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A barrier options approach to modeling project failure: The case of hydrogen fuel infrastructure

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ABSTRACT

Hydrogen fuel cell vehicles have the potential to contribute to a sustainable transport system with zero tailpipe emissions. This requires the construction of a network of fuel stations, a long-term, expensive and highly uncertain investment. We contribute to the literature by including a knock-out barrier option in an *n*-fold compound real option model to take account of immediate project failure in a multi-stage sequential investment project. Our model allows to explicitly incorporate the default possibility of large-scale energy infrastructure projects. In our case study of hydrogen infrastructure development, we find that even for the least conservative valuation method no profitable business case can be made for the development of hydrogen as a sustainable transportation mode. However, we do provide some suggestive scenarios that plausible tax schedules can be designed to overcome the starting problems for hydrogen infrastructure development.

1. Introduction

Over the past decades, real option modeling has become an increasingly popular approach for the valuation of large infrastructural projects, for the valuation of innovative projects in the natural resources and energy sector and in technology-intensive industries. Examples of the former include

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applications to toll road development (Rose, 1998), airport expansion (Smit, 2003), and highway development (Zhao et al., 2004). Examples that apply real option valuation to natural resources and energy problems include Conrad (2000), Fisher (2000), Sanders et al. (2013) and Sarkar (2009). Applications of real option modeling of innovative projects in technology-intensive industries can be found in Cassimon et al. (2004, 2011a), Fuss et al. (2009), and Schwartz (2004). Real option valuation is preferable to net present value computations because it takes into account the value of waiting and operational flexibility (Cassimon and Engelen, 2015).

Typically, real option valuation is based on the hypothesis that the underlying project value changes over time according to some stochastic process with high volatility (e.g. Conrad and Kotani, 2005). The only uncertainty taken into account is the possibility of a deviation from an expected condition based on the variation of one or more environmental conditions that drive the stochastic process. Standard option models assume that the option stays alive irrespective of the value of underlying asset during the life time of the option. However, some investment projects may have knock-out features that may immediately and completely terminate the model between two decision points. Here, one may think of a physical catastrophe causing the loss of crucial societal and/or governmental support, insurmountable technological problems, or unexpected extra costs requiring additional funding at excessive prices and leading to financial distress. Less dramatically, governments or regulators may cancel or cut the funding if technological progress stays below their expectations; or investors may abandon their plans when an unplanned event causes a very low expected present value of the underlying investment because they do not want to spend additional money up till the moment of the next decision point to proceed or not to the next phase. A real-world example of such termination is a pilot project for hydrogen-fueled buses in the Amsterdam public transport system. After its start in 2008 it encountered a leakage between the hydrogen tank and the hydrogen refueling system leading to immediate project termination (Backhaus and Bunzeck, 2010). Failure to account for such knock-out characteristics may lead standard real option models to overvalue a project.

In this article, we extend the existing real option literature by including a (down-and-out) barrier into an *n*-fold compound real option framework to value a large and innovative infrastructure project. An *n*-fold compound option framework typically captures the decision moments of a multi-stage investment project where the different phases can be seen as a sequence of real options and where each phase gives the option to move to next phase (Cassimon et al., 2004). We will develop and present a model to estimate the fair value of an innovation project that will be knocked out if at any time the underlying project value breaches the minimum level that is acceptable to investors. We thus model an exogenously defined minimum constraint, which the investor of the project is not willing to fall short of.

Options with barrier features are quite common in the financial option literature. The original pricing formula for continuously monitored knock-out barrier options goes back to Merton (1973). Recently, financial options with barriers have been frequently used to analyze a firm's default probabilities (see Broadie et al., 1997; Brockman and Turtle, 2003; Kou, 2003). The basic idea is that corporate equity cannot be modeled as a standard path-independent call option on the value of the firm. It will always be in the interest of the equity holder – that is, the holder of the option on the firm's residual value – to hold on to the option until expiration. However, before expiration the bondholders may pull the plug and declare bankruptcy if firm assets drop to a critically low value. Consequently, it is argued that equity should be modeled as a path-dependent option that can be terminated prior to expiration. A similar reasoning applies to the real option approach of valuing large and innovative infrastructure projects. Cost overruns, financial distress, extra funding needs, or the breakthrough of a competing technology can lead to an immediate termination of the project prior to expiration of the option and the next decision moment. This is particularly important for project financing. To the best of our knowledge, we are the first paper to apply barrier options in an *n*-fold compound real option setting.

We will apply our barrier approach to the case of hydrogen infrastructure development. In our view, the hydrogen case is not only an appropriate application of a barrier model but it is also of relevance in its own right. From a societal perspective, the search for a feasible and sustainable source of energy to reduce the emission of greenhouse gasses has increasingly gained priority and hydrogen is one of the most attractive alternatives known so far (Adamson and Pearson, 2000). We focus on