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Does risk aversion affect transmission and generation planning? A Western North America case study

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ABSTRACT

We investigate the effects of risk aversion on optimal transmission and generation expansion planning in a competitive and complete market. To do so, we formulate a stochastic model that minimizes a weighted average of expected transmission and generation costs and their conditional value at risk (CVaR). We show that the solution of this optimization problem is equivalent to the solution of a perfectly competitive risk-averse Stackelberg equilibrium, in which a risk-averse transmission planner maximizes welfare after which risk-averse generators maximize profits. This model is then applied to a 240-bus representation of the Western Electricity Coordinating Council, in which we examine the impact of risk aversion on levels and spatial patterns of generation and transmission investment. Although the impact of risk aversion remains small at an aggregate level, state-level impacts on generation and transmission investment can be significant, which emphasizes the importance of explicit consideration of risk aversion in planning models.

1. Introduction

Transmission planners in liberalized electricity markets face large amounts of uncertainty. This includes short-term uncertainty about demand, intermittent generation, and equipment outages, but more importantly, long-term fuel prices, load growth, construction cost, and policy uncertainty. The amount of both short-term and long-term uncertainty is likely to increase even further in the coming decade, with increasing amounts of renewable generation capacity, increasing uncertainty about the availability of fossil fuels, and worldwide proliferation of policies to stimulate renewable development. This has implications for investment, since investments in both transmission and generation capacity usually have very long lead times of multiple years or even decades, and decisions are not easily reversible (Barradale, 2010; Fuss et al., 2008; Hu and Hobbs, 2010).

To allow transmission planners to make better decisions in this uncertain environment, stochastic planning models have been developed (see, e.g., De la Torre et al., 1999; Sauma and Oren, 2006; Roh et al., 2009; van der Weijde and Hobbs, 2012; Munoz et al., 2014; Go et al., 2016). However, these models usually assume risk-neutral transmission planners, and that generation firms that invest in new capacity following transmission are, likewise, risk neutral. Most empirical evidence on investments suggests that decision makers, whether public or private, are instead risk averse.[1] Modeling of risk aversion might change near-term investments, for instance by increasing the attractiveness of delaying investments in order to gain

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[1] As discussed in Munoz et al. (2015), both the Midcontinent and the California Independent System Operators use engineering rules that aim at identifying "robust" or "least regret" transmission projects. Although risk aversion is not explicitly mentioned in these studies, their methodologies suggest that the planning authorities are more concerned with worst-case situations (i.e., risk averse preferences) than with the expected performance of the selected projects across all considered scenarios (i.e., risk neutrality).

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more information, or by increasing the value of diverse portfolios of transmission investments that avoid the risk of poor performance under some future scenarios. Risk neutral stochastic transmission planning models may therefore a) be inappropriate if the transmission planner is risk averse and b) incorrectly model the response of risk averse generators to transmission investment.

Others have analyzed the impact of risk aversion, and therefore the effect of a simplifying risk-neutrality assumption, on transmission and generation planning problems; some of this literature is surveyed in Section 2 below. However, the vast majority of these studies only look at either generation or transmission investment, and fail to capture the important interactions between the two that have been identified in the earlier transmission-generation planning literature (e.g., Munoz et al., 2014; van der Weijde and Hobbs, 2012). Moreover, they are generally based on very small models, which are not necessarily representative of large real-world transmission networks and cannot capture the full spatial patterns of transmission and generation investment.

This paper is a first attempt to investigate the impact of risk aversion on the results of large-scale electricity planning models that represent the interactions between transmission and generation investment. We compare the transmission and generation expansion plans identified by such a model under assumptions of risk neutrality and risk aversion, to see where risk aversion makes a difference, and consequently, whether the existing studies and models that assume risk neutrality are adequate or not.

We model a proactive risk-averse transmission planner, who maximizes a risk-adjusted measure for social welfare, and, because transmission expansion changes nodal electricity prices, anticipates a response by risk averse investors in generation capacity. As we will see, the solution to this Stackelberg equilibrium problem is, under some reasonable assumptions, equivalent to a risk-averse cost minimization, allowing us to solve the problem at scale for a 240-bus representation of the Western Electricity Coordinating Council (WECC) network of North America.

Naturally, our approach has limitations: we only model a single decision stage, the complex interactions between individual generators and between generators and the transmission planner that occur in real-world imperfectly competitive markets are not fully captured, and we use a simple case study with a linearized DC representation of the electrical flows on the network. Nevertheless, our results do indicate that risk aversion can have impact on the amount of investment in transmission and generation capacity, on the type of capacity, and on the spatial distribution of that capacity.

The next section will review some of the existing literature on risk-averse generation and transmission planning. In Section 3 we describe our methodology and derive the equivalence of the risk-averse Stackelberg equilibrium problem and the risk-averse cost minimization. Section 4 summarizes the assumptions and approach of the WECC case study, the results of which follow in Section 5. Section 6 concludes.

2. Existing literature

In this section we first overview different methods to include risk aversion in planning models. We then briefly review the existing literature on risk-averse generation and transmission planning.

2.1. Modeling risk aversion

There are several ways to include risk aversion in planning models. In the economics literature, concave utility functions are popular: these can be used to convert monetary costs (or profits) into utilities, whose expected value is then optimized instead of the original objective (Fishburn, 1970). Possible specifications for the utility functions include exponential functions (exhibiting constant absolute risk aversion, CARA) and isoelastic functions (exhibiting constant relative risk aversion, CRRA) (Eeckhoudt et al., 2005). These functions are, of course, non-linear, which makes including them in large-scale planning models challenging. If, in addition to investors being CARA risk averse, the distribution of possible outcomes is normal, the exponential utility function can be written as a linear combination of expected outcomes and the standard deviation of the outcome distribution, which is quadratic. This mean-variance utility approach simplifies the problem significantly, which is one of the reasons for its popularity, but it is, unfortunately, often used in settings where the assumption of normality is clearly invalid (such as a stochastic planning problem with a small number of scenarios).

Another way to model risk aversion, which originates in the financial mathematics literature, is to include the value at risk (VaR) (Duffie and Pan, 1997) or conditional value at risk (CVaR) (Rockafellar and Uryasev, 2000) in the decision maker's objective or constraints. VaR gives the probability that outcomes are worse than a given threshold; however, its mathematical properties are unattractive. CVaR gives the expected outcome over outcomes that are worse than the VaR. Rockafellar and Uryasev (2000) demonstrate that, for a given quantile, the CVaR can be computed as part of the solution of a simple linear program, which makes its inclusion in large-scale planning models relatively straightforward.

Finally, robust planning models find the minimum cost solution that is feasible under a range of potential realizations of uncertain variables (Ben-Tal and Nemirovski, 2002; Mulvey et al., 1995). A wide range of different formulations has been proposed: some only include constraints that enforce feasibility in all scenarios without considering costs, whereas others are closer to CVaR-based models in that they minimize worst-case costs or maximize worst-case outcomes. The advantage of this approach is that the probabilities of future scenarios do not have to be defined; however, without them, risk aversion is limited to the worst-case outcome and the expected performance of the solution cannot be evaluated.

All of these methods have been applied to transmission and generation planning; Sections 2.2 and 2.3 give an overview of some of these studies and their results, without aiming to be a comprehensive literature review.

2.2. Risk-averse generation planning

Several studies have used the above methods to consider the effect of risk aversion on investment in electricity generation capacity, usually in the setting of a perfectly competitive market. Using theoretical economic models, Neuhoff and de Vries (2004) show that if consumers and investors are risk averse, and these risks cannot be traded, competitive markets will not deliver enough investment because risk premia increase generator costs. Moreover, they skew the generation mix towards less risky, less-capital intensive technologies, which is also undesirable from a social perspective, and is a serious barrier to investment in renewables. Ehrenmann and Smeers (2011a,b) show similar effects using stochastic equilibrium models with CVaR-maximizing investors or stochastic discount rates. In their models, which feature uncertain fuel costs, emissions reduction targets, and numbers of carbon allowances, risk averse investors build more open cycle gas turbines and less coal-fired generation capacity. This is because the latter have a higher up-front capital cost and are therefore more risky; however, they also show that there are important interactions between risk aversion and model constraints, such as price caps or carbon targets. Fan et al. (2010), which have investors maximizing utility functions that exhibit constant absolute risk aversion, show that the way these carbon targets are implemented is highly relevant as well. If a carbon taxed or auctioned permit scheme is anticipated, risk averse generators prefer cleaner generation technologies to ensure against these regulatory costs. If, on the other