ewi Institute of Energy Economics at the University of Cologne

ETCC ENERGY TRANSITION & CLIMATE CHANGE

Retail Unbundling and Tariff Design in Electricity Markets

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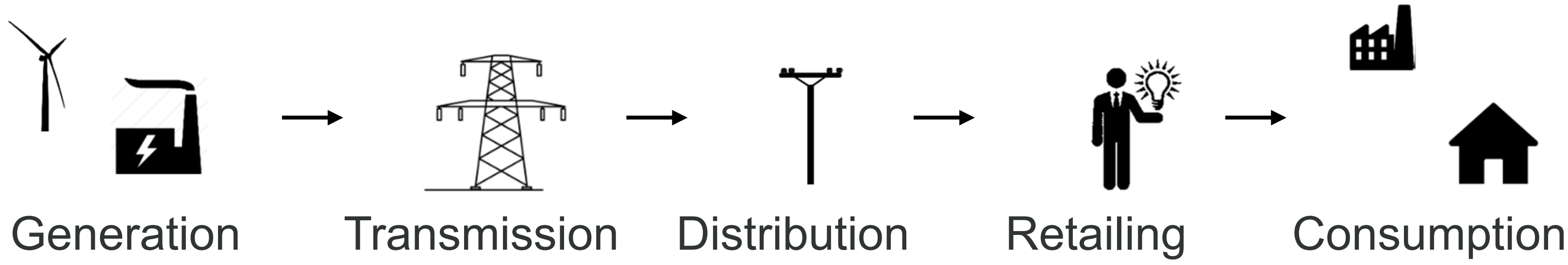
Content

Motivation



Liberalization

- The liberalization has lead to different vertical structures.
- There are different forms of regulation for retailers.

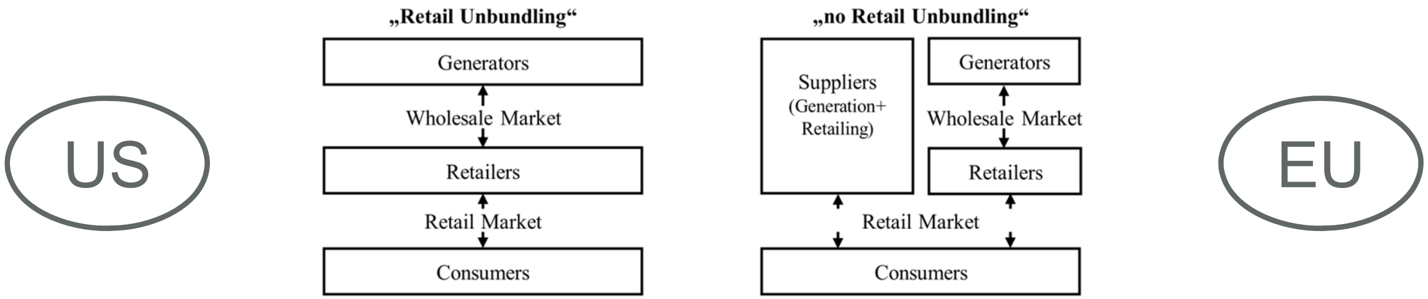
Decarbonization

- Recently, increasing shares of variable renewable generation (wind and solar) are transforming the electricity sector.

Tariff design

- In electricity markets, retail prices are mostly based on time-invariant pricing, especially for household consumers.
- Smart metering infrastructure would make real-time or time-of-use pricing possible.

Motivation



Literature on time-invariant pricing focusses on the case of retail unbundling

- **Borenstein, S. and Holland, S. (2005).** On the efficiency of competitive electricity markets with time-invariant retail prices.The RAND Journal of Economics, 36(3):469–493.
- **Allcott, H. (2012).** The Smart Grid, Entry, and Imperfect Competition in Electricity Markets. Working Paper 18071, National Bureau of Economic Research.
- **Pahle, M., Schill, W.-P., Gambardella, C., and Tietjen, O. (2015).** When Low Market Values Are No Bad News: On the Coordination of Renewable Support and Real-Time Pricing. Discussion Papers of DIW Berlin 1507

Open questions

- What is the efficiency loss from time-invariant pricing under no retail unbundling?
- What is the impact of renewables?
- What are the distributional effects?

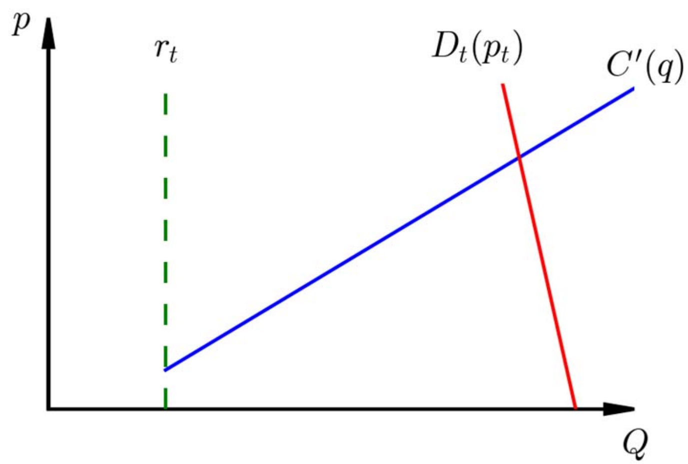
The Model

Demand side

- Demand function $D_t(p_t) = d_t - \varepsilon p_t$
- All consumers are either on real-time pricing at p_t or on time-invariant pricing at $\bar{p}$

Supply side

- Linear marginal costs of conventional power generation for quantity q
- Stochastic renewable generation of quantity r_t based on zero marginal costs
- → $C'(q) = a_0 + a_1(q - r_t)$



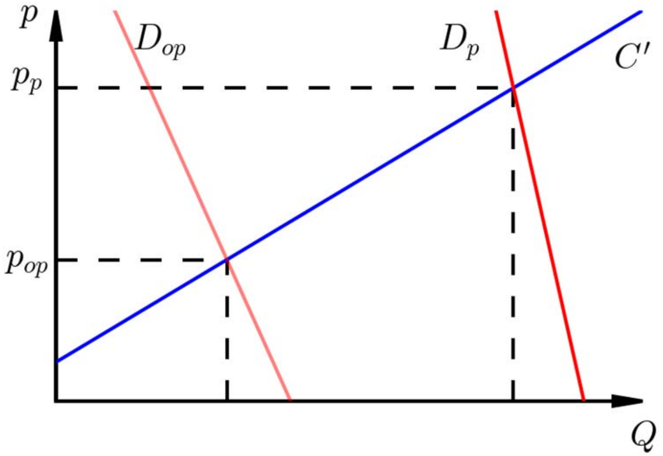
Focus: Perfect competition in the short-run

The Efficiency Loss From Time-invariant Pricing

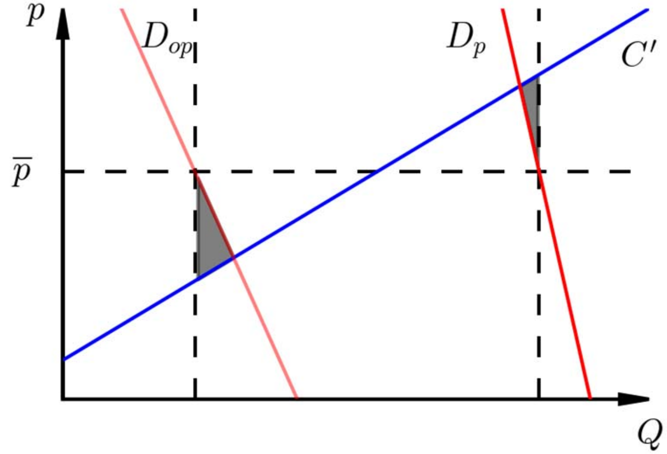
Example for **only conventional production** and **two demand situations** with

- high willingness to pay (peak→d_p)
- low willingness to pay (off-peak→d_{op})

Real-time Pricing



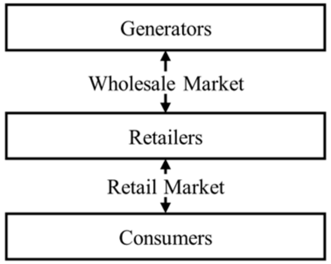
Time-invariant Pricing



- Time-invariant pricing leads to deadweight losses

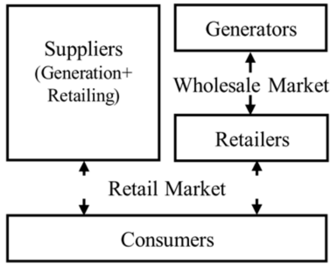
The Case of Retail Unbundling

Retail Unbundling

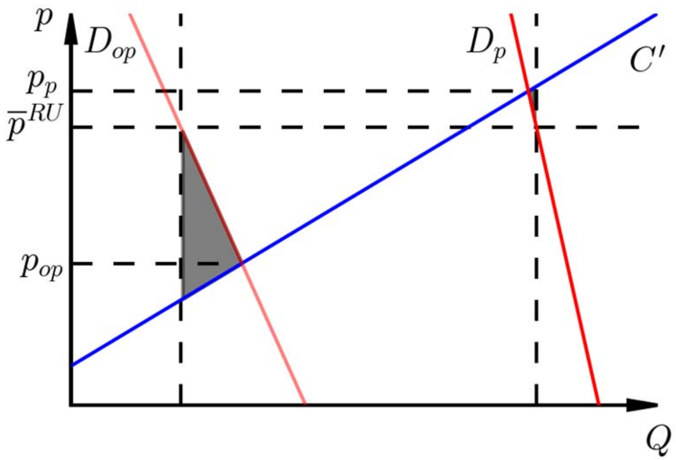


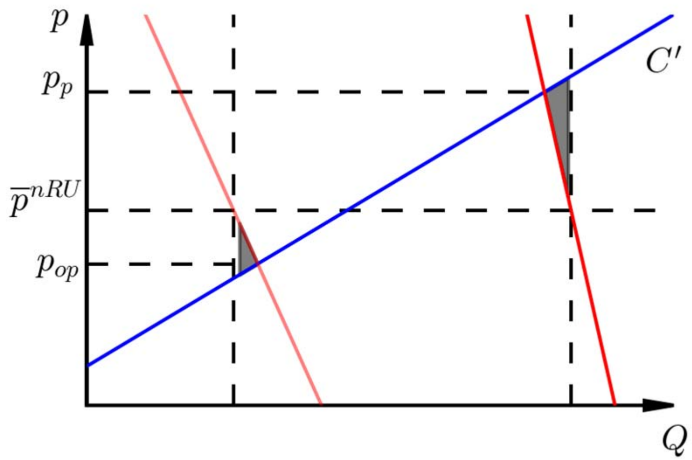
$$\overline{p^{RU}} = \frac{\sum_{t=1}^{T} p_t^{RU} D_t\left(\overline{p^{RU}}\right)}{\sum_{t=1}^{T} D_t\left(\overline{p^{RU}}\right)}$$

no Retail Unbundling



$$\overline{p^{nRU}} = \frac{\sum_{t=1}^{T} p_t^{nRU} D'_t\left(\overline{p^{nRU}}\right)}{\sum_{t=1}^{T} D'_t\left(\overline{p^{nRU}}\right)}$$



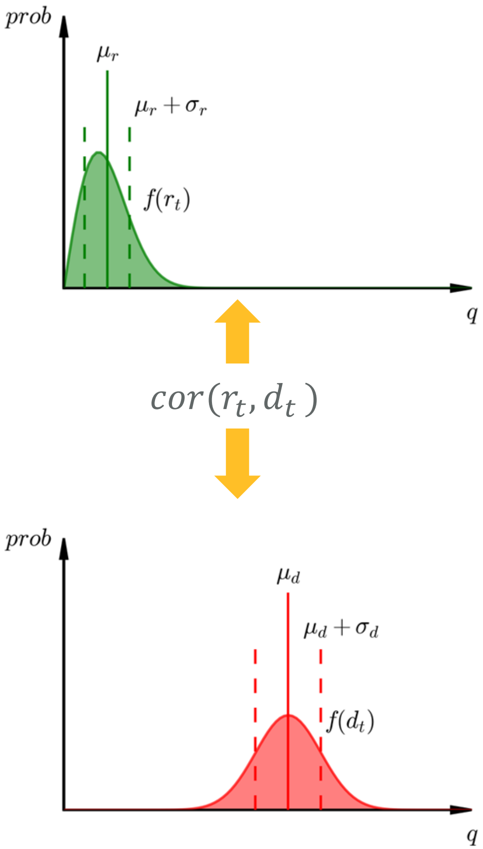


- The difference in prices stems from different averaging based on
  - quantities for RU
  - the gradient of the demand function for nRU
- Efficiency loss is greater under RU
- Consumers may be better off under nRU and TIP due to lower prices

The Efficiency Loss From Time-invariant Pricing

In reality we observe a continuous joint probability function of **renewable generation** (r_t) and **reference demand** (d_t)

$$f(r_t, \mathrm{d_t}) \sim (\mu_r, \sigma_r, \mu_d, \sigma_d, cor(r_t, d_t))$$



The welfare maximizing time-invariant tariff is given by

$$\bar{p} = \frac{1}{1 - a_1 \varepsilon}(a_0 + a_1(\mu_d - \mu_r))$$

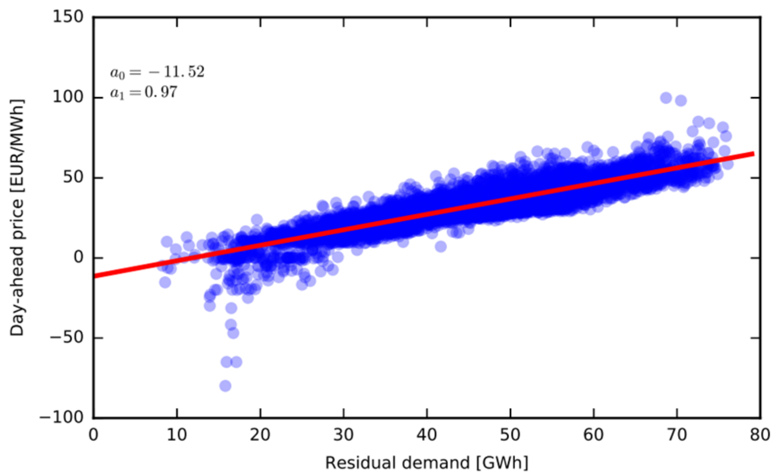
The deadweight loss induced by a time-invariant tariff amounts at least to

$$\Delta W = T \frac{a_1^2 \varepsilon}{2 a_1 \varepsilon + 2}\left(\sigma_d^2 + \sigma_r^2 - 2\sigma_r \sigma_d cor(d_t, r_t)\right)$$

An Illustrative Case Study for Germany

Based on data for 2015 we can evaluate the effect of time invariant tariffs.

- Load data from ENTSO-E
- Renewable generation from EEX Transparency
- Day-ahead prices from the EPEX Spot
- Additional charges c based on EUROSTAT for
  - Network 68.6 EUR/MWh
  - Taxes and levies 151.9 EUR/MWh



	Price [EUR/MWh]	Wind [GWh]	Solar [GWh]	Renewables [GWh]	Load [GWh]
Mean	31.6	9.005	3.985	12.990	57.679
Std	12.7	7.227	6.044	8.609	10.247

An Illustrative Case Study for Germany

The reference demand (d_t) and the level of demand response to prices (ε) are hard to access.

Example for $\varepsilon = 0.2 \frac{GWh^2}{EUR}$

Calculate the willingness to pay based on the observations for load:

$$d_t = Load_t + \varepsilon \cdot (\overline{p_{day-ahead}} + c)$$

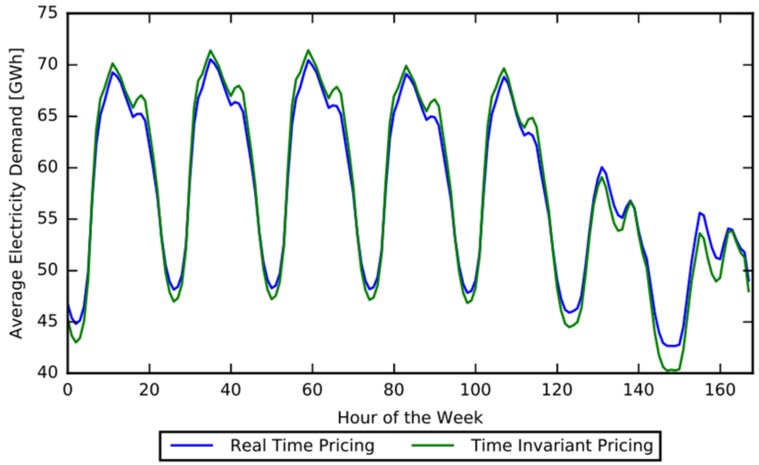
	Renewables [GWh]	Reference demand [GWh]
Mean	12.990	108.104
Std	8.609	10.247

Correlation: $cor(d_t, r_t) = 0.256$

$$\bar{p} = 252 \frac{EUR}{MWh}$$

$$\Delta W = 91.7\ Mio\ EUR$$

Time-invariant pricing leads to deadweight losses of 91.7 Mio EUR compared to real-time pricing.

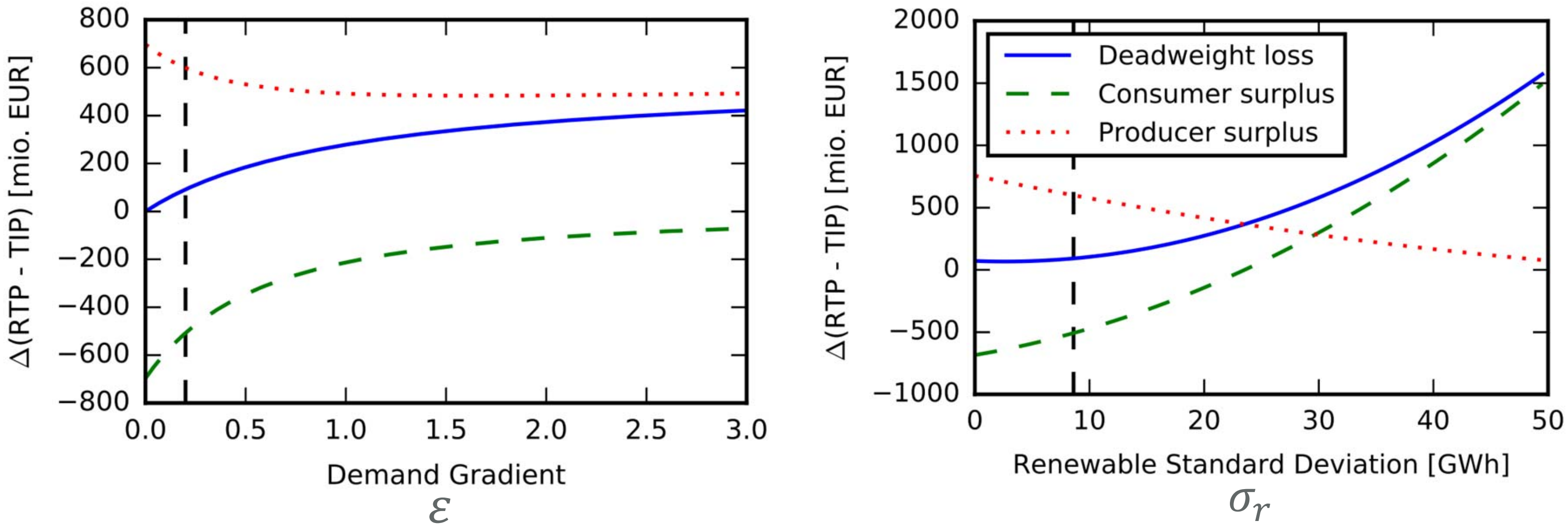


Average price elasticity of electricity demand is -0.088

$$\bar{p} = \frac{1}{1 - a_1\varepsilon}(a_0 + a_1(\mu_d - \mu_r))$$

$$\Delta W = T \frac{a_1^2\varepsilon}{2a_1\varepsilon + 2}\left(\sigma_d^2 + \sigma_r^2 - 2\sigma_r\sigma_d cor(d_t, r_t)\right)$$

An Illustrative Case Study for Germany



Distributional effects and **sensitivity analysis**

- Consumer surplus is higher under TIP compared to RTP.
- Deadweight losses increase if
  - consumers are more price responsive or
  - renewable standard deviation increases.

An Illustrative Case Study for Germany

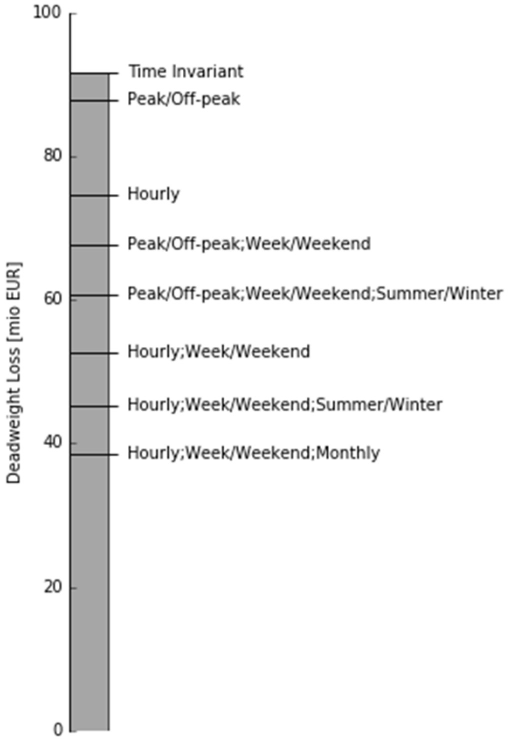
Time-of-use pricing

A time-of-use pricing scheme can reduce deadweight losses if

- the standard deviation of the reference demand (σ_d) in products is low,
- the standard deviation of the renewable generation (σ_r) in products is low,
- the correlation of reference demand and renewable generation withing one product is high.

	Unit	TIP	Peak	Off-Peak	Peak/ Week	Off-peak/ Week	Peak/ Weekend	Off-peak/ Weekend
$\overline{p}$	EUR/MWh	216.4	218.8	212.5	222.2	214.1	210.4	208.6
μ_d	GWh	64.0	69.2	55.4	73.2	57.2	59.1	51.0
μ_r	GWh	13.0	15.2	9.3	15.1	9.1	15.6	9.7
σ_d	GWh	10.2	8.5	6.4	5.9	6.1	5.1	4.8
σ_r	GWh	8.6	8.7	7.0	8.8	6.8	8.4	7.4
$\rho_{d,r}$	-	0.256	0.05	0.059	0.112	0.055	0.079	0.172
N	h	8760	5475	3285	3915	2349	1560	936
$\overline{p}$	EUR/MWh	216.4	218.8	212.5	222.2	214.1	210.4	208.6
ΔW_t	mEUR	91.7	60.2	21.8	30.9	14.5	11.0	4.8
ΔW	mEUR	91.7	82		61.2			

$$\Delta W = T \frac{a_1^2 \varepsilon}{2a_1\varepsilon + 2}\left(\sigma_d^2 + \sigma_r^2 - 2\sigma_r\sigma_d cor(d_t, r_t)\right)$$



Conclusion

- Time-invariant pricing (TIP) leads to deadweight losses.
- Retail unbundling increases deadweight losses under TIP.
- Consumers may be better off under TIP compared to real-time pricing (RTP).
- Deadweight losses depend on
  - the gradient of the supply curve (a_1),
  - the demand elasticity (ε),
  - the standard deviation of the reference demand (σ_d),
  - the standard deviation of renewable generation (σ_r),
  - the correlation of demand and renewable generation $cor(r_t, d_t)$.
- The derived model can be used for optimized tariff design, e.g. time-of-use (TOU) pricing.
- TOU pricing is only able to reduce deadweight losses by ~60%.
- TOU or RTP become more important with an increasing standard deviation of renewable generation.
- A deeper understanding of the demand side in electricity markets is essential for future tariff designs.

Thanks for your attention

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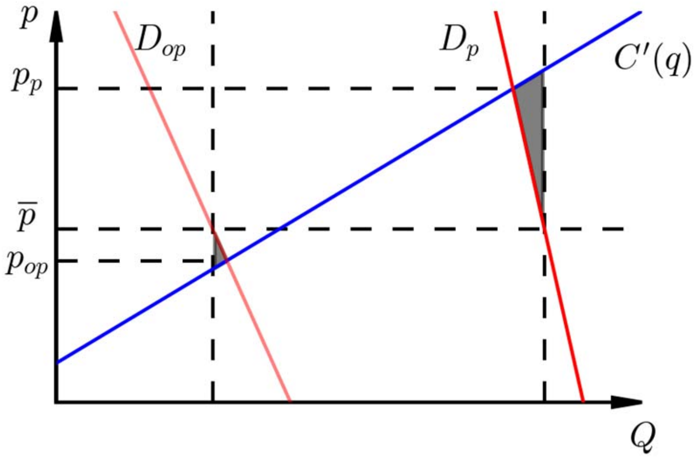
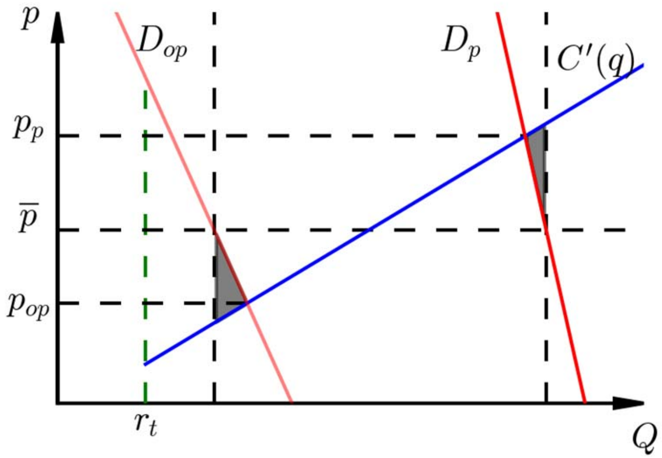
The Efficiency Loss From Time-invariant Pricing

Example for **two demand situations** and **two renewable production states**
- no renewable production
- renewable production of r_t

No renewable generation



With renewable generation



- Result for no retail unbundling (nRU)
- Renewable generation leads to
  - a reduction of the welfare maximizing time-invariant tariff ($\bar{p}$)
  - an increase of deadweight losses

Model settings

Retail Unbundling

Generator profit (RU): $$\Pi_G = \sum_{t=1}^{T} \left[w_t \tilde{D}_t(p_t, \overline{p}) - C\left(\tilde{D}_t(p_t, \overline{p}), r_t\right)\right]$$

Retailer profit (RU): $$\Pi_R = \sum_{t=1}^{T} \left[(\overline{p} - w_t)(1-\alpha) D_t(\overline{p}) + (p_t - w_t)\alpha D_t(p_t)\right] = 0$$

$$\overline{p}^{RU} = \frac{\sum_{t=1}^{T} p_t^{RU} D_t(\overline{p}^{RU})}{\sum_{t=1}^{T} D_t(\overline{p}^{RU})}, \text{ with } p_t^{RU} = C_q'(\tilde{D}_t(p_t^{RU}, \overline{p}^{RU}), r_t).$$

no Retail Unbundling

Supplier profit (nRU): $$\Pi_S = \sum_{t=1}^{T} \left[\overline{p}(1-\alpha) D_t(\overline{p}) + p_t \alpha D_t(p_t) - C\left(\tilde{D}_t(p_t, \overline{p}), r_t\right)\right]$$

$$\max_{p_t, \overline{p}} \sum_{t=1}^{T} \left[\tilde{U}_t(p_t, \overline{p}) - C\left(\tilde{D}_t(p_t, \overline{p}), r_t\right)\right].$$

$$\overline{p}^{nRU} = \overline{p}^* = \frac{\sum_{t=1}^{T} p_t^{nRU} D_t'(\overline{p}^{nRU})}{\sum_{t=1}^{T} D_t'(\overline{p}^{nRU})}, \textit{ with } p_t^{nRU} = C_q'(\tilde{D}_t(p_t^{nRU}, \overline{p}^{nRU}), r_t).$$