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On the role of storage and demand response in shaping electricity prices and social welfare under different market settings.

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Agenda

- Goals and motivation
- Overview of the energy storage and this project
- Methodology
- Results and Conclusions

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3. provide comparisons of welfare effects and measure impact on market prices given different levels of elasticities of final customers
4. compare the advantages and disadvantages of implementing RTP tariff by contrasting it with a fixed tariff scenario.

Motivation

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By having storage facility, retail companies can not only reduce the cost of balancing mechanism but most importantly, **use it for profit maximization**.

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Demand response:

- Wolak et al. 2001, Borenstein 2005 - shortages, blackouts - one of the main things to blame is the absence of reliable demand response program
- Andruszkiewicz et al. 2021, Nicolson et al. 2017 - developing new methods to estimate elasticity of domestic customers. Survey - a third of British customers are willing to turn into flexible tariffs.

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- Ekholm & Virasjoki 2020; Williams & Green 2021 - equilibrium models with storage, effects of storage on private and social returns.

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- By dropping the assumption of inelastic consumers' demand as we base our model on RTP where customers directly react to changing prices;
- We equip retailer with storage as a way of maximizing profits and let all domestic customers face RTP tariff;
- We compare the effects of storage in RTP and fixed tariff;
- We contrast the findings of price-taking retailer with the alternative case when the energy provider has market power.

Methodology

This paper presents a dynamic optimization model to find hourly equilibrium in a market with single retailer that covers the demand for both industrial and domestic customers.

We present a comparison of scenarios without storage in the market as well as a case where retailer uses storage for profit maximization in the domestic market.

We also consider possible market power of the retailer.

The welfare function for one cycle (a day) is given by gross consumer surplus (the integral - total willingness to pay) less retailer's cost of providing electricity summed over 24 hours.

$$\max_{D_t, G_t, r_t^c, r_t^d, R_t} W = \sum_t \left(\int_0^{D_t} \frac{a_t - \delta}{b} d\delta - F(G_t) \right) \tag{1}$$

Subject to:

$$r_t^c \leq s^c \quad \forall t$$

$$r_t^d \leq s^d \quad \forall t$$

$$R_t \leq s \quad \forall t$$

$$D_t + r_t^c = G_t + r_t^d \quad \forall t$$

$$R_0 = R_T$$

$$R_t = R_{t-1} - r_t^d + r_t^c \times \eta \quad \forall t$$

$$D_t, R_t, G_t, r_t^c, r_t^d \geq 0 \quad \forall t$$

- Time varying demand function has the following linear form:

$$D_t = a_t - b \times PR_t \tag{2}$$

- Retailer's cost function:

$$F(G_t) = \gamma \times (G_t)^2 \tag{3}$$

- Profit from storage operation:

$$\pi = \sum_t \left(PW_t \times r_t^d - PW_t \times r_t^c \right) \tag{4}$$

For the market power case:

$$\max_{D_t, G_t, r_t^c, r_t^d, R_t} W = \sum_t \left(\int_0^{D_t} \frac{a_t - \delta}{b} d\delta - F(G_t) - \frac{1}{2}\gamma(G_t)^2 \right) \quad (5)$$

We add one term $-\frac{1}{2}\gamma(G_t)^2$ to capture the impact of market power that includes the effects of charging and discharging - retailer buying more electricity for storage purposes increases its output and conversely, while discharging, it buys less electricity that it would without storage.

Input data and model setting

- Data encompasses demand and wholesale price of a typical summer day in 2017 for the UK market and is taken from European association for the cooperation of transmission system operators (ENTSO-E).

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- We compare results with separate cases of different power and storage capacities: 500MWh/3GWh, 500MWh/5GWh and 800MWh/5GWh. Storage efficiency is set at the level of 90%.

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Results

Impact of storage in RTP tariff

Profit of the Storage			
	500MW/3GWh	500MW/5GWh	800MW/5GWh
Price- Taker	79,263	85,043	126,249
Market Power	101,341	108,732	161,416

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Price- Taker	79,263	85,043	126,249
Market Power	101,341	108,732	161,416

	No storage	500MW/3GWh	500MW/5GWh	800MW/5GWh
Change in consumer surplus				
Price-taker	0	31,309	32,970	51,864
Market Power	-3,941,532	-3,911,859	-3,910,538	-3,891,985
Change in MP	0.00	29,673	30,994	49,547

	No storage	500MW/3GWh	500MW/5GWh	800MW/5GWh
Change in welfare				
Price-taker	0	81,190	87,480	131,420
Market Power	-6,792,740	-6,770,120	-6,680,890	-6,624,720
Change in MP	0.00	103,810	111,850	168,020

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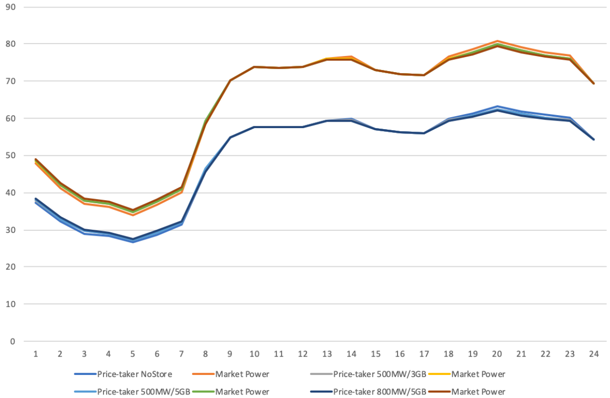
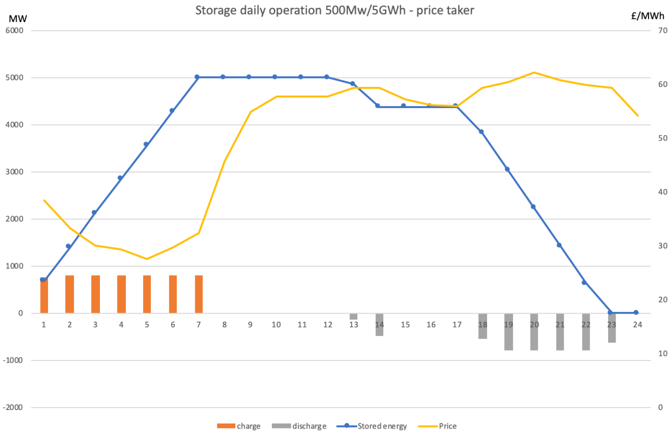
Impact on prices



Example of a daily storage schedule of storage as a price taker and capacity of 800MW/5GWh



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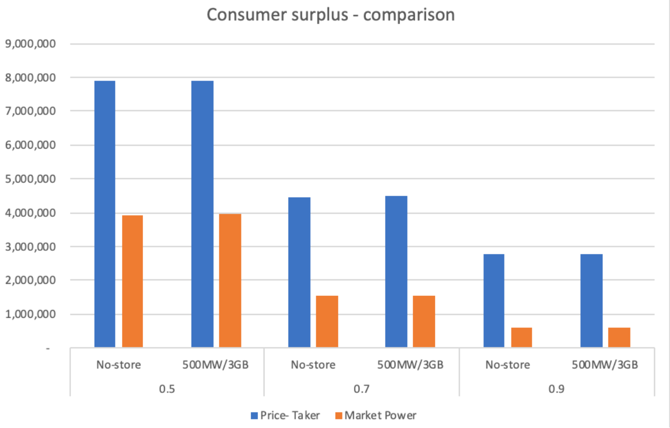
Impact of storage across different levels of domestic elasticity



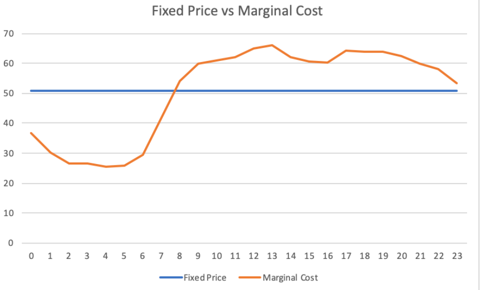
Average electricity prices across different levels of elasticity.

Prices across different elasticities												
Price - taker												
elasticity	***-0.5***				***-0.7***				***-0.9***			
	Daily	Peak	Off-Peak	St. dev.	Daily	Peak	Off-Peak	St. dev.	Daily	Peak	Off-Peak	St. dev.
No storage	49.90	58.7	39.5	13.27	48.7	57.2	38.6	13.03	47.7	55.9	37.9	12.8
500MW/3GWh	49.9	58.5	39.7	13.3	49	57	39	12.63	47.7	55.74	38.2	12.44
Market Power												
elasticity	***-0.5***				***-0.7***				***-0.9***			
	Daily	Peak	Off-Peak	St. dev.	Daily	Peak	Off-Peak	St. dev.	Daily	Peak	Off-Peak	St. dev.
No storage	63.80	75	50.5	16.97	61.12	71.8	48.5	16.35	58.9	69	46.8	15.8
500MW/3GWh	63.8	74.6	50.8	16.4	61	71.6	48.8	15.8	58.9	68.9	47.15	15.37

Impact of storage on CS across different elasticities (comparison with no-storage case)

Change in CS solely due to the storage unit (comparison with no-storage CS)			
elasticity	***-0.5***	***-0.7***	***-0.9***
Price- Taker	0.4%	0.6%	0.9%
Market Power	0.8%	1.5%	3.1%

Level of prices throughout the day in fixed and RTP tariff



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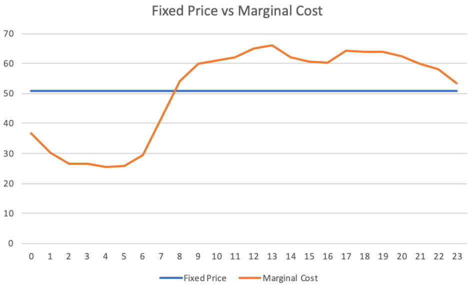
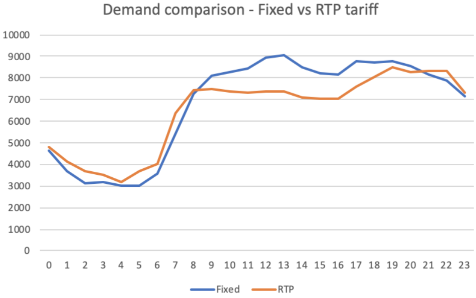


Demand levels in fixed and RTP tariff



Comparison of consumer surplus, welfare and total daily demand across tariffs and storage/no-storage

No Storage			
	Consumer Surplus	Welfare	Total demand
RTP	-	-	-
Fixed	up by 10%	down by 1%	up by 3%
Storage - 500MW/3GWh			
	Consumer Surplus	Welfare	Total demand
RTP	-	-	-
Fixed	up by 10%	down by 1%	up by 3%

Conclusions

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3. Profit gains are possible by exploiting arbitrage in electricity price differences.

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2. We conclude that storage operation generates positive returns for both private and social sectors by creating profits or by positively impacting consumer surplus and general welfare.
3. Profit gains are possible by exploiting arbitrage in electricity price differences.
4. The findings show that storage has strong positive effect on welfare especially in a competitive environment.

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2. In a price-taker case, for relatively small storage, the impact of storage on price is very limited. Hence, profit and welfare maximization goals are matched and increase with additional storage capacity until it reaches the point where size of the storage triggers price effects.
3. We also found out that growing price elasticity of demand may not necessarily bring ubiquitous benefits.

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Future research: Equipping final customers with storage devices seems as the logical next step in storage exploration. Measuring the welfare effects and changes in elasticity caused by this process leaves the room for further research.

Thank you