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Real option valuation of power transmission investments by stochastic simulation

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ABSTRACT

Network expansions in power markets usually lead to investment decisions subject to substantial irreversibility and uncertainty. Hence, investors need valuing the flexibility to change decisions as uncertainty unfolds progressively. Real option analysis is an advanced valuation technique that enables planners to take advantage of market opportunities while preventing or mitigating losses if future conditions evolve unfavorably. In the past, many approaches for valuing real options have been developed. However, applying these methods to value transmission projects is often inappropriate as revenue cash flows are path-dependent and affected by a myriad of uncertain variables. In this work, a valuation technique based on stochastic simulation and recursive dynamic programming, called Least-Square Monte Carlo, is applied to properly value the deferral option in a transmission investment. The effect of option's maturity, the initial outlay and the capital cost upon the value of the postponement option is investigated. Finally, sensitivity analysis determines optimal decision regions to execute, postpone or reject the investment projects.

1. Introduction

In the last decades, the global electric power industry has faced large and paradigmatic structural changes. The power transmission sector suffered a major shift, mainly in how system expansions are planned and implemented. In the traditional vertically integrated electricity industry, centralized planning of transmission expansions is coordinated with generation system planning. In current competitive markets, expansion of transmission infrastructure has been decoupled of the generation planning, making difficult investment coordination. Consequently, transmission investment decisions are undertaken by transmission network owner or outside investors based on expectations of future development of the generation system and consumption.

Different regulatory framework approaches for planning and expansion of electricity networks have been proposed in the context of electricity markets, from approaches based on regulatory incentives (Oren et al., 2002; Vogelsang, 2006) to fully liberalized mechanisms, in which private investors evaluate different projects and invest at own risk (Hogan, 2003; Kristiansen and Rosellón, 2006). Although there is significant progress in each of these proposals, including schemes of mixed regulatory frameworks (Hogan et al., 2010), the problem of transmission system expansion in electricity markets has not yet been satisfactorily solved. As a consequence, power markets often show problems of congestion, market power, high energy prices and decreased levels of supply reliability (Joskow, 2005). In addition, the changes in the electricity industry increased in the uncertainty of key variables involved in expansion planning and valuation of investments. This uncertainty is a consequence of decentralization of decision making and asset operation, limited exchange of information between players, and lack of knowledge on long-term plans of market participants.

In the context of competitive markets, the investors are more interested in returns on short-term investments and are reluctant to get committed in transmission expansions that require earlier large outlays and long payback periods. The reason is that in the long term there is much more uncertainty about generation expansion, electricity demand growth and regulatory framework.

The current development of theoretical models and tools for transmission expansion planning is still below of practical needs posed by electricity markets. A main challenge is to value flexibility and dynamic

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adaptability in the context of planning under substantial uncertainty (Latorre et al., 2003; Rosellón, 2003; Wu et al., 2006).

The financial viability of investment projects or the selection of investment alternatives is typically assessed by cost–benefit analysis. The most widely used method is updating the future cash flows generated by the project. This method is often referred as Discounted Cash Flow (DCF). DCF-based techniques allow summarizing the economic performance of complex large-scale investment projects in a single metric, such as the net present value (NPV). In order to address uncertainty on project variables, the assessment methodology commonly indicates to perform sensitivity analysis, analyze different scenarios, or get the probability distribution of the project value through Monte Carlo simulations.

Even though these attempts are useful to incorporate uncertainty into decision making, they do not solve the natural limitations of the DCF methodology. Indeed, the inherent flexibility embedded into most investment projects is not accounted for by traditional appraisal methods. It has been shown that the NPV rule often leads to suboptimal decisions when irreversible investments are subjected to uncertainty and investors have flexibility into decision making (Dixit and Pindyck, 1994; Mun, 2006; Trigeorgis, 1996).

In uncertain environments, managerial flexibility has a significant economic value. Methods that recognize the monetary value of the options embedded in investment opportunities have been developed in the past. In order to quantify the monetary value of flexibility, the consequences of future decisions contingent up on unfolding uncertainties must be assessed. This paradigm is called contingent decision making.

Contingent investment decisions can be evaluated with Decision Tree Analysis (DTA) technique. The potential of DTA is reflected when the uncertainty affects sequential investments that resolve in different times. However, DTA has important limitations that make it unfeasible for a proper assessment of many investment projects. These problems are the curse of dimensionality and the use of a constant risk-adjusted discount rate. Using a constant discount rate is wrong because in each decision point the earlier uncertainty is resolved and the risk level of the project is modified (Mun, 2006).

An emerging paradigm called real option analysis (ROA) has proved to be a powerful approach for addressing contingent decision making. This is an adaptation of financial options analysis applied to valuing of physical or real assets. The ROA assesses the implied value of flexibility that is embedded in many investment projects (Amram and Kulatilaka, 1999). Flexibility acknowledges that investment plans are modified or deferred in response to the arrival of new (though never complete) information or until the uncertainty is fully resolved. Under this approach, the investor is able to take advantage of new opportunities while mitigating or preventing losses in a timely manner.

The advent of liberalized electricity industry has created a suitable space for development and implementation for real option analysis. This is mainly because the investments in power infrastructure are partially or fully irreversible, affected by several uncertainties and with flexibility in making investment decisions.

Real options have been successfully applied to generation projects considering different types of options and uncertainties. Flexible investments in nuclear power plants, hydroelectric plants and renewable energy projects have been evaluated by real option analysis (Caminha et al., 2006, Gollier et al., 2005, Kiriyama and Suzuki, 2004). Besides, real options are used in selecting generation technologies and in optimal scheduling of multi-fuel power plants (Botterud et al., 2005; Murto and Nesse, 2002; Näsäkkälä and Fleten, 2005, Sekar, 2005).

However, the development of real options for valuing investments in the transmission system has been much more limited. In recent years, the importance of this technique has been shown and some important progress has been achieved.

The early works deal with the investment transmission problems as an optimal stopping problem. These works incorporate the uncertainties in demand, regulatory process and congestion-rent among others (Ocampo-Tan and Garcia, 2004; Saphores et al., 2002). Simple analytical frameworks to evaluate flexible investment decisions in transmission infrastructure are proposed in Saphores et al. (2002) and Boyle et al. (2006). The great potential of real option analysis to evaluate power transmission investments is described in a few theoretical works (Hedman et al., 2005; Ramanathan and Varadan, 2006). The findings highlight the superiority of real options in deregulated markets, encouraging experts in the field to show companies and practitioners the value of this approach (Wijnia and Herder, 2005). Besides, assessments of flexibility in network investments considering flexible distributed generation and FACTS have been proposed (Blanco et al., 2011a; Vazquez and Olsina, 2007). The results indicate that flexible alternatives are often preferred to conventional expansion projects. Finally, real option analysis was used to design regulatory frameworks for the expansion of transmission systems (Pringles et al., 2014).

Even though there is a great interest in applying real option analysis for appraising transmission network investments, the published literature reveals the lack of methodologies to properly perform this task. The early state of the field causes many conceptual mistakes and inappropriate assumptions in the application to power systems, mainly because the electricity market operates under physical laws and uncertainties are very different from markets with experience in real option applications.

The objective of this work is to provide a framework capable of correctly evaluating power transmission investments in competitive electricity markets under conditions of uncertainties and strategic flexibility. Options embedded in transmission investment projects are valued by a stochastic simulation method. Simulation methods enable to successfully capture the characteristics of investments in transmission system (i.e. path-dependent returns and investments that can be executed at any time). The remainder of this article is organized as follows. In the next section, the fundamentals of real option analysis are summarized. The advantage of simulative techniques over other valuation methods is highlighted. The stochastic simulation method for assessing the value of flexible investments under uncertainty is described in Section 3 and a framework for evaluating investments in the electric power transmission is proposed. Section 4 presents an example of transmission investment valued with ROA. Numerical results and sensitivity analysis on an example case for demonstrating the practicability of the proposed valuation method are provided. Finally, Section 5 draws the conclusions of the research.

2. Background

2.1. Investment valuation under uncertainty and managerial flexibility

Currently, the electricity markets require strategic investment decisions in an environment of increasing uncertainty, where future market conditions, development costs and behavior of competitors are highly uncertain.

Typically, managers anticipate and respond to uncertainty by making corrections on the project implementation, invest in stages, abandon projects, and acquire licenses or patents among others. In modern language, managers are making contingent decisions, i.e. decisions to invest or disinvest that depend on the development of events. This illustrates that project managers often intuitively are aware about the existence of options on assets, but they lack of formal decision tools to properly value flexibility.

The presence of flexibility or real options may drastically increases the economic value of investment projects. The value of a project with flexibility is determined as the value of project without options using the traditional NPV plus the economic value of the options:

$$\begin{aligned} NPV_{flexible} = {} & NPV_{classic} \\ & + \text{Value of flexibility (value of real options).} \end{aligned} \tag{1}$$

In contrast to classical theory of valuation (DCF) that considers management as a passive actor, real options deem management as an active