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 realistic test network 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, this paper fills 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. 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.

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 1***). 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 2***). In fact, if the generation sector is sufficiently competitive, then the behaviour 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, R^*, we induce the profit-maximising storage owner to invest in the same level of storage capacity as the welfare-maximiser (***Figure 3***). 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 cost, I, or the generation cost, B, reduces R^*. Such a ramping charge can increase social welfare (***Figure 2***, in red) above the levels attained with the welfare-maximising storage owner (***Figure 2***, in green) because R^* 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.

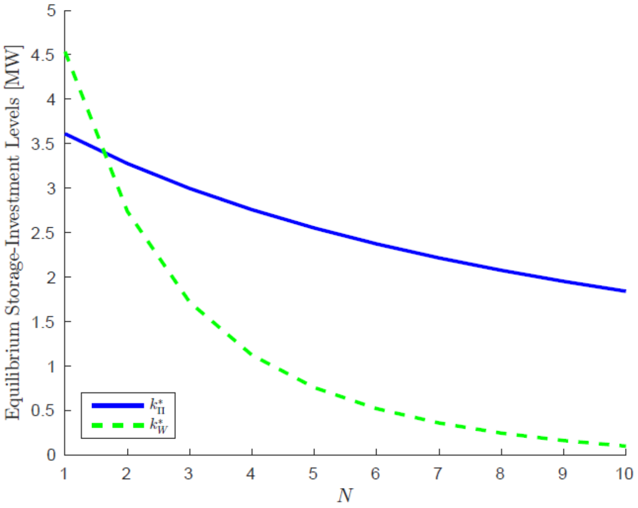

Figure 1. Equilibrium Storage-Investment Levels of Profit- and Welfare-Maximising Storage Owners

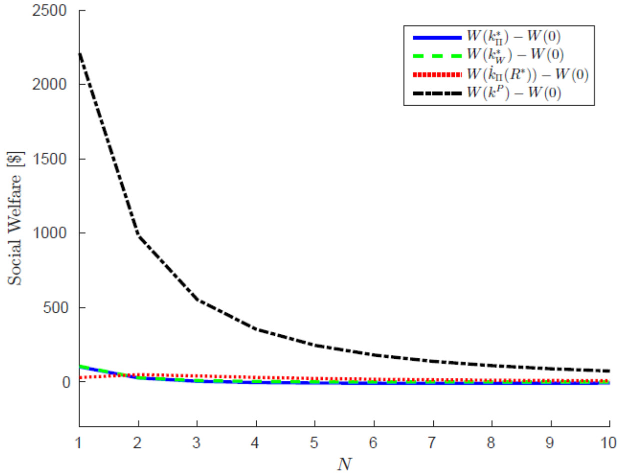

Figure 2. Change in Social Welfare under Different Storage-Investment Equilibria Relative to No-Storage Case

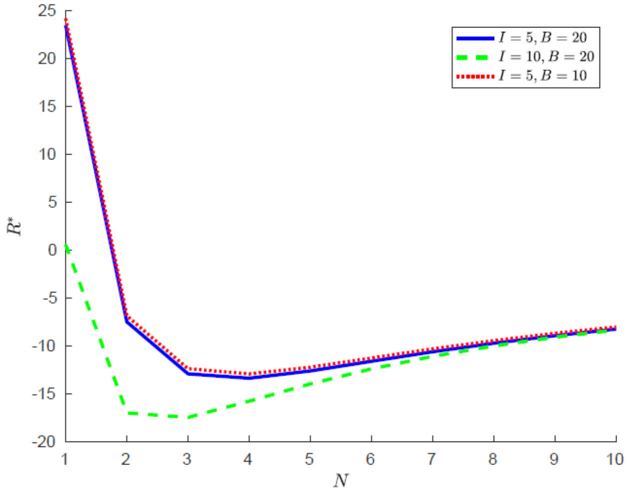

Figure 3. Ramping Charge that Induces Socially Optimal Storage Investment from Profit-Maximising Storage Owner

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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