Power System Transformation towards Renewables: An Evaluation of Regulatory Approaches for Network Expansion

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Outline

- The Model
- Test Cases (Generation Technology)
- Results (Regulatory Regimes)
- Conclusions

The Model

J. Egerer, J. Rosellón and W.P. Schill, (2013), Power System Transformation towards Renewables: An Evaluation of Regulatory Approaches for Network Expansion, DIW Berlin Discussion Papers, 1312.

Lower Level/ISO Power-Flow Model

$$\max_{\substack{q,g,\Delta,\\ \lambda_1,\lambda_2,p,\\ \lambda_4,\lambda_5,}} \sum_{t\in T}\left(\sum_{\tau\in \mathrm{T}}\sum_{n\in N}\left(\int_0^{q^*_{n,t,\tau}} p_{n,t,\tau}(q_{n,t,\tau})dq_{n,t,\tau} - \sum_{s\in S} c_s g_{s,n,t,\tau}\right)\frac{1}{(1+\delta_s)^{t-1}}\right)$$

$$s.t.\quad \sum_n \frac{I_{l,n}}{X_{l,t}}\Delta_{n,t,\tau} - P_{l,t} \le 0 \qquad (\lambda_{1,l,t,\tau}) \qquad \forall l,t,\tau$$

$$-\sum_n \frac{I_{l,n}}{X_{l,t}}\Delta_{n,t,\tau} - P_{l,t} \le 0 \qquad (\lambda_{2,l,t,\tau}) \qquad \forall l,t,\tau$$

$$\sum_s g_{n,s,t,\tau} - \sum_{nn} B_{n,nn}\Delta_{nn,t,\tau} - q_{n,t,\tau} = 0 \qquad (p_{n,t,\tau}) \qquad \forall n,t,\tau$$

$$g_{n,s,t,\tau} - \overline{g}_{n,s} \le 0 \qquad (\lambda_{4,n,s,t,\tau}) \qquad \forall n,s,t,\tau$$

$$slack_n \Delta_{n,t,\tau} = 0 \qquad (\lambda_{5,n,t,\tau}) \qquad \forall n,t,\tau$$

The Model

Upper Level: *NoReg*, *CostReg*, *HRV*

$$\max \Pi = \sum_{t \in T} \left(\left(\sum_{\tau \in \mathrm{T}} \sum_{n \in N} \left(p_{n,t,\tau} q_{n,t,\tau} - \sum_{s \in S} p_{n,t,\tau} g_{s,n,t,\tau} \right) + fixpart_t - \sum_{l \in L} \sum_{tt < t} ec_l ext_{l,tt} \right) \frac{1}{\left(1+\delta^p\right)^{t-1}} \right)$$

$$\frac{\sum_{\mathrm{n} \in \mathrm{N}} \sum_{\tau \in \mathrm{T}} \left(p_{n,t+1,\tau} q_{n,t,\tau} - \sum_{s \in S} p_{n,t+1,\tau} g_{s,n,t,\tau} \right) + fixpart_{t+1}^{HRV}}{\sum_{\mathrm{n} \in \mathrm{N}} \sum_{\tau \in \mathrm{T}} \left(p_{n,t,\tau} q_{n,t,\tau} - \sum_{s \in S} p_{n,t,\tau} g_{s,n,t,\tau} \right) + fixpart_{t}^{HRV}} \leq 1 + RPI - X$$

$$fixpart_{t+1}^{CostReg} = \sum_{l \in L} \sum_{tt < t+1} ec_l ext_{l,tt} (1+r) + fixpart_t^{CostReg}$$

The HRV Model

Upper level (Transco)

$$\max_{k,F} \quad \pi = \sum_t^T \left[\sum_i (p_i^t d_i^t - p_i^t g_i^t) + F^t N^t - \sum_{i,j} c\left(k_{ij}^t\right) \right]$$

s.t.

$$\frac{\sum_i (p_i^t d_i^w - p_i^t g_i^w) + F^t N^t}{\sum_i (p_i^{t-1} d_i^w - p_i^{t-1} g_i^w) + F^{t-1} N^t} \le 1 + RPI + X$$

Regulatory constraint

Lower level (ISO)

Welfare maximization

$$\max_{d,g} \quad W = \sum_{i,t} \left(\int_0^{d_i^t} p(d_i^t) \mathrm{d}d_i^t \right) - \sum_{i,t} mc_i g_i^t$$

s.t.

Line capacity restriction $\quad \left| pf_{ij}^t \right| \le k_{ij}^t \quad \forall ij$

Energy balance $\quad g_i^t + q_i^t = d_i^t \quad \forall i,t$

Plant capacity restriction $\quad g_i^t \le g_i^{t,\max} \quad \forall i,t$

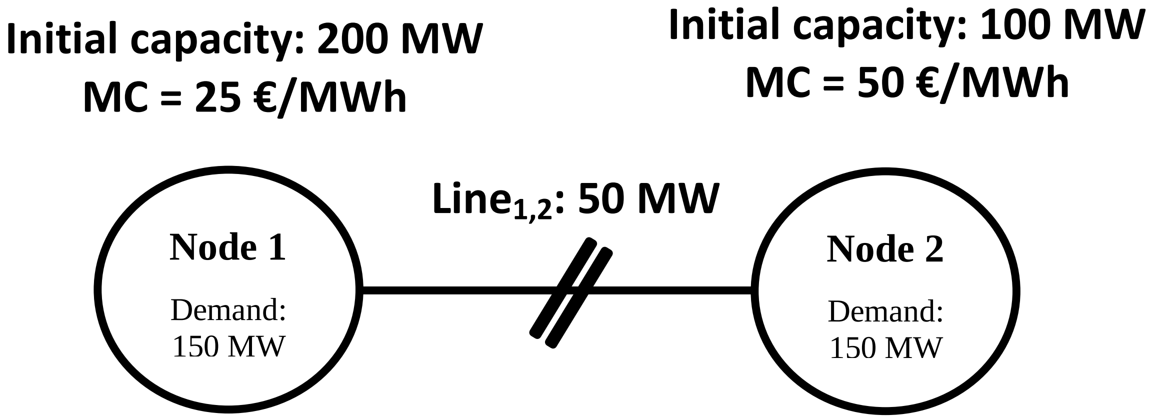
The Model

Welfare Benchmark: *WFMax*

$$\max wf = \sum_{t \in T} \left(\left(\sum_{\tau \in \mathrm{T}} \sum_{n \in N} \left(a_{n,\tau} q_{n,t,\tau} + \frac{1}{2} m_{n,\tau} q_{n,t,\tau}{}^{2} - \sum_{s \in S} c_s g_{s,n,t,\tau} \right) - \sum_{l \in L} \sum_{tt < t} ec_l ext_{l,tt} \right) \frac{1}{\left(1+\delta^s\right)^{t-1}} \right)$$

Test Cases

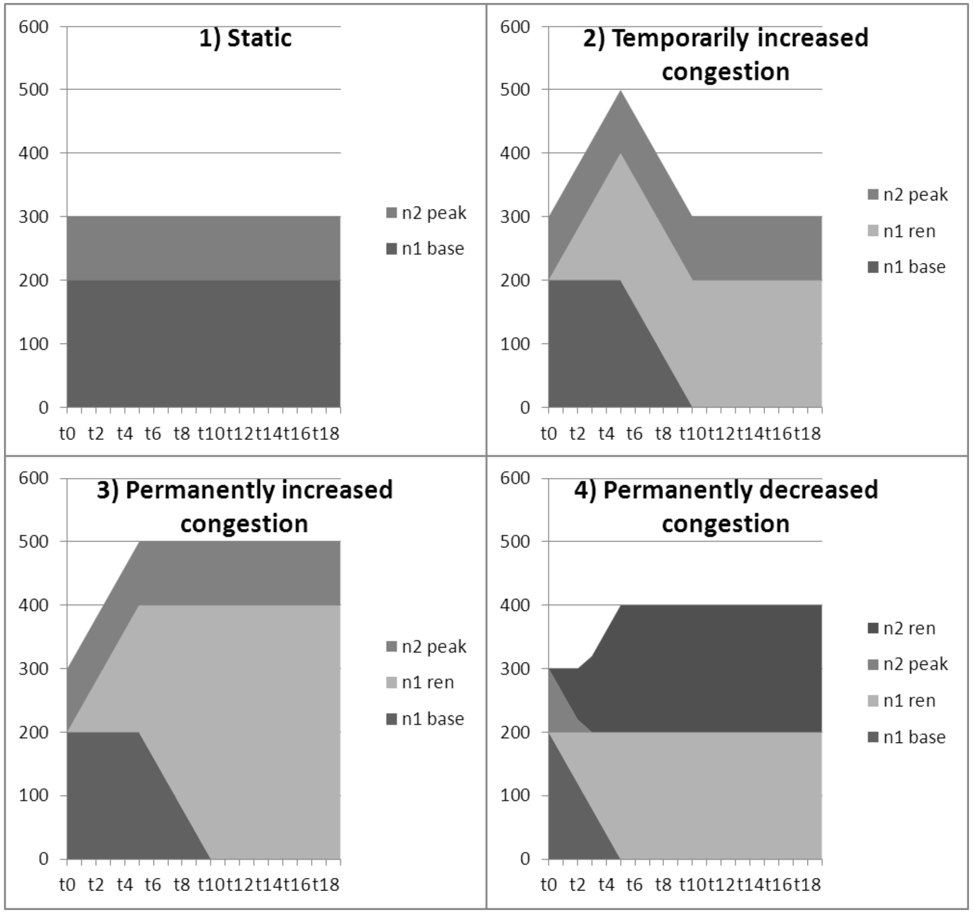
Network Setting



The network setting in the initial period

Test Cases

Network Congestion



Exogenous development of generation capacities in different cases

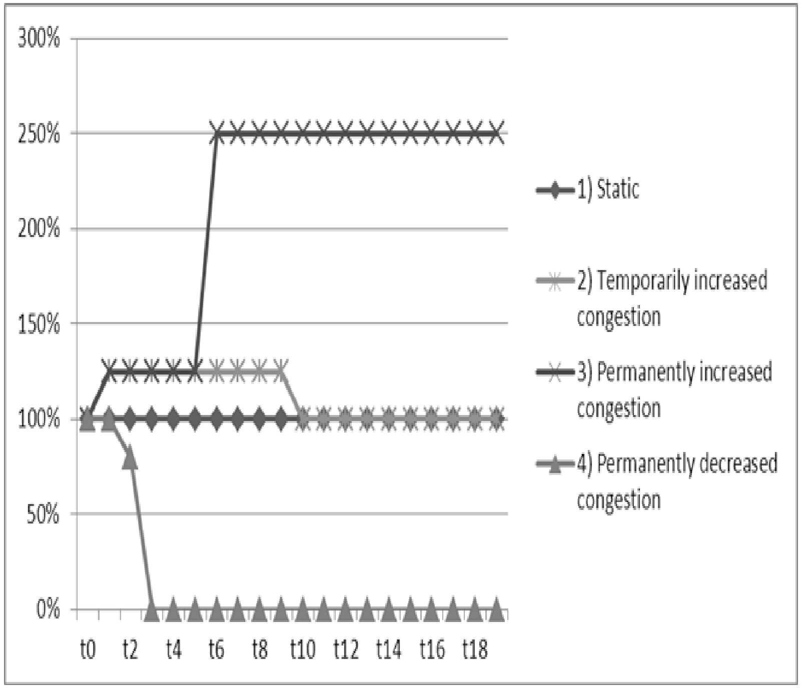


Fig. 3: Development of congestion (without network expansion)

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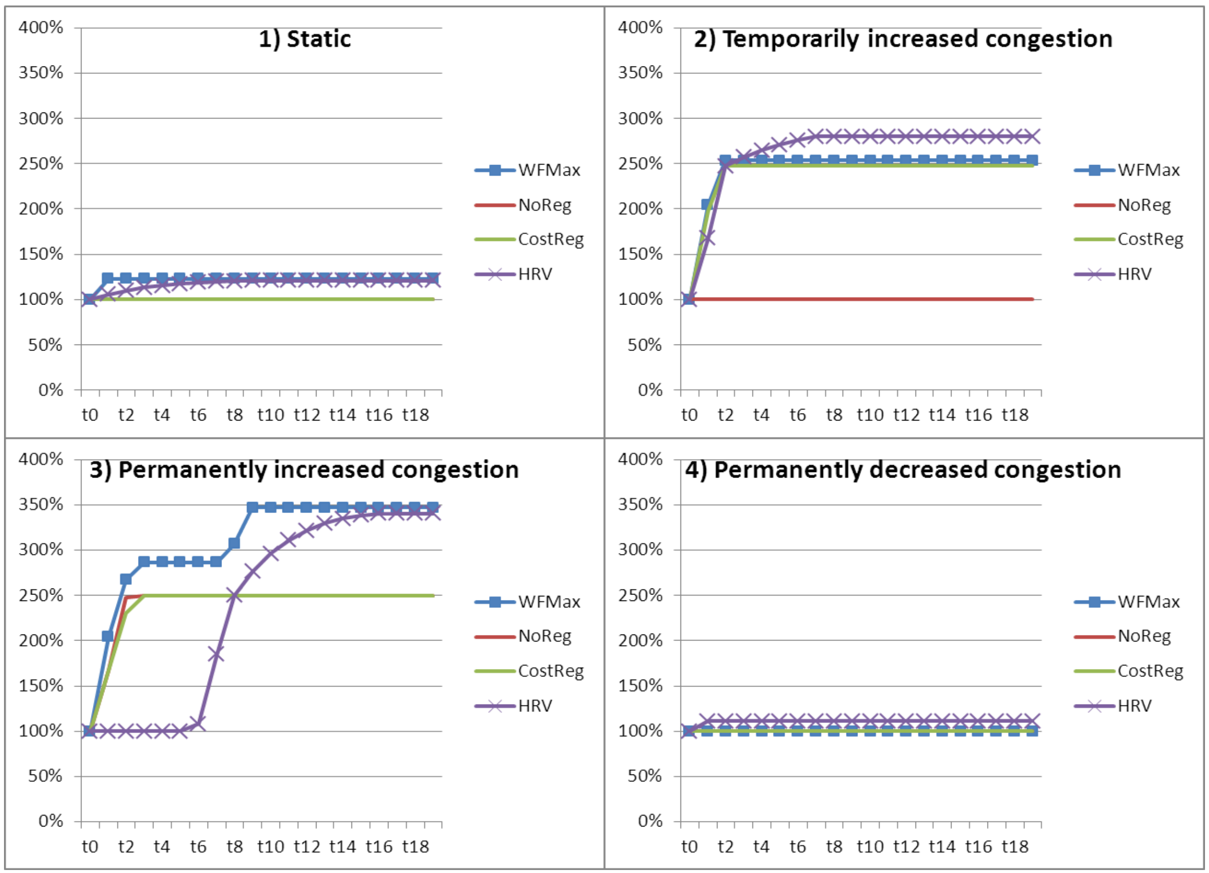
Results

Previous-Period (Laspeyres) Weights



Line extension results (relative to initial line capacity, Laspeyres weights)

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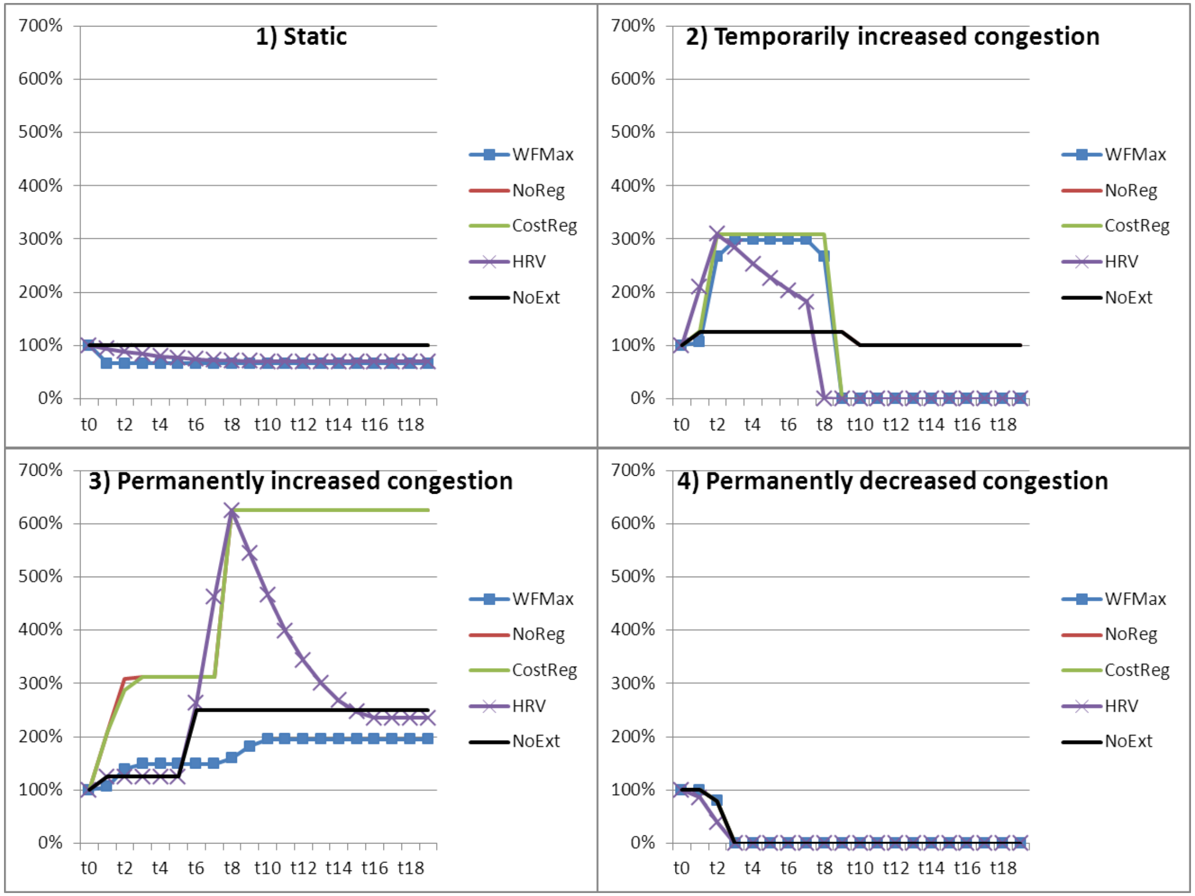
Results

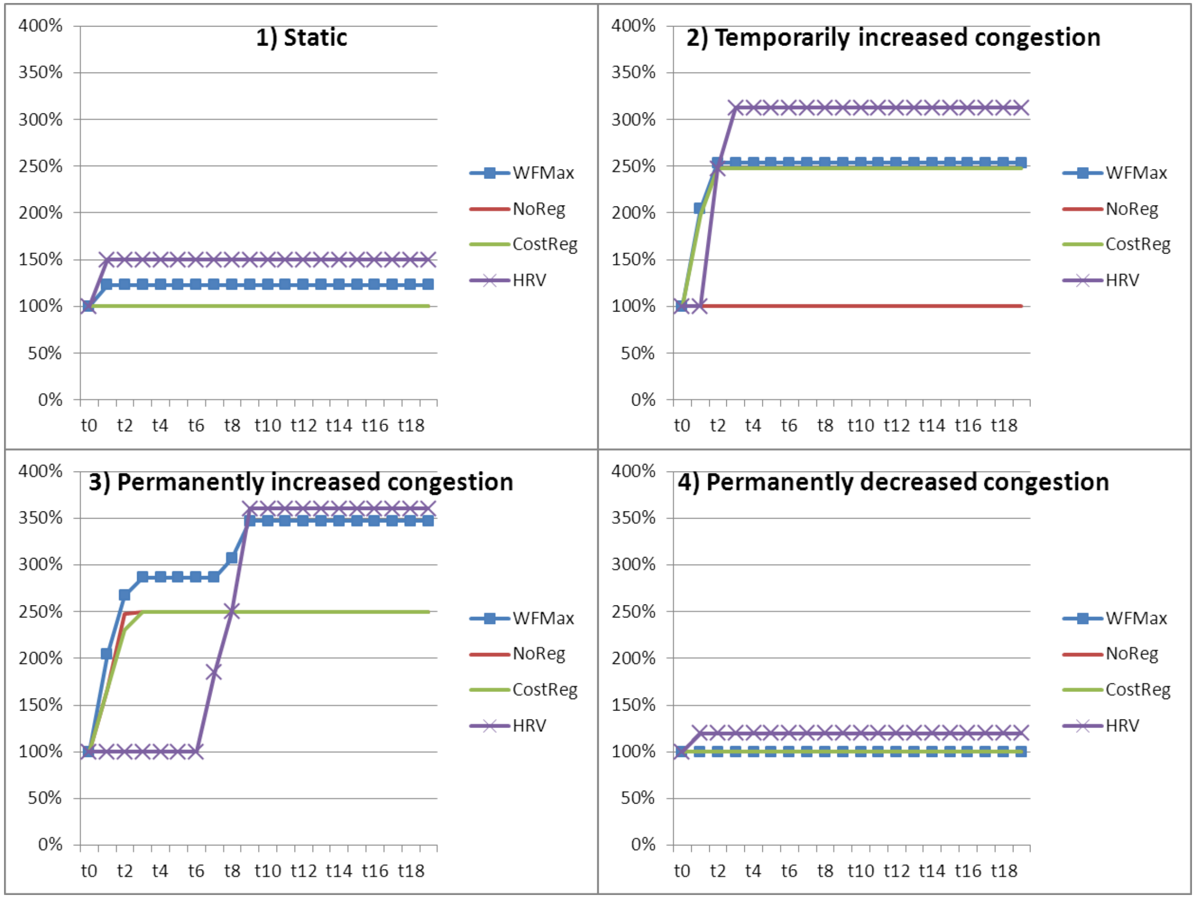
Previous-Period (Laspeyres) Weights



Congestion rents (nominal values)

Results

Current-Period (Paasche) Weights



Line extension results (relative to initial line capacity, Paasche weights)

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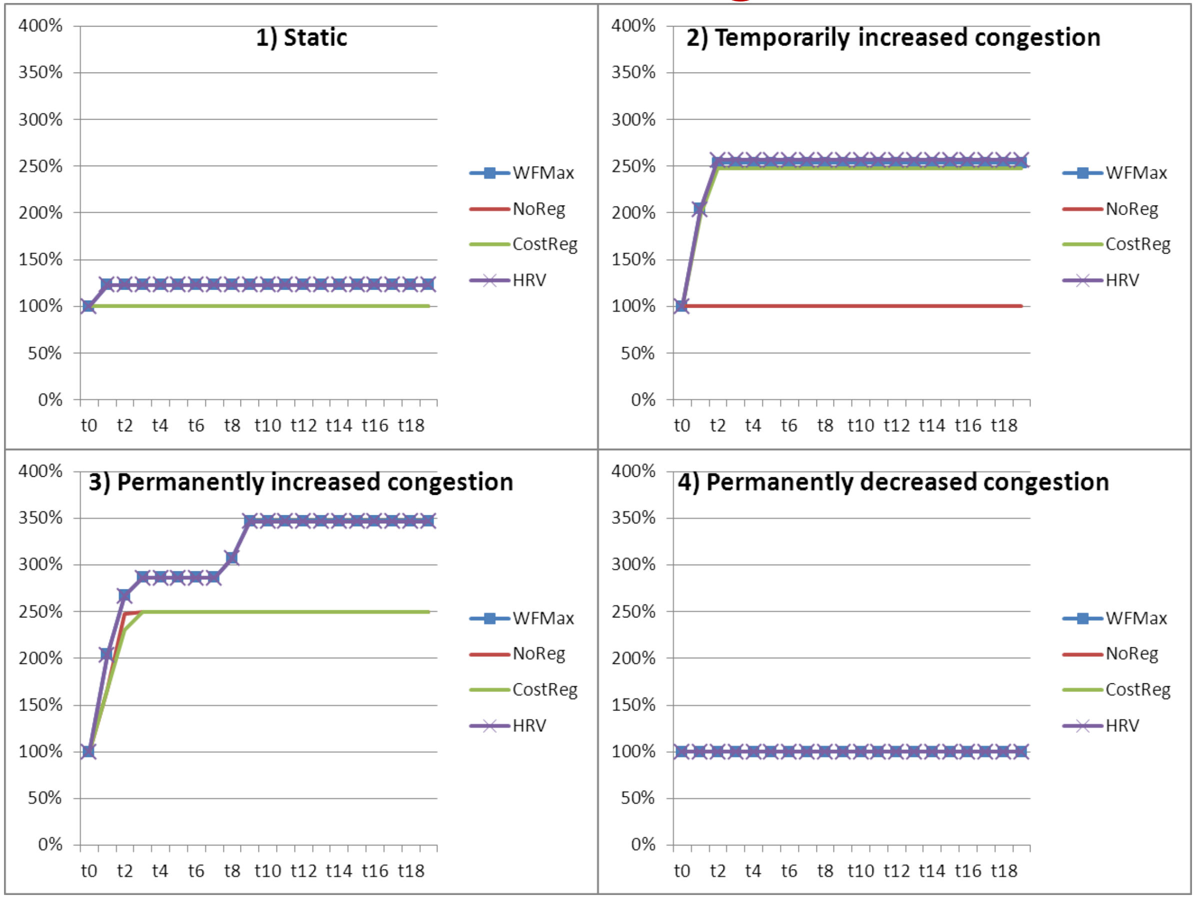
Results

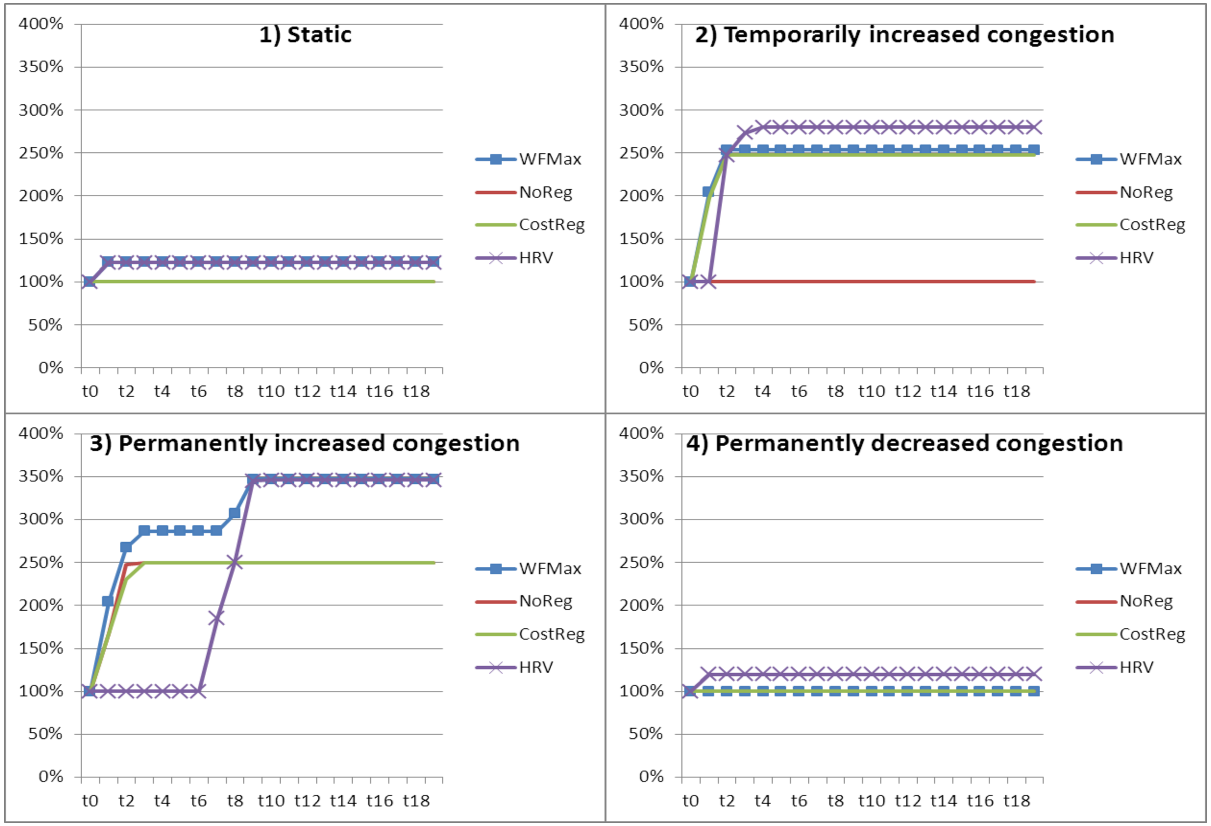
Ideal Weights



Line extension results (relative to initial line capacity, ideal weights)

Results

Laspeyres-Paasche Weights



Line extension results (relative to initial line capacity, average Laspeyres-Paasche weights)

Results

Welfare Comparison

Welfare changes relative to the case without extension

	Weights	1) Static	2) Temporarily increased congestion	3) Permanently increased congestion	4) Permanently decreased congestion
WFMax		0.29%	1.28%	11.62%	0.00%
NoReg		0.00%	0.00%	9.25%	0.00%
CostReg		0.00%	1.27%	9.22%	0.00%
HRV	Laspeyres	0.25%	1.01%	9.02%	-0.17%
	Paasche	-0.11%	0.38%	9.39%	-0.32%
	Av. Lasp.-P.	0.29%	0.89%	9.21%	-0.32%
	Ideal	0.29%	1.28%	11.62%	0.00%

Welfare results in Static Case with Fluctuating Supply and Demand

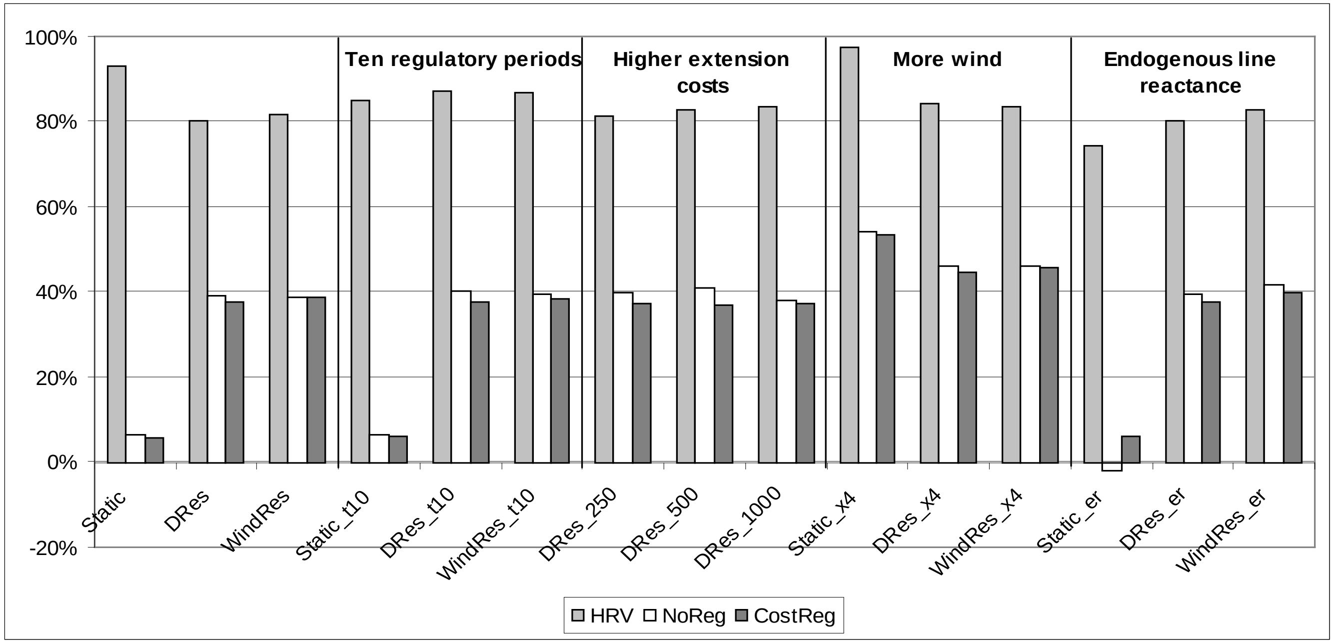


Figure 17: Social welfare gain of extension compared to *WFMax* for different model runs

→ Fluctuating demand and wind power both increase the gap between wf-max and the regulatory cases

→ HRV much closer to wf-optimum in all cases → robust!

Conclusions

- Transmission capacity expansion driven by arousal of new cheap wind generation.
- Previous literature had not considered interaction among generation, transmission and demand in the regulation of transmission expansion.
- Another possible source for welfare change is the shift towards renewables in the power plant fleet.
- Setting a regulated tariff scheme, with right incentives for welfare-optimal transmission expansion under changing generation technology, is challenging.
- Incentive HRV regulation:
  - Laspeyres weights: excessive (stranded) investments.
  - (Quasi) ideal weights: welfare-efficient results.
- Further research on weight regulation to characterize optimal regulation for transmission expansion under renewable integration.