Towards Optimal Regulation of Transmission Network Investment under Renewable Integration

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(1) Overview

We analyze different regulatory regimes for electricity transmission investment in the context of transformation of the power system towards renewable energy. We study distinctive developments of the generation mix with different implications on network congestion, assuming that a shift from conventional power plants towards renewables may go along with temporary or permanent exogenous shocks on transmission requirements. We specifically address the relative performance of a combined incentive price-cap mechanism, a cost-based rule, and a non-regulated approach in the assumed dynamic generation settings. Through applications both in a stylized two-node network as well as in a 15-node Northwestern European test case, we find that incentive regulation performs satisfactorily only when the appropriate weights are used under the specific renewable integration processes. While quasi-ideal weights generally restore the beneficial properties that incentive regulatory mechanisms are well-known for in static settings, pure Laspeyres weights may lead to typical overinvestments (or stranded investments) compared to the welfare optimum benchmark. However, depending on the expected evolution of network congestion, a combination of Laspeyres, Paasche, and average Paasche-Laspeyres weights achieve convergence to welfare-optimal investments. Even more, stranded investments are not a problem anymore through proper handling of weights. This analysis motivates further research aimed to characterize optimal regulation for transmission expansion in the context of renewable integration.

(2) Methods

We assume a market design with nodal pricing based on real power flows. A single Transco holds a natural monopoly on the transmission network. The Transco decides on network extension. Accordingly, we assume that the Transco maximizes profit, which consists of congestion rents and – depending on the regulatory regime – a fixed income part. Whereas the Transco is not involved in electricity generation, an independent system operator (ISO) manages the actual dispatch in a welfare-maximizing way. The ISO collects nodal payments from loads and pays the generators. The difference between these payments is the congestion rent, which is assumed to be transferred to the Transco. We model three different regulatory cases in which we assume the Transco to be unregulated regarding network expansion (*NoReg*), cost-regulated (*CostReg*), or *HRV*-regulated[4]. We compare these regulatory cases to a baseline case without any network expansion (*NoExtension*) and to a welfare-maximizing benchmark (*WFMax*), in which a social planner makes combined decisions on network expansion and dispatch. The problem formulation entails two levels (bilevel programming). In the regulatory cases, the Transco's profit maximization constitutes the upper-level optimization problem. In the welfare-maximizing benchmark, the upper-level program represents the social planner's maximization problem. On the lower level, we formulate the ISO's welfare-maximizing dispatch as a mixed complementarity problem (MCP). The combination of lower and upper level problems constitutes a mathematical program with equilibrium constraints (MPEC). The above regulatory cases are initially analyzed for four stylized cases of changing generation capacities in a simple two-node network (n1, n2) over a timeframe of 20 years. Both nodes are connected by a capacity-constrained transmission line with a capacity of 50 MW in the initial period. Figure 1 shows the network setting in the initial period.

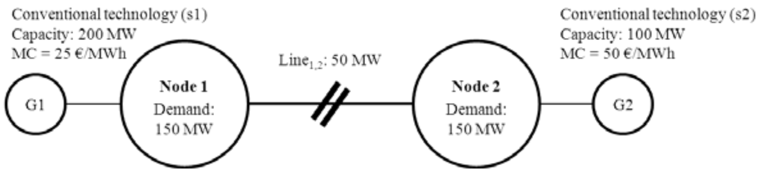

Figure 1: The network setting in the initial period

Demand at both nodes is characterized by a linear demand curve with a reference demand of 150 MW at a reference price of 30 €/MWh. The price elasticity of demand is -0.25 at the reference point. There are two conventional generation technologies (t1, t2) with marginal costs of €25/MWh and 50 €/MWh, respectively. The cheap conventional technology is assumed to be located at node 1, the expensive technology at node 2.

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[4] HRV regulation refers to: Hogan, Rosellón, and Vogelsang (2010).

Renewable power is dispatched without marginal costs, which is true for both wind and solar power. The four stylized cases of generation capacity changes are:

I. The static case: There are no changes in generation technologies over time.
II. Temporarily increased congestion: Increasing generation capacities of renewable sources at node 1. There is an overlap of renewables phasing in and conventional generators phasing out, such that congestion is temporarily increased.
III. Permanently increased congestion: Growing renewable capacities at node 1 over-compensate the phase-out of conventional power plants at this node, giving rise to temporarily increased congestion.
IV. Permanently decreased congestion: Renewable power generation increases equally at both nodes, such that conventional generation is completely phased out. Consequently, transmission congestion vanishes.

We also include an application to a stylized 15-node Northwestern European test case[5], in which we assume an increasing substitution of base-load generation technologies by renewables.

(3) Results

Welfare results for the two-node example are presented in Table 1.[6] The table shows relative differences to the baseline case *NoExtension* for the welfare-maximizing benchmark (*WFMax*) and the regulatory cases *NoReg*, *CostReg*, and *HRV-regulation* (under Laspeyres, Paasche, average Paasche- Laspeyres weights and quasi- ideal weights).[7]

Table 1: Welfare results relative to the baseline *NoExt*

Regulatory case	Weights	I. Static	II. Temp. incr. cong.	III. Perm. incr. cong.	IV. Perm. decr. cong.
WFMax		0,3%	1,3%	11,6%	0,0%
NoReg		0,0%	0,0%	9,3%	0,0%
CostReg		0,0%	1,3%	9,2%	0,0%
HRV	Laspeyres	0,3%	1,0%	9,0%	-0,2%
	Paasche	0,2%	0,8%	9,3%	0,0%
	Avg. Pa.-Lasp.	0,2%	1,2%	7,8%	0,0%
	Quasi-ideal	0,3%	1,2%	11,2%	0,0%

The use of quasi-ideal weights (leaning on Laffont and Tirole, 1996) allows for early convergence in investment and welfare values of incentive regulation. However, the actual implementation of ideal weights seems challenging in regulatory real-world practice. We thus found that, according to the expected evolution of network congestion, a combination of Laspeyres, Paasche, and average Laspeyres-Paasche weights achieve convergence to welfare-optimal investments. More specifically, under assumed temporarily increased and permanently increasing congestions, average Paasche weights and Paasche-Laspeyres weights provide the best welfare results, respectively. In the case of permanently decreasing congestion, either Paasche or average Paasche-Laspeyres weights achieve the best results. Cost-based regulation seems to be slightly better in terms of welfare increase only in the case of temporarily increased congestion. However, we believe that this would not generally support the use of cost regulation due to its the well-known drawbacks.

(4) Conclusions

Incentive regulation still performs well under renewable integration. The regulator must just beware of the weights she implements according to the expected evolution of congestion, under the specific renewable integration process. With proper handling of weights, stranded transmission investments are also avoided. Our analysis motivates further research on weight regulation aimed to characterize optimal regulation for transmission expansion under a transforming renewable-based energy system.

References

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Schill, W.-P., J. Rosellón and J. Egerer (2011), Regulated Expansion of Electricity Transmission Networks: The Effects of Fluctuating Demand and Wind Generation“, *DIW Berlin* Discussion Paper 1109.

Laffont, J-J., and J. Tirole (1996). “Creating Competition through Interconnections: Theory and Practice.” *Journal of Regulatory Economics* 10:227-256.

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[5] Compare Schill, Rosellón and Egerer (2011).

[6] The complete version paper will also include simulations for the Northwestern European test case.

[7] Results on investment in transmission capacity are not shown in this extended abstract due to space restrictions, but we have basically obtained that HRV-regulation does not lead to (stranded) overinvestments when the proper mix of Laspeyres, Paasche and Paasche-Laspeyres weights are used in each assumed case of evolution of the generation mix and congestion rents.