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Decision Support

Risk induced resource dependency in capacity investments

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ABSTRACT

A capacity acquisition process is resource dependent when the existing resources impact the valuation of new resources and thereby influence the investment decision. Following a formal analysis of resource dependency, we show that uncertainty and aversion to risks are sufficient conditions for resource dependent capacity acquisition. Distinct from the technology lock-in effects of increasing returns to scale or learning, risk aversion can induce diversity. We develop a stochastic programming framework and solve the optimization problem by decomposing the problem into investment and operational horizon subproblems. Our computational results for an application to the electricity sector show, inter alia, that technology choices between low carbon and fossil fuel technologies, as well as their investment timings, are dependent upon the resource bases of the companies, with scale, debt leverage and uncertainty effects increasing resource dependency. Particularly, we show that resource dependency can significantly impact the optimal investment decisions and we argue that it should be evaluated at both company and policy levels of analysis.

1. Introduction

The emergence of heterogeneity in the production technology mix of capital intensive industries raises fundamental questions on the dynamics of investment decision-making in practice and the specification of models in theory. With rational expectations and efficient product markets, convergence to homogenous production processes might be expected, yet heterogeneity is common and persistent in many industrial sectors. Understanding this aspect of market evolution is clearly of importance to both investors in the industry and policy-makers who might be seeking to influence the technology mix (e.g., to a low carbon economy). Although this topic in general has motivated extensive reflections upon the distinctions between resources and capabilities (Hoopes, Madsen, & Walker, 2003), the effective bundling and co-ordination of resources (Banal-Estanol & Micola, 2009), dynamic capabilities (Dierickx & Cool, 1989), and asymmetric market structure (Reynolds & Wilson, 2000), as observed by Lockett, O'Shea, and Wright (2008), the dependencies in resource acquisitions and the investment processes leading to asset heterogeneity still retain many open research questions. In particular, although a general convergence to the lowest cost technology in a highly price-competitive product market is to be expected, many technical and operational aspects can motivate different choices with different cost characteristics amongst the producers.

Thus, resource dependency in capital investment has been extensively observed and researched, e.g., in diversifying into new industrial markets (Lemelin, 1982), into previously precluded and related financial product markets (Ingham & Thompson, 1995), and from the perspective of technology lock-ins, due to increasing returns (Arthur, 1989; Cowan & Gunby, 1996) and learning (Rosenberg, 1982). But the factors inducing resource dependency are various. In this paper, we focus only upon two factors, namely uncertainty in resource valuation and its associated risk aversion, which are usually crucial elements when investment decisions are made, but which have not been analyzed for inducing resource dependency, per se, in capacity acquisition. Whilst it is self-evident that different risk attitudes can motivate different investment choices, how the risks of new assets may interact with an existing resource base is a more elusive question, and how these may become a source of resource dependency invites further explicit analysis. In addressing this topic, we formulate how the concept of risk induced resource dependency can be included in capacity investment models and we apply it to a stylized model of electricity investment under revenue and carbon policy risks.

More specifically, we research the topic by (i) analyzing the theoretical conditions for risk to induce resource dependency, (ii) defining a new measure for the strength of resource dependency, and (iii) formulating an innovative capacity acquisition model that includes relevant factors for resource dependency in sufficient computational detail for a practical application. We show the importance of

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evaluating resource dependency and the inefficiency of investment decisions if it is ignored. Furthermore, over time, as investments accumulate, the impacts of ignoring resource dependency can get amplified. Thus, a risk averse power company facing carbon policy risk and looking only at the project may delay and await clarity on new technology costs and low carbon subsidies, whilst a company looking at synergies with its resource base, may choose to act sooner and create a policy-hedged portfolio. For firms, therefore, accounting for the resource dependency provides a better understanding of the asset synergies in risk mitigation and improves optimal capacity planning. For policy makers, a misleading view of market evolution can occur if resource dependency is not considered.

Our motivation for this research follows from the various market interventions that many governments have made to incentivize sustainable and low carbon technology innovations. In formulating such incentives in deregulated markets, policy makers need to understand how the participants might respond. Likewise, market participants as investors need to understand how performance in the product markets might evolve under policy risks and business risks, as well. With these perspectives in mind, our analysis is first structured in a formal way that establishes a theoretical foundation for the concept of resource dependency in capacity acquisition. We then apply this concept in a computationally intensive formulation, and develop a capacity investment optimization model with features that account for the resource dependency in both investment and operating decisions. The model is a stochastic mixed integer optimization model with a probabilistic objective function, where the integer variables are for investment selection decisions, real valued variables for operating decisions, and a probabilistic objective function captures the risk aversion. We solve the optimization problem by decomposing it into investment and operational horizon subproblems. This is done by optimizing the operational performance for new and existing resources at different times and states of the investment horizon first and then, subject to this, optimizing the investment choice and timing. By decomposing the problem this way, it becomes computationally tractable and facilitates experimental insights into our resource dependent case study.

In operations research, the capacity investment problem under uncertainty has been considered in many studies using mathematical programming models (see the review by Martinez-Costa, Mas-Machuca, Benedito, & Corominas (2014)). Thus, Dangl (1999) investigates capacity investment under demand uncertainty and the impact of flexibility to delay an investment. He shows using a dynamic programming model that demand uncertainty results in more capacity and that even small uncertainty causes the investment to be delayed. Harrison and Van Mieghem (1999) study capital investment decisions under demand uncertainty including both investment and production decisions. They derive optimal investment policies and show that the invested capacity is almost never fully utilized under the realized demand levels. Eppen, Martin, and Schrage (1989) develop a capacity planning model under demand uncertainty where the amount of capacity, location, and type of facilities are being decided. They emphasize the importance of accounting for risk aversion via using a downside risk measure. The importance of accounting for the risk, and how it can be hedged, is also articulated in the review paper of Van Mieghem (2003). More recently, Yang and Ng (2014) examine the capacity acquisition problem including production decisions under demand uncertainty and financial budget constraints, deriving optimal investment policies as a function of unit capacity costs.

Our approach is distinct from all those themes of work by focusing upon the impacts of existing resources on new capacity investment decisions. Particularly, we consider the impacts of existing (i) tangible resources (the number and type of existing capital assets), (ii) intangible resources (existing capital asset financing arrangements), and (iii) operating conditions (magnitude of uncertainties and flexibility in the timing of the new investment). We undertake this whilst considering uncertainties during both the investment and operating horizons. We thereby include decisions about the technology type and timing of the investment as well as operating and financing decisions for the new and existing plants. Our case study from the electricity sector offers a rich context with substantial policy risk and with strong asset specificity effects in that different kinds of technologies (e.g., nuclear, coal, gas, wind) vary in their operational risks, capital intensity, and exposure to carbon emission policies. Also, the power plants are long-lived and thereby create a sequence of large, lumpy acquisitions.

Modeling capacity investment in the power sector has been a major field of methodological innovation with large-scale decomposition techniques, stochastic methods, and real options analysis being well represented. Thus, Parpas and Webster (2014) develop a stochastic optimal control model to couple both the long-term power plant investment and short-term operations decisions. They show that the problem can be solved using a dimensionality reduction technique stemming from perturbation theory. Sen, Yu, and T-Genc (2006) formulate a stochastic programming model for the power plants' unit commitment problem including long-term decisions about the financial power contracts. They demonstrate that the problem can be solved by decomposing the problem using nested column decomposition approach into a master problem, a coordination problem for financial contracting, and a generation problem. Epe et al. (2009) model a regional power generation system as a multistage stochastic programming problem including a long-term planning horizon with short-term operational decisions. They employ recombining scenario trees and decompose the problem using nested Benders decomposition. Our formulation extends this context of work with an emphasis upon risk, resource dependency, and computational intensity.

The paper is structured as follows. In Section 2, we formalize the resource dependency due to risk aversion and develop the optimization model that makes the investigation of the resource dependency amenable. Section 3 describes the power sector context where the model is applied and presents analysis of the computational results. Finally, in Section 4 we conclude.

2. Risk induced resource dependency

We begin by presenting a general utility function for risk averse resource acquisition, Section 2.1. From this, in Section 2.2 we develop theoretical properties for resource dependency. We first consider the situation in which the investment decision has to be made without flexibility to delay, and then look at the flexibility to delay the investment decision in Section 2.3.

2.1. Utility function for risk averse resource acquisition

We formalize in this section the utility function used to assess the value of each resource acquisition alternative $\omega = 1, \ldots, G,\ G \in \mathbb{Z}^+$ with existing resources $\Omega \in \mathbb{Z}^+$. We denote the random value of a new resource alternative as ζ_ω, $\omega = 1, .., G,$ random value of existing resources as ζ_Ω, and the utility of a new resource with existing resources as $U[\zeta_\omega + \zeta_\Omega]$. The utility is a function of both expected value of new and existing resources, i.e., $\mathbb{E}[\zeta_\omega + \zeta_\Omega]$, and their risk, i.e., $R[\zeta_\omega + \zeta_\Omega]$. The risk aversion factor, $\lambda \in (0, 1)$, captures the associated risk aversion the uncertainty may induce. When λ approaches 0 and 1, we have risk neutral and risk averse decision makers, respectively.

$$U(\zeta_\omega + \zeta_\Omega) = (1 - \lambda)\mathbb{E}[\zeta_\omega + \zeta_\Omega] - \lambda R[\zeta_\omega + \zeta_\Omega] \quad (1)$$

The resource acquisition selection problem is thus $\max_\omega U$.

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