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A real options analysis of carbon dioxide sequestration for Trinidad and Tobago: a case study of the Mahogany field

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Abstract

In 2009 Trinidad and Tobago (T&T) ranked 57\textsuperscript{th} in the world as a contributor to carbon emissions with some 50 million metric tonnes being emitted as compared to the world’s top contributors; China who produced 7 billion metric tonnes and the United States which produced 5.5 billion metric tonnes. However, the population of T&T is relatively small; resulting in a CO\textsubscript{2} emissions per capita ranking that is quite high. As such T&T is ranked 2\textsuperscript{nd} to only Qatar in CO\textsubscript{2} emissions per capita in 2009. This indicates that T&T should be concerned about its levels of CO\textsubscript{2} emissions and should look at options to control and reduce its volume. In T&T, carbon dioxide (CO\textsubscript{2}) can be strategically placed in deep saline aquifers or depleted oil and gas reservoirs as a CO\textsubscript{2} mitigation measure. Theoretical case studies have been performed on the British Petroleum’s (bpTT) Mahogany field, off Trinidad’s east coast. The migration of injected CO\textsubscript{2} was analysed using the CMG-GEM reservoir simulation software [1]. Initial runs show that CO\textsubscript{2} sequestration is technically feasible. However, uncertainty surrounds the economics of successfully undertaking a CO\textsubscript{2} sequestering program. Given the time frame required to monitor and evaluate the effectiveness of this mitigation measure, the traditional discounted cash flow (DCF) approach may not be suitable [2]. The real option valuation (ROV) method is often presented as an alternative to the DCF approach because it is able to quantify the additional asset value arising for flexible asset management.

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1. Introduction

For over 20 years, the global community has been considering how to manage human-induced net emissions of carbon dioxide (CO₂) so as to reduce the probability of climate changes which may prove to be harmful over time. Carbon capture and storage (CCS) has been identified as one of the more promising (CO₂) emission mitigation techniques in the short term. One of the major issues involved in the implementation of this technology is the high cost incurred in the capture process (accounting for more than 80% of the total cost). When high cost is coupled with the associated transport and geological storage costs, the overall process is often deemed uneconomical. The method of economic analysis is usually the discounted cash flow (DCF) method. Given the time frame required to monitor and evaluate the effectiveness of this mitigation measure, the DCF approach may not be suitable [2]. The real option valuation (ROV) method is often presented as an alternative to the DCF approach because it is able to quantify the additional asset value arising for flexible asset management.

1.1. Using Real Options Valuation

Independently, for 25 years, various people have suggested that commercial organisations, particularly in the upstream petroleum industry, should take into account, in their evaluation of decisions about their asset structure and management:

1. the multi-dimensional structure and the time evolution of the uncertainty in the determinants of asset cash-flows; and
2. how asset structure, including the flexibility that asset managers have to change that structure, influences the effect of underlying uncertainties on asset value.

ROV is the term most commonly used for the methods of doing this that are most soundly grounded in our current knowledge about asset valuation [3, 4]. The uncertainties that arise from the potential for CO₂ sequestration projects are complex, multi-dimensional, new and long-term. The management of the impact of these uncertainties will require flexible responses. For this reason, this case provides a test-bed for the potential costs and benefits of using ROV.

One key element of a ROV is the specification and parameterisation of the model for the probabilistic process by which uncertainties in the underlying variables of the analysis are resolved. This paper focuses on the differences between how standard DCF and ROV methods determine the effects of uncertainty on value. In the concluding section of this paper, various elaborations of this preliminary analysis are discussed.

1.2. The suitability of the Mahogany Field for CCS

On the west coast of T&T, major pure CO₂ point sources are centrally located inside the Point Lisas Industrial Estate through the various ammonia production facilities. This is advantageous, as all related CO₂ emissions generated therein are already “captured” or separated as this step is inherent in the ammonia synthesis process. As a consequence about 80% of the investment needed for a CCS is eliminated.

The Mahogany Field is a deep saline aquifer located off the south east coast of T&T and is less than one hundred and fifty kilometers from the Point Lisas Estate. Theoretical work has shown that this field is a suitable site for CCS [5, 6]. The solution conceptualised for T&T is therefore a utility plant located within the Point Lisas Industrial Estate collecting and conditioning a given volume of CO₂ from ammonia production before being transported by pipelines for eventual storage.

2. The Sequestration Project: Parameters

The total volume of annual CO₂ emissions available for use in the Point Lisas Industrial Estate from the eleven ammonia plants located there is about six million tonnes (taking present re-use amounts into consideration) [7]. It is assumed one-third of this amount or two million tonnes of CO₂ (4% of total emissions) would be utilised annually.
The investments needed were derived from computing capital expenditure (CAPEX) and operational expenditure (OPEX) for this project. The CAPEX were utilised at the beginning of the respective project and included all infrastructure needed for collection, dehumidification, transportation and injection. The OPEX were mainly categorised into those resources needed for CO₂ purchasing, CO₂ conditioning (collection, dehumidification and transportation) and CO₂ injection during the project life cycle. These were then combined to give total investment needed. A number of assumptions were made and applied in computing the total investment; these are:

- Project technological life of 32 years,
- A discount rate of 10% and
- An escalation rate of 1% per annum for all OPEX.

The income were analysed in the same manner. The income streams where applicable were reported over the technological life of the project and Net Present Value (NPV) function was utilised to compute the overall income. The same discount rate of 10% was adopted for this analysis and the resulting income was compared with associated expenditure to determine the economic feasibility.

<table>
<thead>
<tr>
<th>Project Parameters</th>
<th>Cost (USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Cost to build plant including transport infrastructure</td>
<td>236 million</td>
</tr>
<tr>
<td>CO₂ Purchase Price</td>
<td>2 $/mscf</td>
</tr>
<tr>
<td>Operating and Maintenance Cost</td>
<td>0.5 $/mscf</td>
</tr>
<tr>
<td>Injection Cost</td>
<td>1.8 $/ton</td>
</tr>
</tbody>
</table>

In terms of revenue streams, the only theoretical available avenue is through the sale of carbon credits. In this case a conservative price of USD $15/tonnes of CO₂ was assumed.

3. Comparing the DCF and ROV methods of evaluation

3.1. Overall Structure

The model of the underlying variables is based on a tree of scenarios for the relevant aspects of the future, where branching on the tree represents the arrival of new information that differentiates among different groups of possible scenarios, and states on the tree are where branching, cash-flows or decisions can occur [8]. It should be noted that, if there is no uncertainty about the future, and thus only one possible scenario, the scenario tree collapses to a time line, with one state at each time.

3.2. Explanation of the Valuation Methods

Two methods were used to calculate an estimate of the incremental value of this opportunity to sequester CO₂. In each case, we have made the approximation that decisions are made, and cash-flows occur, annually.

Firstly, the value using standard single scenario DCF methods in the scenario of expected CO₂ prices, using a continuously compounded risk-adjusted discount rate of 10% per year was done. Subsequently, the value was determined using ROV methods.

The DCF calculations are standard and well known in the industry, and it will not be describe here in detail. The ROV calculation is based on a consistent model of financial markets, which are the markets where value, in the sense defined above, is determined. This model is based on the approximation that transactions costs or barriers are low enough in these markets, that trading quickly drives two assets with the same cash-flow characteristics to have the same price [3,4,8,9,10,11,12].
These references show that the computation of asset value in each method can be represented as:

\[
\text{The asset value} = \text{the sum over states on the relevant scenario tree of} \ (\text{the asset cash-flow in each state} \times \text{the unit price for cash-flow in that state}).
\]

The scenario tree and the unit prices may be different for the different methods. 
For the single-scenario DCF valuation, the scenario tree is the time line for the scenario involved. The unit price for the cash-flow at a given state on the time line is the discount factor for the time of that state, where the discount factors are produced by using the risk-adjusted discount rate for the valuation. For future reference, it will be useful to think of the discount factor as being the product of two discount factors: one for time generated by the risk-free rate and the other for risk generated by the risk premium in the risk-adjusted discount rate.

The scenario tree for the ROV valuation is the actual scenario tree produced by the diffusion process model for CO₂ prices. The unit price for the cash-flow at each state in the scenario tree is determined using the Black-Scholes-Merton dynamic replication [8]. We find a dynamic trading strategy, involving financial instruments with prices already known or modelled (in this case, claims to risk-free cash and to CO₂ trading prices), that replicates the payoff of a unit of cash in the state being considered. Because of the "no transactions costs" approximation, the unit price for cash-flow in that state is the value of portfolio that begins the trading strategy.

The unit price can be broken down into the product of what may be called the "risk-adjusted probability" of the state and the time discount factor for the time at which the state occurs. The time discount factor for each time is the unit price for risk-free cash to be received at that time.

While the risk-adjusted probabilities have all of the properties of a probability distribution, if there is any risk discounting, they are not the actual probabilities for the variables being considered. In fact, the risk-adjusted expectation (i.e., the expectation with respect to the risk-adjusted probability distribution) of each of these variables is its true expectation discounted for risk. It is shown that, if the underlying variables are commodity prices, as is the case here, these risk-discounted expectations are the corresponding forward prices [8]. It was also shown that, where the only uncertainty is in the proportional price forecast movements, the risk-adjusted probabilities have the same proportional uncertainty structure as the true probabilities [8].

4. Discussion of results

Using the parameters outlined, the DCF method of analysis is uneconomical incurring a net-present value of negative USD 150 million. The ROV method of evaluation also incurred a loss, but this was reduced to negative USD 123 million over the life of the project.

5. Conclusion

The aim of this analysis was not to highlight one evaluation method over the other. In fact, both evaluation methods have relative strengths and weaknesses. However, the key relative strength of ROV is the incorporation of the valuation of managerial flexibility in project evaluation, which makes it a particularly compelling method to use in the evaluation of CCS projects. Large multifaceted capital projects, such as those in the geological and hydrocarbon industries, are often associated with diverse sources of both internal and external risks and uncertainties.

Risks can cause delays to the planned schedule of a project, add a significant cost, and greatly influence its profitability. Uncertainties can be associated with project risks, as well as with opportunities that can develop throughout the project’s lifecycle. Having the ability to plan for these uncertainties, by incorporating flexible alternatives into systems design, is increasingly recognized as critical to long-term corporate success. Flexibility is defined in this paper as the ability of a system to sustain performance, preserve a particular cost structure, adapt to internal or external changes in operating conditions, or take advantage of new opportunities that develop during a carbon dioxide sequestration program by modifying operational parameters. By engaging in planning for flexible sequestration systems, the effects of risk on a particular project value can be examined, project volatility can be calculated, and potential flexible sequestration alternatives can be evaluated.
Once identified, a real options valuation provides a strategic decision-making tool for managers and technocrats to determine the value of incorporating flexible alternatives into a carbon sequestration program. This may contribute to the acceptance of CCS as an economically viable method of CO₂ and lead to the increase in the implementation of CCS projects. Capturing value is important in any process. Further analysis utilising ROV to evaluate CCS coupled with enhanced oil recovery (EOR) projects may be useful in a T&T context.

Acknowledgements

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References