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An Optimal Welfare Analysis of Electricity-Transmission Regulatory Regimes: The Case of Germany

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DIW Berlin and CIDE

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Introduction

- All this came up from a question at DIW Berlin on how to evaluate the regulatory regime for electricity-transmission in Germany.
- They wanted an outsider, with knowledge on regulatory economics, to carry out this task.
- Firstly, it has been difficult to understand this regime (partly because most of the information is in German!).
- Secondly, and perhaps most importantly, the way to come up with a formal model seems quite complex.
- I will present an approach to this problem. I think it could possibly be interesting both from an analytical regulatory point of view, as well as for policy making.

Outline

- Optimal transmission expansion
- The TSO and ISO regimes:
  - Step by step
  - International experiences
- The case of Germany
- Conclusions

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Price-cap vs. cost-plus regulation

Brunekreeft and Borrmann (2011)

- Effects of price-cap and cost-plus regulations on lumpy investments by a natural monopoly.
- For increasing variable-cost and demand-growth cases, cost-based regulation accelerates investment compared to price-based regulation.

Brito and Rosellón (2011)

- Formulate the problem from standpoint of consumers that face incomplete markets.
- Find that consumers prefer to pay excess capacity rather than bearing congestion.
- Network investments can be regulated with cost-plus rule without loss of welfare.

Schill et al (2015)

- Incentive price-cap regulation is a superior alternative to cost-plus or no-regulation.

Egerer et al (2015)

- Price-cap regulation is superior in promoting investment in electricity networks compared to cost-plus regulation when proper *weights* are used in the price-cap formula.

Price-cap vs. revenue-cap regulation

- German electricity transmission network is subject to revenue-cap regulation,
- Choice of revenue-cap rather than price cap means that regulated firm does not face major quantity risk. (*Jamasb and Pollitt, 2001*).
- Quantity demanded is largely outside the control of regulated firm.
- *Crew and Kleindorfer (1996)*: Show revenue caps do not necessarily cap prices.
  - May provide incentives for price increases above the unregulated monopoly level.
- *Lanz (2005)* further show that this result is robust to two-part tariff pricing.
  - Revenue-cap regulation: imply decreases in consumer surplus, and not be cost minimizing as opposed to price cap regulation (as in *Vogelsang, 2001*, and *Hogan et al, 2010*).
- Revenue-cap and price-cap regulations coincide when ouput is ex-ante given (not a choice variable). Regimes with ex-ante transmission planning.

Optimal transmission expansion

- Range of different regulatory schemes and mechanisms have been proposed and applied (Léautier 2000, Kristiansen and Rosellón 2006, Tanaka 2007, Léautier and Thelen 2009).
- One approach to transmission expansion is traditional central planning, either carried within a vertically integrated utility or by a regulatory authority.
- Another alternative might be traditional cost-of-service regulation.
- In contrast, transmission decisions could also be determined in a decentralized, non-regulated way.
- The Hogan-Rosellon-Vogelsang price-cap mechanism (Hogan et al. 2010, *HRV*) combines merchant and regulatory structures to promote the expansion of electricity networks.

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Hogan, W. J. Rosellón, and I. Vogelsang (2010), "Toward a Combined Merchant-Regulatory Mechanism for Electricity Transmission Expansion," Journal of Regulatory Economics, Vol. 38, No. 2, 113-143.

Upper level problem: **Profit maximizing Transco:**

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

s.t.

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

Regulatory constraint

Lower level problem:

ISO welfare maximization:

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

s.t.

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

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

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

Optimal transmission expansion under renewable-integration

- Schill et al (2015):
  - Comparative analysis of different regulatory regimes under intermittent renewable generation, and fluctuating demand.
  - Incentive price-cap HRV regulation is a superior to cost-plus or no-regulation.
- Egerer et al (2015):
  - Transformation of power system toward renewables (e.g., wind substituting coal generation).
  - Assume different scenarios on the implied effects on transmission network congestion.
  - Performance of price-cap incentive regulation depends on the different types of price weights that are used:
    - *Ideal* weights restore beneficial properties.
    - *Laspeyres* (previous-quantity) weights lead to overinvestment.
    - Current period Paasche weights worsen these effects.
  - Notwithstanding, excessive investments might be avoided through the proper combination of weights.

Schill, W.-P., J. Egerer, and J. Rosellón (2015), "Testing Regulatory Regimes for Power Transmission Expansion with Fluctuating Demand and Wind Generation." Journal of Regulatory Economics, vol. 47, issue 1, February.

Lower level as in Hogan et al. (2010), but with more temporal resolution:

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

$$\begin{aligned}
s.t.\quad & \sum_n \frac{I_{l,n}}{X_{l,t}}\Delta_{n,t,\tau} - P_{l,t} \le 0 && (\lambda_{1,l,t,\tau}) && \forall l,t,\tau \\
& -\sum_n \frac{I_{l,n}}{X_{l,t}}\Delta_{n,t,\tau} - P_{l,t} \le 0 && (\lambda_{2,l,t,\tau}) && \forall l,t,\tau \\
& \sum_s g_{n,s,t,\tau} - \sum_{nn} B_{n,nn}\Delta_{nn,t,\tau} - q_{n,t,\tau} = 0 && (p_{n,t,\tau}) && \forall n,t,\tau \\
& g_{n,s,t,\tau} - \bar{g}_{n,s} \le 0 && (\lambda_{4,n,s,t,\tau}) && \forall n,s,t,\tau \\
& slack_n \Delta_{n,t,\tau} = 0 && (\lambda_{5,n,t,\tau}) && \forall n,t,\tau
\end{aligned}$$

Upper level as in Rosellón and Weigt (2011):

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

s.a.

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

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

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Comparison of welfare and extension results

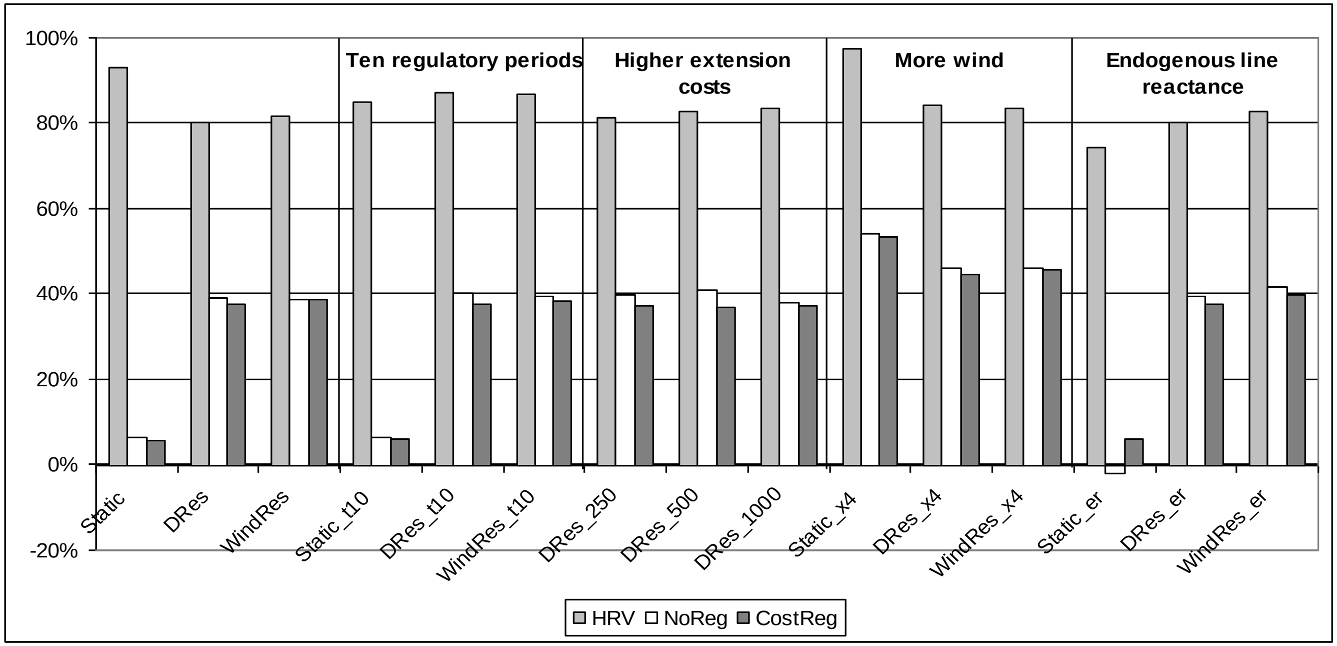

Figure 17: Social welfare gain of extension compared to *WFMax* for different model runs

→ 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!

Egerer, J., J. Rosellón and W-P. Schill (2015), "Power System Transformation toward Renewables: An Evaluation of Regulatory Approaches for Network Expansion," The Energy Journal, Vol. 36 (4)

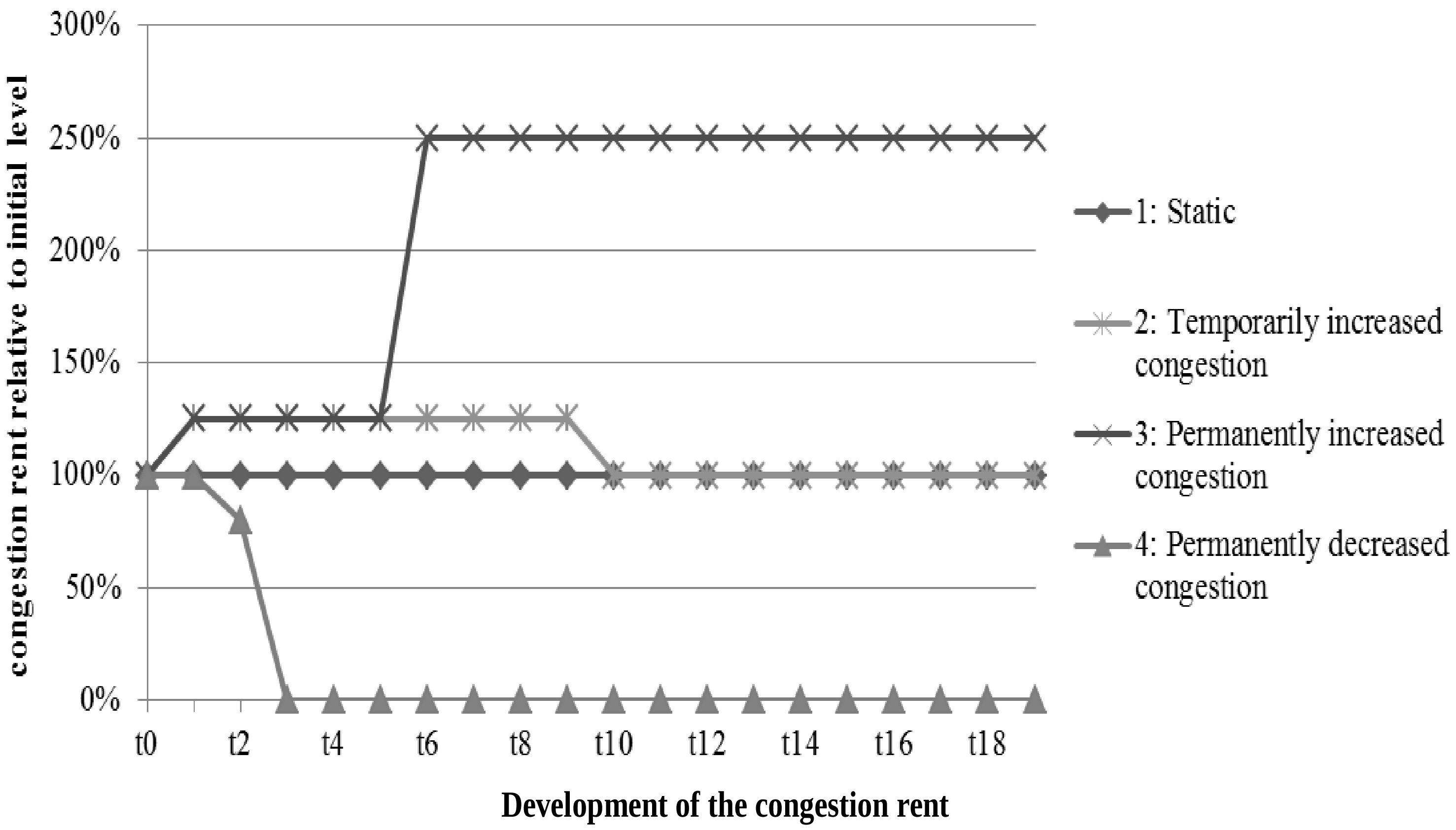

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Figure 1: Line extension results (relative to initial line capacity, Laspeyres weights)

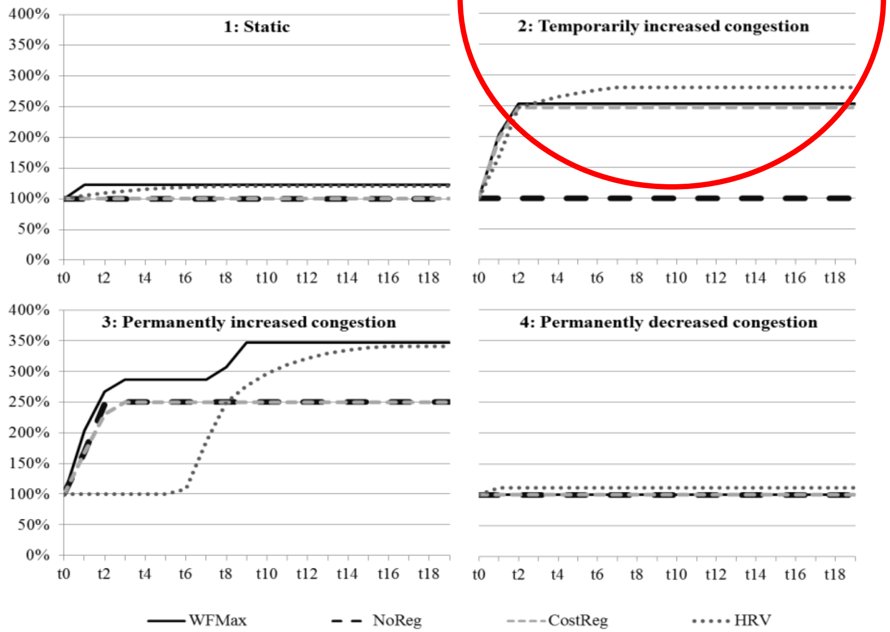

Table 1: Welfare changes relative to the case without extension

	Weights	Static	Temporarily increased congestion	Permanently increased congestion	Permanently decreased congestion
		1	2	3	4
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%
	Average Lasp.-Paasche	0.29%	0.89%	9.21%	-0.32%
	Ideal	0.29%	1.28%	11.62%	0,00%

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TSO Regime

- System operation and ownership of the grid are integrated in a single company (TSO). There is a regulator which sets up a regulatory constraint on transmission tariffs, and a planning entity.
  - FIRST STEP: Exogenous definition of expected generation supply with certain technology mixes and demand capacity needs are carried out by the planning entity in market studies under different scenarios.
  - SECOND STEP: Given generation-demand assumptions, a national transmission development plan (NDP) is carried out by the TSO in order to derive their proposed expansion of the transmission grid. NDP is reviewed by stakeholders, and approved by the regulator
  - THIRD STEP: Given the NDP, TSOs carry out the investment under a regulatory constraint, which may take the form of cost-plus or incentive regulation. Incentive regulation might take various forms: price caps, revenue caps, benchmarks, two-part tariff regulation and, even, a menu of contracts.

ISO Regime (with planning)

- There is an independent system operator (ISO), a transmission company (TRANSCO), a regulator, and a planning entity.
  - FIRST STEP: Exogenous definition of expected generation supply with certain technology mixes and demand capacity needs are carried out by the planning entity in market studies under different scenarios.
  - SECOND STEP: Given these generation assumptions, the NDP is carried out by the ISO, typically using a power-flow model, in order to derive the optimal dispatch and transmission expansion (as in the welfare-benchmark cases in Rosellón and Weigt, 2011, and Schill et al, 2015).
  - THIRD STEP: Given the NDP, the TRANSCO carries out investment under a regulatory constraint, which may take the form of cost-plus or incentive regulation. Incentive regulation might take various forms: price caps, revenue caps, benchmarks, two-part tariff regulation and, even, a menu of contracts.

ISO Regime (without planning)

- There is an ISO, a TRANSCO, a regulator, as well as nodal pricing and FTRs:
  - FIRST STEP: A pre-existing network and point-to-point transmission prices that the TRANSCO has charged up to the present are in place.
  - SECOND STEP: The regulator sets the (incentive) regulatory pricing constraint.
  - THIRD STEP: The TRANSCO collects information about generation supply and electricity demand at all relevant geographical locations (or at each node).
  - FOURTH STEP: The TRANSCO invests in grid capacity.
  - FIFTH STEP: The TRANSCO auctions off point-to-point FTRs, based on the available grid capacity.
  - SIXTH STEP: There is an ISO, who asks for (sequences of) bids from generators and loads at each node and then calculates nodal prices. Loads (ex post) pay the ISO according to their last bids and generators receive payment of their last bids in such a way that markets always clear. The owners of FTRs receive as congestion payments the difference between what loads pay and what generators receive. Any excess congestion payments that cannot be allocated to an FTR (because less FTRs were sold than the point-to-point transmission available), go to the Transco.
  - EIGHT STEP: Fixed fees are then calculated from the regulatory constraint, based on congestion charges, and are paid by the loads.

International experience (TSOs)

- Many European countries follow the TSO regime (or a variation of it).
- Belgium and Germany:
  - Regulatory scheme used in third step is cost-plus regulation for new capacity investments, and revenue-cap for O§M expenditures (OPEX).
- France:
  - Incentive regulation is used for both OPEX and CAPEX with revenue-cap over two-part tariffs for new capacity investments.
- Netherlands:
  - Incentive revenue-benchmark regulation (based on European TSOs) for expansion investments, and revenue-cap for OPEX.
- Great Britain:
  - New regulation scheme is used (RIIO): mix of cost-plus and incentive regulation, with emphasis on resource adequacy, innovation, and incentives to improve outputs to consumers.
  - RIIO also includes a menu of contracts to incentivize self-selection by the TSO.
- In most countries, regulatory schemes complemented with other measures that provide cost-minimizing incentives, or help to handle risk.
- In the latter case, adjustments to compensate the TSO for the difference between forecasted and actual needed transmission capacities are considered.

International experience (ISOs)

34 M.G. Pollitt / Energy Policy 47 (2012) 32–48

Table 1
Electricity ISOs around the world and NGC—size and characteristics (2009/2010).
Sources: Capgemini (2009), ISO's websites, DECC (2010), Government of Alberta (2011), Ofgem 2010a, ONS (2010), Swiss Federal Office of Energy (2011), US EIA (2010), and World Bank (2010). For US companies: Balmert and Brunekreeft (2008) and Greenfield and Kwoka (2010). Transmission lines and installed generation capacity updated with latest data from IRC (2010a, b).

ISO	First year of data	Mean annual load (GWh)	Area covered	HQ	Installed generation (MW)	Transmission lines (miles)	Population served (millions)	Ownership structure
AEMO (Australia)	2009	205,700 (2009)	Australia, except Western Australia and Northern Territory.	Melbourne, Australia	48,600[c]	24,854.8	21.9[c]	60% government members and 40% industry members
AESO (Canada)		69,904 (2009)	Alberta	Calgary, Alberta	12,900	13,049	3.7	Statutory (public)corporation
CAISO (US)	1998	229,857[e]	California	Folsom, California	57,124	25,526	30	Public benefitcorporation
CAMMESA (Argentina)		111,333 (2009)	Argentina	Buenos Aires, Argentina	27,000	7365	40.3[a]	80% owned by Market Participants, 20% by the public ministry.
EirGrid (Ireland)		27,000 (2009)	Ireland	Dublin, Ireland	6246 (2009)	4038.9	2.5[b] (4.45[a])	Public
ERCOT (US)	1999	308,278 (2009)	85% of Texas load, 75% of Texas land	Austin, Texas	88,227	40,327	22	Membership-based non-profit corporation
IESO (Canada)	1999	158,900 (2009)	Ontario	Toronto, Canada	34,557	18,160	13	Not-for-profit, non-taxable statutory corporation
ISO-NE (US)	1998	126,842 (2009)	Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont	Holyoke, Massachussetts	33,700	8130	14	Public (limited liability, non-stock company incorporated in the state of Delaware)
MISO (US)	2002	553,815[e]	North Dakota, South Dakota, Dakota, Nebraska, Minnesota, Iowa, Wisconsin, Illinois, Indiana, Michigan and parts of Montana, Missouri, Kentucky and Ohio	Carmel, Indiana	144,132	55,090	43	Non-profit, member-based organisation
NBSO (Canada)		21,811 (2010)[d]	New Brunswick, Nova Scotia, Prince Edward Island, and Maine	Fredericton, New Brunswick, Canada	7509	8000	2	Public (statutory corporation)
NGC (GB)		286,000 (2009/10)	England, Wales, Scotland	London	78,254.7	12,987	27.3[b] (60[a])	Private (investor-owned)
NOSBiH (Bosnia & Herzegovina)		N/A	N/A	Sarajevo, Bosnia & Herzegovina	N/A	3768.6 (2006)	3.8[a]	Public (owners are the Federation of Bosnia and Herzegovina and the Republic of Srpska, i.e. Bosina and Herzegovina)
NYISO (US)	2000	160,487[e]	New York	Rensselaer, New York	40,685	10,893	19	Public (Incorporated in the State of New York, not for profit organisation)
ONS (Brazil)		1,573,438 (2009)	Brazil	Rio de Janeiro,Brazil	96,600 (2007)	N/A	193.7[a]	Private (not for profit, member based)
PJM (US)	1998	420,837 [e]	Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia and the District of Columbia	Valley Forge, Pennsylvania	164,895	56,499	51	Public (limited liability, non-stock company incorporated in the state of Delaware)
SPP (US)	2001	194,979[e]	Kansas, Oklahoma and parts of New Mexico, Texas, Louisiana, Missouri, Mississippi and Arkansas	Little Rock, Arkansas	66,175	50,575	15	Not-for-profit member organisation.
SWISSGRID (Switzerland)		49,479 (2010)	Switzerland	Laufenburg, Switerland	19,400	4163.2	7.73[a]	Private and public grid owners (directly or indirectly, the majority shareholders are public - counties/local council)

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Germany

Cost-plus regulation for capacity expansion

- TSO-PLANNING regime.
- Expansion transmission factors are permanently non-influenceable costs (PNIC). Include congestion rents and investment budget (IB) costs.
- IB includes investments costs projects approved by BNetzA for the expansion of transmission systems.
- The PNIC costs are passed through directly in the consumer tariff.

Revenue-cap regulation for O&M costs

- Revenue-cap regulation is applied to O&M costs.
- O&M costs include temporary non-influenceable and influenceable costs (TNIC+IC, respectively), and capital expenses (CAPEX) for the assets in the regulated asset base.
- TNIC + IC applied a total expenditure (TOTEX) revenue-cap with efficiency and productivity targets.

Germany

$EO_t = KA_{dnb,t} + (KA_{vnb,0} + (1 - V_t) \cdot KA_{b,0}) \cdot (VPI_t / VPI_0 - PF_t) \cdot EF_t + Q_t + (VK_t - VK_0) + S_t$

where:

V_t = distribution factor for the reduction of the inefficiency (inefficiency needs only to be decreased fully at the end of the regulatory period, or for the first period after the end of the second regulatory period)
$KA_{vnb,0}$ = efficient costs (not influenceable at least in the current regulatory period)
$KA_{b,0}$ = inefficient costs (influenceable in the current regulatory period)
VK_t = volatile part of cost (e.g. lost head)
S_t = balance for the regulatory account
bK = inefficient costs (influenceable in the current regulatory period) ($KA_{b,0}$)
vnbK = efficient costs (not influenceable at least in this period) ($KA_{vnb,0}$)
dnbK = not influencable costs ($KA_{dnb,t}$)

Yearly adjustments are then made for:

- Inflation VPI_t/VPI_0
- Not influencable costs $KA_{dnb,t}$
- Quality element Q_t
- Coverage factor ("Erweiterungsfaktor", EF_t) for extension of the network, which applies for distribution only.

Germany

Generation scenarios and transmission planning

- Cost-Plus-Revenue-Cap regime relies on transmission-network planning since the amendment of the EnWG in 2011.
- The planning process includes generation and demand scenario definitions, and a network development plan (NEP).
- Uniform pricing.
- Based on generation-forecast scenarios, TSOs develop initial draft of the NEP, which is then published for consultation with stakeholders, and finally approved by regulator (BNetza).
- NEP determined independently from generation-power market dispatch.
- NEP programming model seems not to be public information.
- Whole planning process repeated yearly for a time horizon of 10-20 years.
- TSOs' role is to carry out such projects, and charge the prices that are allowed under the combined regulatory cost-plus revenue-cap constraint.

Assessment

- DENA-Verteilnetzstudie (2012): network investment requirement of ca. €27- €42 billion up to 2030.
- Revenue-cap regulation alone did not allow full cost-recovery given the high required investments for replacement and expansion (suggested the change to cost-plus regime).
- However, others believe that the current modified regime (cost-plus for new investment and revenue-cap for O&M) is not optimal either:
  – Capacity is not being extended where it is most needed: north-south corridor to bring northern wind power. TSOs tend to connect lignite power plants.
  – Over-investments.
  – TSOs tend to inflate costs.

ANALYTICAL ASSESSMENT OF REGULATORY INCENTIVES NEEDED!

Assessment

(NAÏVE) QUESTIONS FROM AN OUTSIDER

- Is the determination of the NEP free of any strategic behavior by the TSOs?
- Is the planning tool that TSOs use public information?
- Is the NEP maximizing welfare (consumer surplus minus generation costs minus the cost of transmission capacity expansions)?
- Are the German TSOs inflating costs since they are subject to cost-plus tariff regulation?
- Is the lack of needed investment (to develop north-south corridors) due to the fact that there is no incentive in the system to connect renewable generators (market integration vis a vis *green* integration?).
- How could one carry out an optimal welfare analysis of the German regulatory regime?

Assessment

How could one carry out an optimal welfare analysis of the German regulatory regime?

NEP

- Assumes scenarios for evolution of generation capacity and technologies
- Non-transparent transmission model to determine network capacity expansions.
- Model is independent from the generation market model.
- TSOs do NEP knowing *ex ante* they will be subject to cost-plus regulation**.**

German TSOs

- Incentives to determine strategically capacity expansions, since SO and ownership are integrated, and they anticipate cost-plus regulation in expansion costs.
- Do not seem to maximize welfare.
- Incentives to inflate costs**.**

Assessment

How could one carry out an optimal welfare analysis of the German regulatory regime?

Comparative welfare analysis for NEP

- Model with transition from the current uniform pricing scheme in the German electricity industry to a nodal-pricing regime.
- FTRs also included.
- ISO maximizes welfare in an integrated transmission-generation-dispatch power-flow model.
- Compare NEP expansions to welfare-benchmark case simulations.
- Simulate the German system, but using a price-cap constraint on expansion costs.
- Rewrite bi-level programming model in HRV (2010) in terms of revenue-cap on O&M costs, and cost-plus for expansion costs.
- Evaluate the welfare losses associated with proposed NEP specific network expansions.

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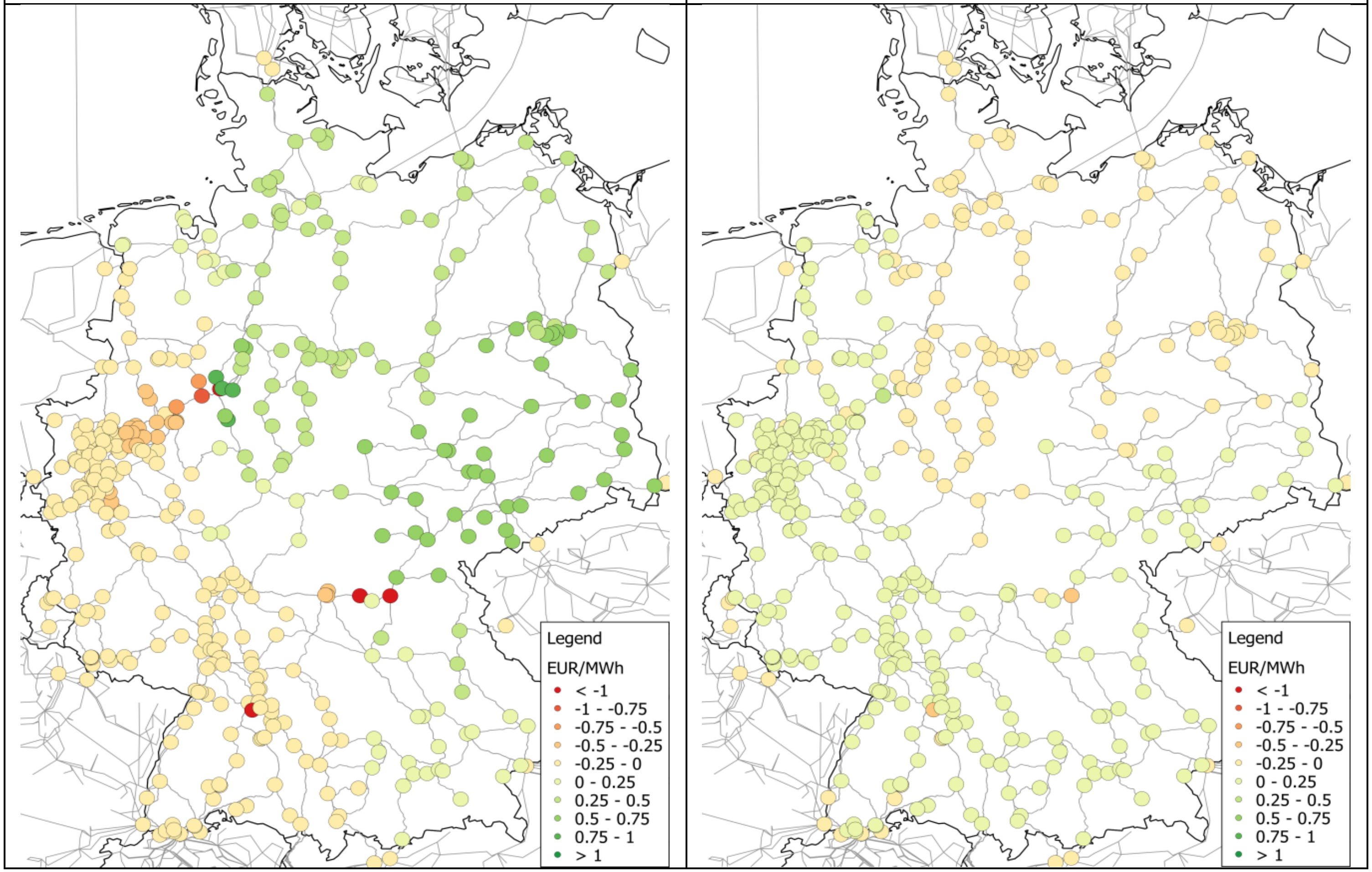
Kunz, F., K. Neuhoff and J. Rosellón (2014). "FTR Allocations to Ease Transition to Nodal Pricing: An Application to the German Power System," Discussion Papers of DIW Berlin 1418, German Institute for Economic Research.

No FTR allocation | **Full FTR allocation**



Average change in surplus of demand in the high wind winter week under production-based allocation approach

Conclusions

- One may anticipate that German TSOs have incentives to overinvest and inflate costs in a non-welfare-efficient way.
- How much welfare losses: measured through comparison with simulated welfare-benchmark.
- Further comparison with price-cap regulation:

Fluctuating renewable generation

- The German cost-plus regime for transmission investment is then prone to cause non-optimal effects on transmission expansion.
- Regarding the revenue-cap regime on OPEX and CAPEX, this in turn may imply potential incentives for transmission-tariff increases and output (throughput) decreases (Crew and Kleindorfer, 1996).
- Combined effect of cost-plus regulation on investment costs and revenue-cap on OPEX and CAPEX: even more (non-efficient) price increases.
- German regulatory regime should most likely lie between price-cap and (pure) cost-plus regulation in terms of convergence to optimal welfare and grid expansions.

Transformation of the power sector toward renewable integration

- *Laspeyres* (previous-quantity) weights may lead to overinvestment.
- However, excessive investments might be avoided through the proper combination of weights.
- Under certain assumptions, cost-plus regulation might provide satisfactory results than price-cap regulation.
- German regulatory scheme combines regulatory measures to balance off risks in new investments and efficiency incentives for operation of the already existing network.

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