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Managerial flexibility in levelized cost measures: A framework for incorporating uncertainty in energy investment decisions

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ABSTRACT

Many irreversible long-run capital investments entail opportunities for managers to respond flexibly to changes in the economic environment. However, common levelized cost measures used to guide decision-making, such as the levelized cost of electricity, implicitly assume that the values of random economic variables are known with certainty when investment decisions are made. This assumption implies, often incorrectly, that managerial flexibility carries zero value. This paper improves levelized cost measures by deriving an expansion that accounts for both uncertainties in relevant variables and the value of managerial flexibility in responding to them. This method is applied to quantify the value of flexibility in two example decision problems. In one, an operator of a natural gas electricity generation facility evaluates whether to invest in carbon capture capabilities. Another considers retirement decisions for U.S. nuclear plants. These examples illustrate that simplified cost metrics can inaccurately guide decision-making by inflating cost estimates relative to the proposed levelized cost measure that accounts for uncertainty and flexibility.

1. Introduction

Decision-making about irreversible long-run capital investments is an essential managerial duty in industries such as electricity generation. Such investments often entail opportunities to respond flexibly to a variety of economic signals by, for example, deferring or staging investment decisions and expanding or contracting the scale of assets. The value of this flexibility has been well-established in the corporate finance literature, in which it is generally captured by the value of "real options" [1] embedded in the investment opportunity, but not in cost-based measures used to assess investment opportunities.

In certain industries, it is common to evaluate investment opportunities based on cost effectiveness rather than solely corporate finance metrics, such as the net present value (NPV). In these cases, the "levelized product cost" (LPC) metric advanced by Reichelstein and Rohlfing-Bastian [2] provides decision-makers with a relevant cost measure. The LPC is the average unit price that a facility must earn over its entire output to break even. In the energy literature, the LPC concept has been applied as the levelized cost of electricity (LCOE), which is defined as "*the constant dollar electricity price that would be required over the life of the plant to cover all operating expenses, payment of debt and accrued interest on initial project expenses, and the payment of an acceptable return to investors*" [3]. Generally, an investment is deemed *cost-competitive* with respect to other facilities when it produces an output (e.g., electricity) at an LPC (e.g., LCOE) at a cost equal to – but no higher than – the prevailing market price.

Since the LPC ensures that the facility would cover all expenses and provide an acceptable return to investors, the measure is conceptually consistent with guidance from corporate finance that investors pursue opportunities with an NPV at least equal to zero. When managerial flexibility exists, however, a wedge may exist between the guidance provided by the LPC and NPV analyses. This is because only the latter approach has well-established methods to include managerial flexibility.

Despite the popularity of the LCOE among both energy practitioners (e.g. [4,5]) and academics (e.g. [6–8]), and the inherent uncertainty of economic signals in the energy context, the energy, accounting, finance, and economics literature does not include a

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formal analysis to guide the inclusion of managerial flexibility in LPC metrics. This paper fills this research gap. The main contribution of the paper is the derivation of a cost measure, the expanded LPC, to guide long-run investment decision-making in the presence of managerial flexibility. This metric presents two chief benefits. First, the expanded LPC is an appropriate cost measure for firms in competitive markets in which managers can fully incorporate the value of capital and operational flexibility. Second, the expanded LPC extends the agreement between corporate finance- and cost metric-driven investment recommendations, as established in the context of a static economic environment by Reichelstein and Yorston [9]. In doing so, it facilitates the use of LPC metrics in the presence of managerial flexibility. While expanded NPV metrics are widely used to guide managerial decision-making under uncertainty [10], the expanded LPC allows a supplemental analysis that is frequently employed in the energy context: the comparison of assets with different time horizons and capital intensities that nonetheless compete in the same markets.

The expanded LPC can accommodate a range of uncertainties and can be applied to a variety of investment settings where the parameters characterizing decision variables are uncertain. When applied in the electricity context to calculate LCOE values, the expanded LPC can guide decision-making for electricity generating facilities. These applications are illustrated in this paper with two examples. The first example studies the decision to invest in carbon capture technology by an operator of a natural gas power plant, provided uncertain future timing and cost of CO_2 emission penalties. The second example considers retirement decisions for the U.S. nuclear fleet, given uncertainty about future costs and revenues alongside currently low electricity prices.

2. Literature review and related work

The motivation for and contribution from the expanded LPC must be contextualized within the three literature threads connected by this work: real options and managerial flexibility, planning under uncertainty, and investment decision measures. This section provides a survey of these literature and positions the contribution of this work accordingly.

2.1. Real options and managerial flexibility

The concept and analysis of real options is the explicit consideration and inclusion of uncertainty in economic analysis. Real options analysis combines multiple scenarios built upon one or many relevant uncertain parameters into one economic evaluation [11]. While real options is the domain of evaluation, managerial flexibility provides necessary context, as it considers the value of control on an outcome. Managerial flexibility is the ability of asset or project management to respond to the resolution of relevant uncertainty [10,12]. Such instances of control include the ability for a manager to determine (i) investment timing, (ii) asset abandonment, (iii) asset contraction/expansion, and (iv) operational switching/idling [13]. The literature has extensively explored managerial flexibility within a real options framework. For capital investment flexibility ((i) – (iii) above), key examples across industries include: sequential investment in chemical reactor assets [11], IT asset purchases [14], nuclear reactor investments [15], wind farm investments [16], solar farm investments [17], and carbon capture equipment attached to coal generation [18]. Other studies have examined both capital and operational flexibility ((i) – (iv) above), including for carbon capture and its operation [19], new product design [20], and even managerial performance indicators [21]. Notably, while various economic and/or decision measures are used in the studies surveyed, the authors are not aware of any that have integrated the concepts of real options and managerial flexibility to advance the LPC measure.

2.2. Planning under uncertainty

An element of real options analysis is the assessment of parameter uncertainty to guide decision-making. Here, extensive research has been conducted within the domains of decision analysis and operations research (e.g., Ref. [22]). Such representations of uncertainties are used as part of optimization studies. For example, [23] build robust bounds on parameters, focusing on developing an approach to ensure adherence with system constraints given multiple, interacting uncertainties. Majewski et al. [24] employ another approach of a mixed-integer linear program with multi-objective optimization. The works of [25] and [26] provide more comprehensive approaches of enumerating uncertainties. Within the energy context, decision-making under uncertainty has a long history in large-scale energy modeling with early stochastic programming examples like [27]. The energy modeling history of incorporating uncertainty into long-range planning is surveyed in Refs. [28] and [29]. However, even in this context, such assessment of parameter uncertainty has not been used to enhance levelized product cost measures with a representation of managerial flexibility.

While methods of resolution for such uncertainties are not explicitly discussed in this work, the proposed method is compatible with a variety of uncertainty assessment and quantification techniques (e.g., statistical methods, expert elicitation, etc.). Furthermore, the levelized cost framework developed here is agnostic toward the decision analytic framework used to evaluate strategies under uncertainty, allowing decision-makers to select a framework that is best suited for a particular application. The expanded LPC can be applied in tandem with deterministic and stochastic models, similar to the example in Section 6 where the LPC is linked with outputs from an energy-economic model.

2.3. Investment decision measures

By enabling a cost-based comparison of assets, the LPC informs investment decision-making and serves as an investment decision measure that is similar to those such as the NPV or internal rate of return (IRR). While the latter measures have been formally expanded by Refs. [1] and [10] to account for real options and managerial flexibility to guide investments under uncertainty, the LPC has not.

Previous research has explored the impact of uncertainty on LPC measures but has stopped short of developing a general LPC metric that accounts for both uncertainty and managerial flexibility. Prior work has explicitly included uncertainty in key model parameters [30–32]. However, in these cases and the broader LPC literature, the LPC metric has not been appropriately developed to account for managerial flexibility. For example, to account for uncertainty, [33] derive a distribution of LCOE measures from input parameter distributions to a Monte Carlo simulation. However, the LCOE derived from the expectation of underlying parameter values is not generally equal to the expected LCOE derived from distributions on underlying parameter values, especially when managers of affected assets can respond flexibly. Refs. [2] and [34] provide two exceptions; both papers develop an LPC metric that allows for price uncertainty and the potential for managers to cease production when prices are sufficiently low.

The present work addresses the gap in the literature of incorporating the value of managerial flexibility in levelized product cost metrics in the context of a fully general set of uncertain economic variables. Besides addressing a critical gap in the literature, the