**Adjusting or shifting? - The economic differences between demand response and energy storages in a long-run equilibrium model**

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## Overview

With increasingly decarbonising electricity markets, the share of renewable energy rises, which comes together with a more volatile electricity supply. In electricity markets demand and supply have to be physically balanced in every point in time, thus calling for either flexible generators or flexible demand. This discussed need for flexibility is often economically and technical inaccurate or not sufficiently comprehensive. It is important to consider flexibility of demand in one single point in time and flexibility of demand between different points in time. The first is typically referred to price elasticity of demand whereas the latter can be either the cross elasticity of demand or a storage facility shifting electricity in time. A shortcoming of many existing analyses is the missing consideration and distinction between these two types of flexibility.

We build on several strands of literature: In many power system models (typical total system cost minimization problems) demand is assumed as inelastic or exogenuously given for every point in time. In such models energy storages or demand side management are included as an opportunity to (costly) shift energy through time. However, regardless of losses, this opportunity neither changes the total amount of electricity demand nor does it affect the elasticity of demand in that point of time (i.a. Bertsch et al., 2016). Contrarily, other publications assume the power demand to be elastic and treat the power system as welfare maximization problem (i.a. De Jonghe et al., 2012). This enables consumers to react on prices by adjusting their demanded quantity. In this setting, demand response is mainly attributed to the price elasticity of demand in every point in time. The ability of demand side management of shifting demand through time has similar characteristics compared to storage technologies such as batteries. This similarity is already acknowledged in current research (i.a. Geske, Green and Qixin, 2017). However, the impact of the underlying production and consumption schedules in demand shifting, which can often be characterized by asymmetric patterns, compared to a conventional storage is not analysed in detail, yet. Hence, the fundamental economic differences between these options for demand shifting as well as their differences to demand adjustments incorporated as demand elasticity need to be clarified in more detail.

We combine these existing approaches by formulating a welfare maximization problem with the possibility of endogenuous investment in demand response at a given point in time and energy storages and demand side management for shifting demand through time. By considering the asymmetric nature of production schedules in the industry we add a further aspect to the analysis of demand side management.

Our analysis therefore contributes to the existing literature by analysing the economic effects of demand response, both adjusting and shifting, as well as energy storages on electricity prices and the existence and stability of a long run equilibrium. We distinguish between demand adjusting and several forms of energy storages by focusing on the economic differences rather than the technological differences between these technologies and aim for answering two research questions: What is the difference between adjusting electricity demand in one point in time and shifting electricity demand through time? And: How to find a long-run equilibrium in an energy only market with a high share of renewables and storages?

## Methods

As we consider an elastic power demand, we model our power system as a welfare maximization problem incorporating the volatility of renewables production. Total welfare consists of consumer and producer surplus as long as the demand elasticity is not nil. If demand is inelastic welfare maximization is equivalent to the total system cost minimization problem. In such theroretic energy-only-market investment costs for capacity are recovered in hours with high residual demand and/or hours with less elastic demand. We allow for endogenuous investment in storage including demand side management for shifting energy demand through time and/or demand response for adjusting demand in one point in time. Demand side management additionally has to meet potentially asymmetric production schedules. We assume perfect competition and perfect foresight for all market participants. Corresponding electricity prices are calculated as marginal costs of the gerneration constraint. We thereby check if participation constraints hold for each market participant.

## Results

Demand elasticity reduces residual load in peak price hours and hence, implies lower peak prices in that particular hour. In order to cover the fixed costs of the system, prices rise above marginal costs in more hours. The higher the elasticity of demand, the more hours with prices above marginal costs occur. Hence, demand response in terms of an elasticity value limits the possibility of peak prices in the long-run equilibrium. Shifting demand through time mainly reduces the volatility of prices as it smoothes the stochastic infeed of renewable energies. Whether to invest in a storage technology that enables the shifting of demand crucially depends on the demand elasticity and shifting ability in peak price hours. For demand side management technologies the asymmetric production schedules can significantly restrict their shifting potential in these particular peak price hours. Furthermore, the asymmetric schedules affect the price effect and the number of hours in which demand side management changes the electricity price.

## Conclusions

With an increasing share of renewables, market partizipation of demand-side technologies becomes more important than in the historic energy system with mainly conventional power plants. Therefore, we analyse the fundamental economic differences between adjusting demand in one point in time compared to shifting demand through time by either applying storage technologies such as batteries or demand side management such as flexible industry processes. We find that both the availability of demand adjustment and demand shifting bound the peak prices to a lower level. However, these lower peak prices occur more often such that investments can still be refinanced in a long-run equilibrium. Understanding the economic effect of demand elasticity and demand shifting is crucial for current debates in electricity market reforms, for example the European discussion on the optimal size of market bidding zones or on the necessity of capacity mechanisms for long-run investment decisions.

## References

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