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Determining the optimal installation timing of building integrated photovoltaic systems

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ABSTRACT

Photovoltaic systems offer clean energy production and have the potential to meet future energy demands. As a decentralized power source, photovoltaic systems enhance the security of electricity supplies. One type of photovoltaic systems, building integrated photovoltaic systems, offer additional advantages beyond traditional photovoltaic systems as they do not require large swatches of land as they are integrated into existing buildings. Unfortunately, despite these benefits, uncertainty regarding future electricity prices make valuing photovoltaic systems difficult, which reduces their attractiveness. In scenarios with uncertainty in future electricity prices, investors have managerial flexibility in the form of deferring investment and considering various system sizes, which can affect and improve system valuations. Considering that variation in electricity prices can jeopardize the timely installation of an optimally sized photovoltaic system, the objective of this paper is to propose a real option framework to model the price of electricity and account for the value of managerial flexibility when valuing building integrated photovoltaic systems. A case study using the framework is conducted to calculate the net present value of a real-life building integrated photovoltaic project in Daejeon, South Korea. It was found that the optimal decision for would-be building integrated photovoltaic system owners is to wait to invest in building integrated photovoltaic systems when there are high levels of uncertainty in future electricity prices. This holds true even if the net present values for systems without options are positive. When applying this strategy to the apartment complex in the case study, it generated an option value of approximately $87,000.

1. Introduction

Photovoltaics, a very popular renewable energy technology, offer clean energy production and have the potential to meet future energy demands (Goldemberg et al., 2000). Theoretically, solar energy has the potential to meet all global energy demands (ISPRE, 2009). In addition to the vast energy potential of photovoltaics, it has enormous environmental benefits relative to the use of traditional methods of electricity generation (e.g., fossil fuels). Photovoltaic (PV) systems generate electricity without carbon dioxide emissions, a leading anthropogenic cause of global warming (Fu et al., 2015). Modern PV systems generate more energy than they cost to produce and have comparable energy returns on investment to fossil fuels (Raugeia et al., 2012).

As a decentralized power source, PV systems also enhance the security of electricity supplies (Alazraki and Haselip, 2007). In contrast to centralized electricity generation, PV systems can be installed anywhere and do not necessarily need to be attached to the grid. Consequently, PV system owners are largely unaffected from rising electricity costs and power outages caused by extreme events (Nässén et al., 2002). Further, PV systems face few installation limitations; they can even be installed in densely populated areas by integrating them into building roofs or external walls (Cucchiella et al., 2015). Such systems are known as building integrated photovoltaic (BIPV) systems. PV systems will play a very important role as societies transition to sustainable energy systems.

Despite these benefits, PV systems may not be attractive to some potential customers due to uncertainties in their valuation. The

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potential revenue generated from a PV system directly affects its value. Revenue is calculated by summing the product of each unit of expected power output by the corresponding market price of electricity at that time. While calculating the potential revenue from a PV system seems very straightforward, uncertainties in future prices of electricity complicate the matter. Few studies have addressed the issue of uncertainty in the price of electricity when valuing PV systems (Beliën et al., 2013; Lee et al., 2014). Furthermore, investing in PV systems is inherently flexible; stakeholders have the option to defer investment, choose from a variety of system sizes, etc. This flexibility, which can affect and improve system valuations, has yet to be comprehensively captured in current valuation methodologies. Valuing PV system considering managerial flexibility (e.g., defer installation, choice of system size) in scenarios with uncertainty in electricity prices remains a pressing task.

Since fluctuations in electricity prices can jeopardize the timely installation of an optimally sized PV system, this study provides a real option framework to value PV systems in scenarios where there is uncertainty in the future price of electricity. Using a real option framework, it is possible to capture the value of managerial flexibility in PV system installations that would-be owners have (e.g., defer, expand, contract, and abandon). This flexibility and its corresponding value is implicitly ignored when using traditional discounted cash flow valuation methods. It should be noted that it is not within the scope of this study to estimate a PV system's lifetime power output and the price of electricity. This study focuses on the installation of BIPV systems, which have the potential to become a major player in the PV market. The structure of this paper is as follows. This paper proceeds with a review of the literature on real option analysis and its applications in renewable energy. Next, a real option framework that calculates the value of managerial flexibility when evaluating BIPV systems under scenarios of uncertainty in the future price of electricity is presented. Then, a case study using the framework is conducted to calculate the net present value (NPV) of a real-life BIPV project in Daejeon, South Korea. Finally, the paper is concluded with a discussion of potential methods to increase managerial flexibility as a means to encourage greater uptake of BIPV systems.

2. Literature review

An option is a contract between two parties to buy or sell an underlying asset at a predetermined price (i.e., exercise or strike price) at or before a predetermined date (i.e., expiration date) (Trigeorgis, 1996). If the buyer of an option has the right to buy an underlying asset, its seller has the obligation to sell the underlying asset at the request of the buyer. This is known as a call option. If the holder of an option has the right to sell the underlying asset, it is known as a put option. Options can be further described as either European or American options. A European option is only exercisable on its expiration date whereas an American option can be exercised at any time prior to the expiration date. Several methods are available to calculate option values. The Black-Scholes equation (Black and Scholes, 1973) is one of the most widely used methods. It involves a partition differential equation, based on the assumption that the underlying asset value follows a Geometric Brownian motion. The equation is only able to calculate European option values. American option values can be computed using a binomial model (Cox et al., 1979). This model divides time between present and the expiration date into N discrete periods. The underlying asset value flows through time either increasing or decreasing between each discrete period.

Real options represent managerial flexibility (e.g., defer, expand, contract, and abandon) on a nonfinancial asset. Real option analysis (ROA) corrects for deficiencies inherent to using discounted cash flows valuation methods, which assume that there is no flexibility in decision-making and a constant discount rate (Copeland and Antikarov, 2003). Discounted cash flows account for the downside of a project by using a risk-adjusted discount rate. On the other hand, ROA accounts for the upside of a project in the underlying asset value by capturing managerial flexibility (i.e., real options) over its life cycle. As a result, ROA aligns more closely with reality in how decision makers can adjust managerial plans as new information becomes available.

ROA has proven particularly useful in scenarios with high amounts of uncertainty and has been used to increase the expected value in various renewable energy applications including photovoltaics (Westner and Madlener, 2012; Wesseh and Lin, 2015, 2016; Wang and Du, 2016). Kim et al. (2012) employed ROA to quantify the minimum threshold of government subsidy required to encourage building owners to install PV systems. Martinez-Cesena et al. (2013) used ROA to assess investment timing of PV systems while considering advancements in future PV technology. Kashani et al. (2015) used ROA to identify the investment timing for renewable energy systems with uncertainty in system performance over time, including PV systems. Gahrooei et al. (2016) adopted ROA to analyze the optimal investment timing in PV systems in the presence of demand uncertainties. The previous studies have pioneered and demonstrated the relevance of applying ROA to PV system investment, but managerial flexibility can still be more comprehensively captured. Most studies to date have only have employed a single type of real option to improve PV investment value and have relied on hypothetical cases to demonstrate the application of their frameworks. Therefore, this study attempts to address this gap in the literature by developing a real-option PV valuation framework that considers multiple sources of managerial flexibility inherent to in investing in PV systems and examines it using a real-life project.

3. Methodology

3.1. Real options inherent to BIPV investments

When the owner of a building considers installing a BIPV system, they can capture or create real options to increase the value of the investment. Fig. 1 graphically depicts this managerial flexibility using a simplified scenario with only a few price alternatives. The owner has the right, not obligation, to install a BIPV system during a certain period, *X*, which is the difference between the estimated remaining life of the building and the expected life of the proposed

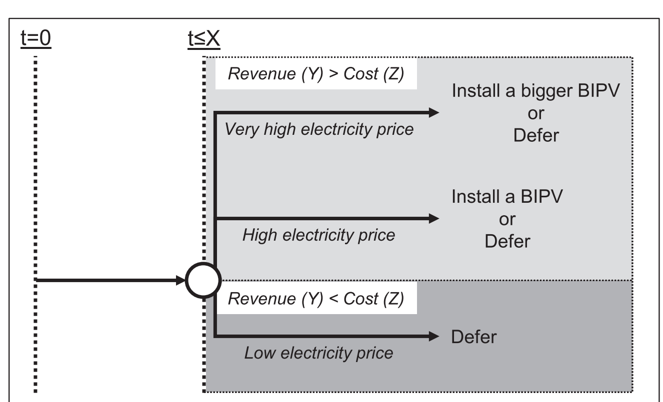

Fig. 1. Investment decision diagram.