Merchant Storage Investment in a Restructured Electricity Industry

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Executive summary

Traditionally, energy storage has been viewed as an alternative to peak generation. Indeed, much of the pumped hydroelectric storage that was constructed in the 1970s was intended to function as a substitute for peak generation. However, restructuring and liberalisation of the electricity industry has created opportunities for profit-maximising (rather than welfare-maximising) storage investment. At the same time, an imperfectly competitive generation sector alters the welfare impacts of storage investment because energy storage could be used strategically to manipulate equilibrium prices. Thus, the incentives of a profit-maximising merchant investor are not likely to be aligned with those of a welfare-maximising investor and may lead to different welfare outcomes.

We explore the welfare implications of storage investment in an imperfectly competitive generation sector and specify the market conditions under which a profit-maximising merchant invests in less storage capacity than the socially optimal level. In particular, we develop a bi-level 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 and storage operations (handled by the storage owner) given the storage capacity. We next insert the parameterised lower-level market equilibrium 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 because it anticipates market operations when making its capacity-investment decision and can be either a standalone profit-maximising merchant or a welfare-maximiser.

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 relative to the welfare-maximising storage owner. Intuitively, this is because the welfare-maximiser uses a large storage capacity to subvert the generators' strategy of withholding generation by discharging stored 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 compared to a no-storage case. 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, we can induce the profit-maximising storage owner to invest in the same level of storage capacity as the welfare-maximiser. 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. Such a ramping charge can increase social welfare above the levels that are attained with the welfare-maximising storage owner because it offers another layer of control to a hypothetical social planner. The ramping charge allows the social planner to mitigate the potential welfare losses from inefficient storage use and the withholding of production by generators.

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We contribute to the literature studying the welfare impacts of energy storage by examining the equilibrium level of storage investment. 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.

Keywords: energy storage; bi-level modelling; market power.

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