ETH zürich

Power Systems Laboratory

Optimal Fixed Charges for Future Electricity Tariffs

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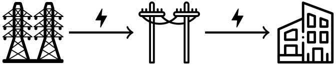
Joint work with Gabriela Hug
Workshop on Future Electricity Tariffs
Florence School of Regulation
21st June 2023

Outline

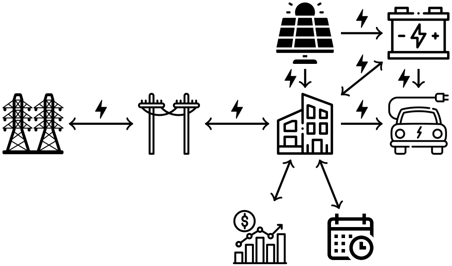
1. Motivation and Context
2. Model
3. Case study data
4. Results: optimal fixed charges for the transition
5. Conclusion

Distribution grid at the energy transition era

Before:



Now:

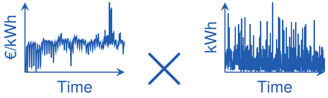


Bottom line in this context: Necessity to make tariffs more **cost reflective**.

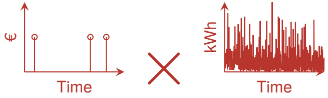
Make tariffs more cost reflective

In theory, 3 components in an efficient retail tariff:

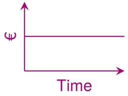
1. Fully **granular** distribution electricity **price** (location & time)



2. Forward-looking peak-coincident charge (scarcity price on grid infrastructure)



3. Fixed charge (independent on consumption) to recover residual DSO costs



Challenges

Every compoment leads to significant challenges:

Granular price	Peak-coincindent charge	Fixed charge
Risk for prosumers	Variable	**Fairness**
Location differentiation	Hard to forecast	**Risk of grid defection**

In this work:

1. We develop a model that describes this ideal pricing.
2. Focus on the description of the equilibrium, not how to reach it.
3. Discuss the implications regarding fixed charges.

Outline

An economic long-term equilibrium problem

Consumers:

$$\max \ \text{Utility from consuming electricity}$$
$$\text{s.t. Consumption limit}$$

Prosumers:

$$\max \ \text{Utility} - \text{Investment costs}$$
$$\text{s.t. Consumption and production limits}$$

DSO:

$$\max \ \text{Revenue from selling electricity} - \text{Costs of electricity on wholesale market} - \text{Investment costs in infrastructure}$$
$$\text{s.t. Technical grid constraints}$$

Walrasian market operator (regulator):

Determine prices such that market clears

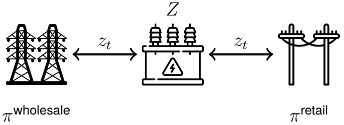
The DSO utility maximizing problem

Simplest model of a DSO:

$$\max \sum_{t \in T} (\pi_t^{\text{retail}} - \pi_t^{\text{wholesale}}) z_t - C^z Z$$

$$\text{s.t. } Z - z_t \geq 0, \quad [\beta_t^+]$$

$$Z + z_t \geq 0, \quad [\beta_t^-]$$



The DSO optimality conditions

$$z_t \text{ free } \perp -\pi_t^{\text{retail}} + \pi_t^{\text{wholesale}} + \beta_t^+ - \beta_t^- = 0$$

$$0 \leq Z \perp C^z - \sum_t \beta_t^+ - \sum_t \beta_t^- \geq 0$$

$$0 \leq \beta_t^+ \perp Z - z_t \geq 0$$

$$0 \leq \beta_t^- \perp Z + z_t \geq 0$$

- Granular price (π_t^{retail})
- Peak-coincident charge (β_t^+, β_t^-)

$\rightarrow$ In the nicest case (convexity, perfect competition), we recover the two first element of the ideal pricing.

What about fixed charges?

They come from one of the imperfection, namely non-convexity, due to fixed costs or lumpy infrastructure investment.

In the simplest form:

$$
\begin{aligned}
\max \quad & \sum_{t \in T} (\pi_t^{\text{retail}} - \pi_t^{\text{wholesale}}) z_t - C^z Z u \\
\text{s.t.} \quad & Zu - z_t \geq 0, \quad [\beta_t^+] \\
& Zu + z_t \geq 0, \quad [\beta_t^-] \\
& u \in \{0, 1\}
\end{aligned}
$$

$\rightarrow$ We are now in the setting of **pricing with non-convexity**

IP pricing

- Possible to obtain an equilibrium by adding one commodity per indivisibility.
- Let u^* be the value of u at the social optimal.
- New "market clearing" constraint added:

$$u = u^* \quad [\rho]$$

$\rightarrow$ Problem: This leads to a trivial non revenue adequate solution.

Solution: connection variables for prosumers

Prosumer i's utility maximizing problems become:

$$\begin{aligned} \max \ & utility_i(x) \\ \text{s.t. } & x \in C(v) \\ & v \in \{0, 1\} \end{aligned}$$

where:

- $C(1) =$ feasibility set when prosumer is connected to the network.
- $C(0) =$ feasibility set when disconnected.

Applying IP pricing

Add a new "market clearing" constraint:

$$v_i = v_i^* \quad [\lambda_i]$$

- Fixed charge (λ_i)

The prosumer's problem becomes:

$$\max \ utility_i(x) - \lambda_i v_i$$
$$\text{s.t. } x \in C(v)$$

$\rightarrow$ This endogenizes the computation of fixed charges while accounting for grid defection.

Selecting a desirable solution

$\rightarrow$ Move to the dual space

$$\begin{aligned} \max \;& \text{Fairness measure}(\lambda) \\ \text{s.t. } & \rho + \sum_i \lambda_i = 0 \\ & \text{Dual welfare} \leq \text{Optimal welfare} \\ & \text{Dual constraints} \end{aligned}$$

where Fairness measure could be: $-\sum_i (\lambda_i - \frac{\sum_i \lambda_i}{|I|})^2$

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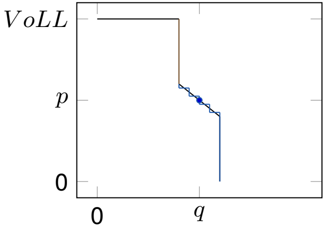
Representative synthetic distribution network in Switzerland

- Hourly load from 50 households, statistically representative of the population (based on LoadProfileGenerator, Noah Pflugradt)
- Rather high Swiss long-term elasticity (average of -1.35, Filippini (2011)) randomly distributed among households



- PV and Storage maximum capacity randomly distributed among household
- Wholesale prices taken from the results of Nexus-e

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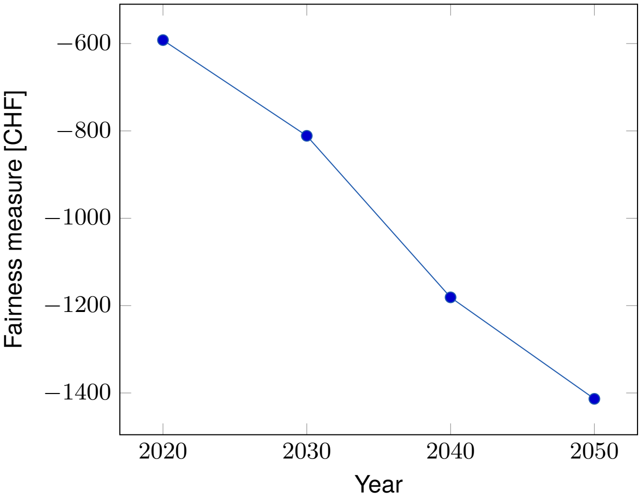
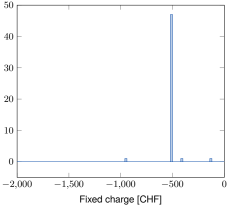
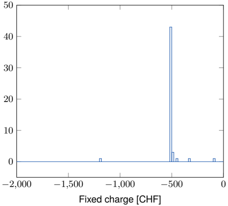
Fairness measure evolution



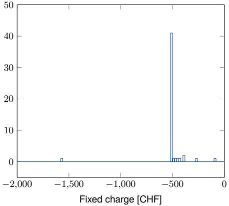
Fixed charge distribution



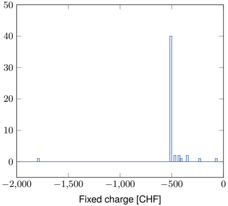
(a) 2020



(b) 2030



(c) 2040



(d) 2050

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Conclusion

Summary

- We build a model that computes the long-term equilibrium under ideal tariff.
- The model endogenizes the computation of fixed charges, accounting for grid defection and fairness.

Take-home messages

- Optimal fairness measure cannot be reached.
- Fairness decreases with unfolding of the energy transition.

Extensions and future work

- Explore other fairness measure.
- Introduce network constraints and investment.

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Thank you

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