nearly pure) CO_2 is pressurized and liquefied. Following IPCC (2005), a major disadvantage of this process is the high amount of impurities in the CO_2 stream which increases the energy consumption of CO_2 liquefaction compared to post-combustion capture systems. In this case, overall plant efficiency is reduced by 10% as pointed by Kather (2007).

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Nomenclature

A	general variable
c	velocity of filling in tons CO_2 per unit of time
D	overall specific costs per ton CO_2 captured and stored
D_c	specific costs for capturing per ton CO_2
D_t	specific costs for transporting per ton CO_2
D_i	specific costs for storing per ton CO_2
E	earnings out of storing CO_2
F	value of an investment opportunity
H	general variable
I	investment costs
L	capacity of a storage facility
n	Generell number
p	market price for CO_2 emission certificates
r_f	risk free interest rate
t	time
T	time to expiration
V	market value of one ton CO_2 in the storage
z	standard Wiener process
ABM	arithmetic Brownian motion
CCS	carbon capture and storage
CO	carbon monoxide
CO_2	carbon dioxide
EEX	European Energy Exchange
ETS	emission trading system
EUA	European Union Allowance
EUR	Euro
GBM	geometric Brownian motion
H_2	hydrogen
IGCC	integrated gasification combined cycle
IPCC	Intergovernmental Panel on Climate Change
NPV	net present value
PDE	partial differential equation
USD	US dollar

technologies. With its real options application, our study belongs to the general class of optimal stopping models that are particularly useful in providing optimal timing for investment decisions under uncertainty. Herein, the valuation of CCS investment provides a natural fit into real options analysis, but, however, is also an important issue itself. The numerous facets of uncertainty[4] when dealing with carbon capture and storage facilities require a dynamic analysis and cannot be appropriately analyzed with static models as, for example, the discounted cash flow method. With this study, we intend to provide valuable insights for policy makers and practitioners concerning key factors that discourage these types of investments. Moreover, our analysis makes several contributions to the literature. First, we demonstrate how to integrate an equilibrium model in the market for carbon dioxide emissions with option pricing theory in order to derive the value for a real option to invest into storage facilities explicitly. Second, our specification of the valuation problem allows a close examination of the theoretical and practical issue for using CCS technologies as alternative investment.

The real option model derived also addresses the question whether investments into CCS technologies are profitable given the current market situation and, consequently, able to assist the realization of the Kyoto protocol. Moreover, we identify the key factors that drive these investment decisions and identify possible starting points for policy makers to stipulate or influence investment decisions.

Therefore, the article is organized as follows. Section 2 gives an overview of the existing literature. In Section 3, we derive the two distinguished real option models, their boundary conditions and numerical solution method. The models' calibration with respect to empirical data and theoretical evidence is given in Section 4, whereas the next two sections provide the numerical solutions and sensitivity analysis for the two derived models, separately. The last section concludes and summarizes the findings.

2. Literature

Currently, there exist only a few articles that deal with emission certificates, investment decisions and real options in combination. Therefore, in the following we provide the reader with insights into the relevant literature that allows us to bring together these areas of research.

Recently, certificates for carbon dioxide are allocated nationally. If there exist a divergence between allocated and produced amount of emissions, the companies have the possibility to participate in the European trading system (ETS) for CO_2-certificates. The ETS is organized in a similar way as a stock exchange. Following Benz and Trueck (2008), the main difference between plain vanilla shares and emission certificates is given by the pricing mechanism. While the price of a certain share is driven by expectations concerning uncertain future profits, the price of an emission allowance is exclusively driven by the current scarcity.

Nevertheless, the economic modeling of pricing dynamics of stocks and emissions turned out to be very similar. In this context, Insley (2002) as well as Abadie and Kutxa (2007a, 2007b) see a geometric Brownian motion (GBM) as an adequate process for the price development of emission certificates or stock price evolution. In contrast to these articles, Laurikka and Koljonen (2006) refer to an Ornstein–Uhlenbeck process, but Dasalakis et al. (2009) highly recommend a GBM for describing CO_2-price development. Other case studies dealing with the European market that have to be mentioned in this context are, for example, Klepper and Peterson (2004) or Tomás et al. (2010).

The existence of storage facilities implies that a certain underlying asset can currently be consumed or stored for future points in time. Hence, it provides the stock holder with additional possibilities other than a non-storable good. Seminal work in this context traces back to Working (1948) and Working (1949) who introduced the "theory of storage" by analyzing the dependence between spot and futures prices of storable commodities. This theory of storage proclaims that firms can have an incentive to store a commodity as it generates additional benefits. This finding is confirmed theoretically as well as empirically by Brennan (1958) and Telser (1958) to the so-called convenience yield. Both authors show that the benefits for consumers arise because holding inventories constitutes the availability of an input factor for future production as well as the possibility of meeting unexpected demand, implying additional trading possibilities. However, these early articles do not model the convenience yield formally. More recently, analysis of wealth generated by the storability of a certain good gives insights into the process and the intertemporal behavior of convenience yields as, for example, Heinkel et al. (1990) who show that the convenience yield

[4] Uncertainty is caused by stochastic evolution of pollution, uncertain demand and prices for emission certificates. A further advantage of implementing real options in this case is given by the possibility to deal with the irreversibility of investment and the ability to delay investment decisions.