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A model for irreversible investment with construction and revenue uncertainty

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A R T I C L E I N F O

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This paper presents a model of investment in projects that are characterized by uncertainty over both the construction costs and revenues. Both processes are modeled as spectrally negative Lévy jump-diffusions. The optimal stopping problem that determines the value of the project is solved under fairly general assumptions. It is found that the current value of the benefit-to-cost ratio (BCR) decreases in the frequency of negative shocks to the construction process. This implies that the cost overruns that can be expected if one ignores such shocks are increasing in their frequency. Based on calibrated data, the model is applied to the proposed construction of high-speed rail in the UK and it is found that its economic case cannot currently be made and is unlikely to be met at any time in the next decade. In addition it is found that ignoring construction uncertainty leads to a substantial probability of an erroneous decision being taken.

1. Introduction

The theory of investment under uncertainty has been successful in the past few decades to help decision-makers understand how uncertainty over future payoffs influences the optimal timing of investment projects.[1] Many investment projects, however, are not only characterized by uncertainty over future payoffs, but also over the costs and time of construction.[2]

In this paper, a model is developed that can be used to value projects, such as large-scale infrastructure projects, that are characterized by three features: (i) there is uncertainty over the construction time, (ii) the decision to start construction is irreversible, and (iii) the benefits of the project only accrue after the construction process is finalized. As an example of an investment project satisfying these characteristics one can think of (large) infrastructure investment, such as the construction of a new airport, a new rail link, or a new (nuclear) power station. From the point of view of investment appraisal the main issues with construction lags are that (i) costs may be borne for longer, depending on (often uncertain) construction speed and (ii) benefits may, consequently, accrue later if construction is delayed. Both effects reduce the value of a project: a delay in construction increases the expected present value of construction costs, while at the same time reducing the expected present value of the benefits.

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[1] See, for example, McDonald and Siegel (1986), Brennan and Schwartz (1985), and Dixit and Pindyck (1994).

[2] Such models have been developed by, among others, Majd and Pindyck (1987), Alvarez and Keppo (2002), Pindyck (1993), Bar-Ilan and Strange (1996), Schwartz and Moon (2000), and Hsu and Schwartz (2008).

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These two factors, revenues and construction, are modeled as two (possibly correlated) Lévy jump-diffusions.[3] For example, if the project under consideration is a railway line, the process underlying the construction could represent the mileage of track that has been constructed up to a certain point in time. In our model the value of a project is the solution to a particular optimal stopping problem of a form not usually encountered in the literature on real options. In this problem, simplistically stated, the irreversible decision to start construction will be based on the current *prediction* of the revenues after construction is completed at an unknown time in the future. This prediction depends, therefore, on the properties of the construction process, which may be correlated with the revenue process. It turns out, and this is the main result of the paper, that an optimal trigger can be found for the current state of revenues (i.e. the revenues that would accrue if the project were operational immediately) beyond which it is optimal to take the irreversible decision to start construction.

It is a common practice in project evaluation to base decisions on the *benefit-to-cost ratio* (BCR).[4] This is the ratio of the (estimated) present value of future revenues and the (estimated) present value of the construction costs. Orthodox theory teaches that a project is worthwhile if the BCR exceeds unity. Standard real options theory shows that this threshold should be increased in order to take into account revenue uncertainty. This paper argues that the threshold will be different when accounting for potential construction delays. Whether the threshold increases or decreases is ambiguous, as we will see. Evidence will be presented, however, that, on balance, investment will be delayed further.

The model is illustrated for a project where the construction process follows a spectrally negative geometric Lévy process and the revenue process follows a geometric Brownian motion. A 2013 report into the viability of a high-speed rail link between the UK cities of London and Birmingham (HS2) serves as the basis for a numerical illustration to estimate the current BCR and its threshold for this project. It is found that the report overestimates the current BCR and that it does not meet the threshold that arises from the methodology advocated in this paper. In fact, it will be shown that the probability that the economic case for HS2 is very unlikely to be met in the next 10 years.[5] In its focus on high-speed rail investment as a case study, the paper is related to Pimantel et al. (2012). That paper does identify time-to-build as an important factor in high-speed rail construction, but does not take it specifically into account.

The importance of the development of techniques dealing with construction uncertainty is well-established empirically. For example, Pohl and Mihaljek (1992) show that there tends to be a divergence between ex ante and ex post project evaluations, especially when construction times are long and uncertain. In particular, appraisal estimates tend to be too optimistic (i.e. the reported BCR is too high). A study by Flyvbjerg et al. (2002), using data on 258 transportation infrastructure projects worth US$90 billion, shows that almost 9 out of 10 projects have higher costs than estimated and that the average cost overrun is 28%. For rail projects this increases to 45%. The same authors, in Flyvbjerg et al. (2004), expand on these results and find evidence that cost overruns are more prominent the longer the implementation phase of the project. Even though the engineering profession continues to work on improving the methods used for cost-benefit analysis, typically these models are not explicitly dynamic.[6] In fact, our model leads to similar estimates of cost overruns as reported in Flyvbjerg et al. (2002, 2004) for reasonable parameter values.

The approach to construction uncertainty advocated here is, to the best of my knowledge, new in the literature. In the existing literature on real options, time to build is incorporated in several ways. For example, Bar-Ilan and Strange (1996) and Alvarez and Keppo (2002) consider a model of investment under uncertainty where the time to build is deterministic. They find that an increase in the investment lag increases the investment threshold and, thus, delays investment. In a recent paper, Sarkar and Zhang (2013) show that this result can be reversed if the project is sufficiently reversible and/or has a high enough growth rate. An alternative approach to investment lag is introduced by Majd and Pindyck (1987) who model the *remaining capital expenditure to completion* (RCEC) as a state variable and allow the decision-maker (DM) to vary construction intensity. In their model the evolution of the RCEC is deterministic and they find that the optimal construction intensity policy is of the bang-bang type: either construct at the maximum intensity or do not construct at all. Schwartz and Moon (2000) and Hsu and Schwartz (2008) extend this approach to the case where the RCEC evolves stochastically over time and apply it to R&D projects in the pharmaceutical industry (Schwartz and Moon, 2000) and the design of research incentives (Hsu and Schwartz, 2008). Finally, Pindyck (1993) distinguishes between technical uncertainty and input cost uncertainty for the construction process, but assumes that the value of the finished project is known and fixed, ex ante. The use of (spectrally negative) Lévy processes in real options analysis has been championed by, among others, Boyarchenko (2002) and Alvarez and Rakkolainen (2010).

Whereas the literature on RCEC tends to focus on the value of construction flexibility, the point of this paper is to analyze a model where construction time (and, thus, RCEC) is random, but the decision to start construction is irreversible. This type of model is particularly suited for investment in infrastructure, where, typically, construction takes place continuously until the project has finished. This feature makes the analytics of the model simpler than the aforementioned literature, because

[3] The advantage of modeling construction uncertainty as a stochastic process, rather than assuming a random time to completion is that in this way revenues and construction can be correlated. Correlating these sources of uncertainty may be attractive, because one could think, for example, that both demand for, say, high-speed rail and its construction costs are partly driven by a common macroeconomic factor. In a booming economy, demand is high but it is also more costly to construct in an environment of rising wages and dearer materials. If construction budgets per unit of time are fixed, this could slowdown construction.

[4] See, for example, Vickerman (2007) for an overview of project evaluation of infrastructure projects.

[5] Another advantage of the model presented here is that the probability that investment will take place in a given period of time can be explicitly computed.

[6] See, for example, Mills (2001), Molenaar (2005), and Touran and Lopez (2006).