Merchant Storage Investment in a Restructured Electricity Industry

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Overview

Restructuring and liberalisation of the electricity industry creates opportunities for storage investment (Denholm et al., 2010), which could be undertaken by a profit-maximising merchant storage operator. Because such a firm is concerned solely with maximising its own profit, the resulting storage-investment decision may be socially suboptimal (or detrimental). Most of the literature on storage, however, overlooks the investment decision and does not analyse how market structure may affect installed storage capacity and social welfare. For example, the stylised equilibrium models of Sioshansi (2010, 2014) investigate the welfare implications only of storage operations, whereas the application of an equilibrium model to a network-constrained test power system focuses on the consequences of storage operations for grid congestion and generation ramping (Virasjoki et al., 2016). While Nasrolahpour et al. (2016) incorporate the storage-investment decision, they assume a perfectly competitive generation sector and do not conduct a welfare analysis. Thus, we fill an important gap in the literature by exploring the welfare implications of storage investment in an imperfectly competitive generation sector. In particular, we specify the market conditions under which a profit-maximising merchant invests in less storage capacity than the socially optimal level. The welfare and storage-capacity investment implications of imperfect generation competition are assessed. Furthermore, given the importance of ramping in electricity markets (Zhao et al., 2017), we demonstrate how a ramping charge could incentivise a merchant investor to install the socially optimal storage capacity.

Methods

We develop a bi-level programming model of an imperfectly competitive electricity market with electricity-generation and storage-operations decisions at the lower level and storage investment at the upper level (Figure 1). Proceeding via backward induction, we first solve for the lower-level Nash-Cournot equilibrium between generation (conducted by N identical firms, where higher N indicates a more competitive industry) and storage operations (handled by the storage owner) parameterised on the storage capacity. We next insert the parameterised lower-level solutions into the upper-level objective function to obtain a closed-form expression for the optimal storage capacity. The storage owner behaves as a Stackelberg leader since it anticipates market operations when making its capacity-investment decision and can be either a standalone profit-maximising merchant or a welfare-maximiser. Thus, the bi-level problem is solved as a mathematical program with equilibrium constraints (MPEC).

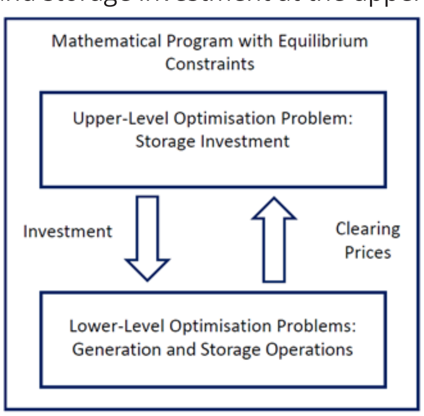


Figure 1. Market Structure

Results

Our analytical results demonstrate that a relatively high (low) amount of market power in the generation sector leads to low (high) storage-capacity investment by the profit-maximising storage operator (in blue) relative to the welfare-maximising storage owner (in green, Figure 2). Intuitively, this is because the welfare-maximiser uses a large storage capacity to subvert the generators' strategy of withholding generation by moving energy to the on-peak period. Conversely, the profit-maximising merchant is content to profit from the high price differential that results from the generators' behaviour. This can result in net social welfare losses with a profit-maximising storage operator (in blue) compared to a no-storage case (Figure 3). In fact, if the generation sector is sufficiently competitive, then the behaviour

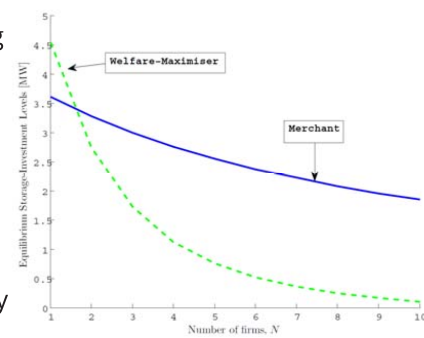
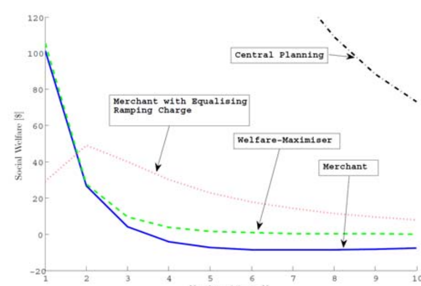


Figure 2. Equilibrium Storage-Investment Levels of Profit- and Welfare-Maximising Storage Owners



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of the profit-maximising merchant is actually welfare-diminishing *vis-à-vis* having no storage at all. Using a charge on generation ramping between off- and on-peak periods, we induce the profit-maximising storage owner to invest in the same level of storage capacity as the welfare-maximiser (Figure 4). The ramping charge penalises generators and the storage operator for a large difference in the off- and on-peak load, thereby mitigating the incentives of storage and generation firms to maintain large price differences between the two periods. Increasing either the storage-investment cost or the marginal cost of generation reduces the equalising ramping charge. Such a ramping charge can increase social welfare (Figure 3, in red) above the levels attained with the welfare-maximising storage owner (Figure 3, in green) because the equalising ramping charge offers another layer of control to a hypothetical social planner. This added control allows the social planner to mitigate the potential welfare losses from inefficient storage use and withholding of capacity by generators.

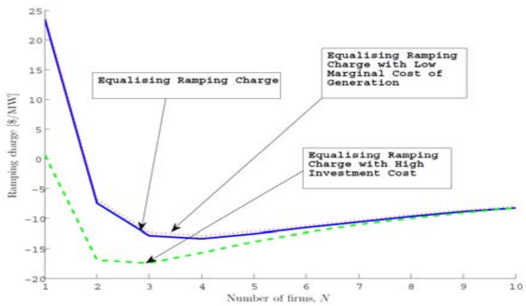

Figure 4. Ramping Charge that Induces Socially Optimal Storage Investment from Profit-Maximising Storage Owner

Conclusions

We contribute to the literature studying the welfare impacts of energy storage by examining the equilibrium level of storage investment under a variety of market structures. By taking a stylised approach, we are able to unpick methodically the countervailing incentives driving storage investment, e.g., the tradeoff between profit margin and trading volume. Hence, the policy insights stemming from our analysis can be used by regulators to align better the incentives of a profit-maximising storage owner with those of society.

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Plenary Session 2: Electricity Market Design

Summarized by Höschle Hanspeter, Researcher - Energy Markets, Unit Energy Technology, EnergyVille – VITO NV

This plenary session was chaired by Bert Willems, Tilburg University, The Netherlands. He was joined by William W. Hogan, Raymond Plank Professor of Global Energy Policy, John F. Kennedy School of Government, Harvard University, USA; Andreas Ehrenmann, Director Energy Economics, Engie Tractebel and Clara Poletti, Head of the Regulation Department, The Regulatory Authority for Electricity Gas and Water, Milan, Italy.

The second day of the conference kicked off with a insightful plenary session on electricity market designs, comparing common practice of US and European markets. In his introduction, prof. Bert Willems (Tilburg University, NL), highlights that the purpose of prices is to reflect all market information, at the same time, he raises the question how prices could possibly reflect reserve requirements in future RES-dominated electricity systems.

From the experience in US markets, prof. William Hogan (Harvard University, USA) argues that getting the market signals in real-time is key. An economic dispatch that includes an operating reserves demand could emphasize the value of scarcity, correct real-time prices and consequently ensure a proper working of all preceding markets (e.g. intraday, day-ahead, year-ahead, etc.).

In response to that, Andreas Ehrenmann (Chief Analyst at Engie, FR) emphasizes the difference to European real-time markets that are not based on an economic dispatch but balancing markets organized by the TSO. He extends the discussion by arguing that even if real-time price signals are correct, a possibility for risk-trading for risk-averse investors would be vital to support the transition.

Clara Poletti (Head of Regulation Department, ARERA, Italian NRA) sees the need for the development of a market that integrates the role of RES. She describes the benefits of the Italian design, including Reliability Options, as the combination of a long-term market signal for investment, at the same time allowing for scarcity pricing in real-time, which is crucial for a proper reaction of demand and RES.

The conclusive discussion addressed again the importance of market price signals to reflect the cost of reserve, even more so with the integration of more and more RES.