A Merchant Mechanism for Electricity Transmission Expansion

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Contents

Structures for Transmission Investment

- First proposal: independent system operator retains some transmission rights in an LTFTR auction
- Second proposal: “Transco” that is regulated through benchmark or price regulation to provide it with incentives to invest in the development of the grid, while avoiding congestion.
- Third proposal: derive optimal transmission expansion from the power-market structure of electricity generation

Structures for Transmission Investment

LTFTR APPROACH

- Based on a centralized ISO that allocates FTRs through an auction and in parallel with LT generation contracts
- LTFTR "merchant" alternative can provide market-based transmission pricing that attracts investors to pay for transmission expansion
- In order to proceed with a line expansion, the investor pays for the negative externalities generated.
- To restore feasibility, an ISO would have to retain some transmission rights in an auction for long-term rights to make sure that the expansion project does not violate the property rights of the original transmission right holders.

Structures for Transmission Investment

- Joskow and Tirole (2003):
  - FTR model relies on assumptions of perfect competition.
  - *Market power* implies prices will not reflect the marginal cost of production.
  - *Lumpiness* implies that total value paid to investors understates social surplus
  - *Contingencies* imply that that existing capacity and incremental capacity are not well defined and are stochastic
  - *Loop flows* imply an addition in transmission capacity might have a negative social value
  - *Information Asymmetries:*
    - Separation of transmission and system operation creates moral-hazard “in teams”
    - No perfect coordination of interdependent investments in generation and transmission.
    - Equal access to investment opportunities is not good assumption

Structures for Transmission Investment

- Hogan (2002c) generalizes Bushnell and Stoft analysis:
  - General axioms to properly define LTFTRs.
  - Institutional structure with various established agents
  - *Feasibility rule*: FTR increment keeps being simultaneously feasible
  - *Proxy awards*: Increment remains simultaneously feasible given that certain currently unallocated rights (*proxy awards*) are preserved
  - *Maximum value*: Investors maximize their objective function
  - *Symmetry*: Awarding process apply both for decreases and increases in the grid capacity
- Bushnell and Stoft: under these conditions allocation of new PTP FTR obligations will not reduce social welfare.

Structures for Transmission Investment

- Defining proxy awards is a difficult task: the *best* use of the current grid along the same direction of the (positive or negative) incremental FTRs
- Two possibilities: one is to define "best" in terms of preset proxy references so that proxy awards maximize the value of such references:

Preset proxy preferences (p)

$$\hat{y} = T + \hat{t}\,\delta,$$

$$\hat{t} \in \arg\max_{t} \left\{ \ \hat{t}p\delta \mid K(T + t\delta) \leq 0 \right\}$$

Structures for Transmission Investment

- Another possibility would be to define "best" in terms of the maximum value of investors' preferences. Proxy awards would then minimize such maximum value:

Investor preferences ($\beta(\mathrm{a}\delta)$)

$$\hat{y} = T + \hat{t}\delta,$$

$$\hat{t} \in \underset{t, K(T+t\delta)\le 0}{\arg\min} \left\{ \max_{a\ge 0} \left\{ \beta(a\delta) \mid K^{+}(T + t\delta + a\delta) \le 0 \right\} \right\}$$

- An auction carried out to attract investment for transmission expansion so that value of investment is maximized in direction δ subject to the simultaneously feasibility conditions and the "best" rule.

Structures for Transmission Investment

- Hogan (2003) recognizes LTFTRs only provide efficient results under assumptions of no market power and non-lumpy marginal incremental expansions. Regulation plays an important role

- Hogan's response to contingency concerns: only contingency conditions that are outside the control of the system operator could lead to revenue inadequacy, but such cases are not important contingency conditions. Most of the remaining contingencies are foreseen in a security-constrained dispatch.

- Hogan (2003) recognizes that information asymmetries and agency problems are present. It is not clear to him how asymmetric information can affect boundary between merchant and regulated transmission expansion project

Structures for Transmission Investment

REGULATORY SCHEMES

- Léautier, 2000, Grande and Wangesteen, 2000, and Joskow and Tirole, 2002: Mechanisms that compare the Transco performance with a measure of welfare loss: the Transco penalized for increasing congestion costs in the network.
- Vogelsang (2001) explicitly study cost and production functions of transmission, and isolate the monopolistic nature of a for-profit Transco
- Main criticisms:

➢ How to define Transco's output? Bushnell and Stoft (1997), Hogan (2002): this is not possible since physical flow through a meshed transmission network cannot be traced

➢ Analysis under loop flows yet to be studied

➢ Increasing monotonic cost function for transmission

Structures for Transmission Investment

MARKET POWER HYPOTHESIS

- How to design a mechanism that defines optimal transmission expansion depending on market-power structure of the generation sector?
- Sheffrin and Wolak (2001) derive optimal expansion of the transmission network according to strategic behavior of generators, and estimate the generators' bidding behavior before and after a transmission upgrade
- London Economics International (2002) discusses a conjectural model where each generator maximizes profits in its residual demand function, and given the predicted other bidder's supply functions.
- Results show that benefits of transmission expansion are small until added capacity surpasses a certain threshold that, in turn, is determined by the possibility of induced congestion by strategic behavior of generators with market power.
- Cost uncertainty implies that many small upgrades are preferable to large greenfield projects.
- However, this approach relies on a transportation model

The Power Flow Model

$$\underset{Y,u \in U}{Max}\, B(d_P - g_P)$$

$$s.t.$$

$$Y = d_P - g_P,$$

$$L(Y,u) + \tau^t Y = 0,$$

$$K(Y,u) \leq 0$$

Y=d_P-g_P real power bus net loads

B(Y) is the net benefit function

u control variable containing remaining parameters

K(Y,u) transmission flows

L(Y,u) losses

The Power Flow Model

FINANCIAL TRANSMISSION RIGHTS

- Hedge market players against differences in locational prices caused by transmission congestion
- The pay-off is given by:

  $$FTR = Q_{ij}(P_j - P_i)$$

  where P_j is the price of location j, P_i is the price of location i and Q_{ij} is the directed quantity specified in the FTR from point i to point j

The Power Flow Model

REVENUE ADEQUACY

- The revenue collected by the ISO with locational prices should at least equal the payments to the FTR holders
- Simultaneous feasibility implies revenue adequacy: $Y = \sum_k t_k^f$

$$L(Y, u) + \tau^t Y = 0,$$

$$K(Y, u) \leq 0$$

The Auction Model

- The FTR expansion model relies on an institutional structure with established agents as generators, a gridco (transmission provider separate from ISO) and marketers interested in transmission expansion
- Initially it is assumed that there are unallocated or proxy FTRs in the network

The Auction Model

Awards of incremental FTRs should satisfy the following criteria:

1. *Feasibility rule*: If T is the current partial allocation of long-term FTRs, an LTFTR increment must keep being simultaneously feasible, $K^{+}(T+a\delta,u)$
2. *Proxy awards*: An incremental FTR award ($a\delta$) remains simultaneously feasible, given that certain currently unallocated rights $\hat{t}\delta$ (proxy awards) are preserved $K^{+}(T+\hat{t}\delta+a\delta,u)\leq 0$

The Auction Model

3. *Maximum value*: Investors should maximize their objective function $\beta(a\delta)$
4. *Symmetry*: The expansion protocol should apply for both decreases and increases in the network capacity

The Auction Model

$$\underset{a,\hat{t},\delta}{Max} \quad \beta(a\delta)$$

$s.t.$

$$K^{+}(T + a\delta) \leq 0,$$

$$K^{+}(T + \hat{t}\delta + a\delta) \leq 0,$$

$$\hat{t} \in \arg\max_{t} \left\{ tp\delta \mid K(T + t\delta) \leq 0 \right\},$$

$$\|\delta\| = 1,$$

$$a \geq 0.$$

The Auction Model

$$L(\hat{t}, \delta, \lambda) = \hat{t} p \delta - \lambda^T (K(T + \hat{t}\delta))$$

$$\frac{\partial L(\hat{t}, \delta, \lambda)}{\partial \hat{t}} = 0, \quad \frac{\partial L(\hat{t}, \delta, \lambda)}{\partial \lambda} \geq 0$$

$$\lambda^T \frac{\partial L(\hat{t}, \delta, \lambda)}{\partial \lambda} = 0, \quad \lambda \geq 0$$

The Auction Model

$$\max_{a,\lambda,\delta,\hat{t}} \quad \beta(a\delta)$$

$$K^{+}(T + a\delta) \le 0, \qquad (\omega)$$

$$K^{+}(T + \hat{t}\delta + a\delta) \le 0, \qquad (\gamma)$$

$$\frac{\partial L(\hat{t},\delta,\lambda)}{\partial \hat{t}} = 0, \qquad (\theta)$$

$$\lambda^{T} \frac{\partial L(\hat{t},\delta,\lambda)}{\partial \lambda} = 0, \qquad (\zeta)$$

$$\frac{\partial L(\hat{t},\delta,\lambda)}{\partial \lambda} \ge 0, \qquad (\varepsilon)$$

$$\|\delta\| = 1 \qquad (\varphi)$$

$$a \ge 0 \qquad (\kappa)$$

$$\lambda \ge 0 \qquad (\pi)$$

The Auction Model

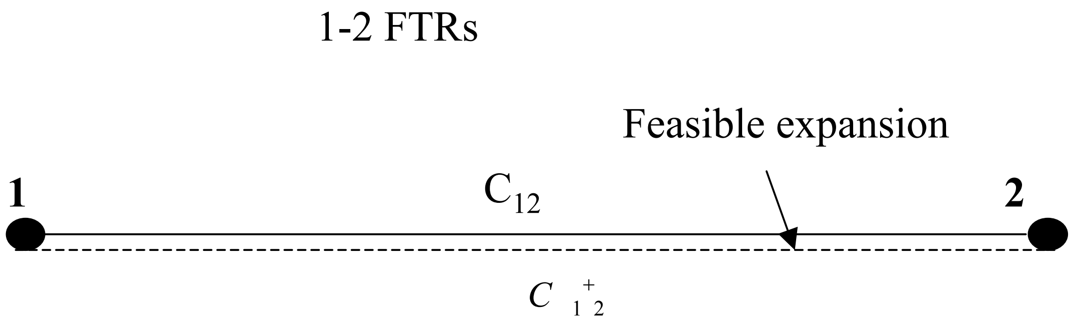
$$L(a,\hat{t},\delta,\lambda,\Omega) = \beta(a\delta) - \omega^T (K^+ (T + a\delta))$$

$$-\gamma^T (K^+ (T + \hat{t}\delta + a\delta)) - \theta^T \frac{\partial L(\hat{t},\delta,\lambda)}{\partial \hat{t}}$$

$$-\zeta^T (\lambda^T \frac{\partial L(\hat{t},\delta,\lambda)}{\partial \lambda}) + \varepsilon^T \frac{\partial L(\hat{t},\delta,\lambda)}{\partial \lambda}$$

$$+\phi^T (1 - \delta^2) + \kappa^T a + \pi^T \lambda$$

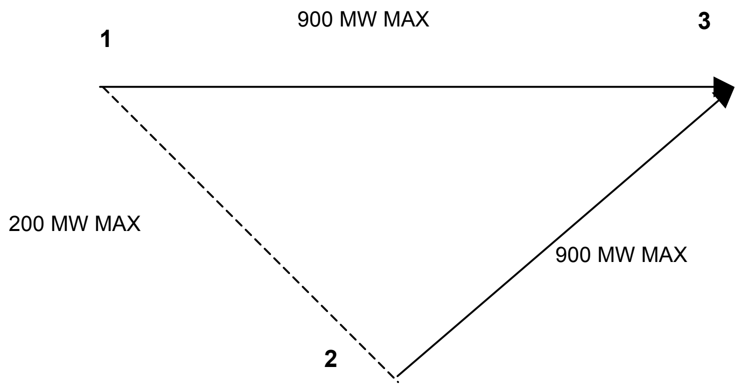
Radial Line

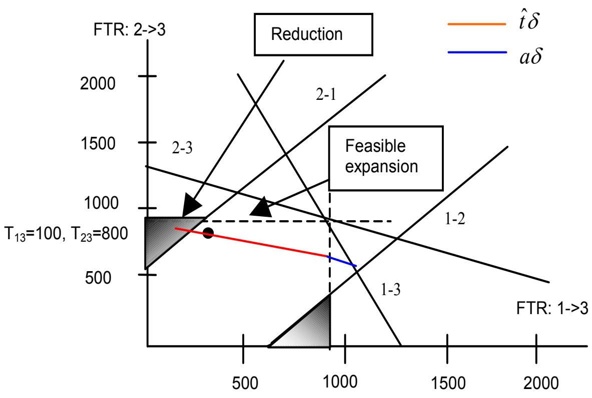


$$\delta_{12} = 1 \qquad \hat{t} = C_{12} - T_{12} \qquad a = C_{12}^{+} - T_{12} - \hat{t} = C_{12}^{+} - C_{12}$$

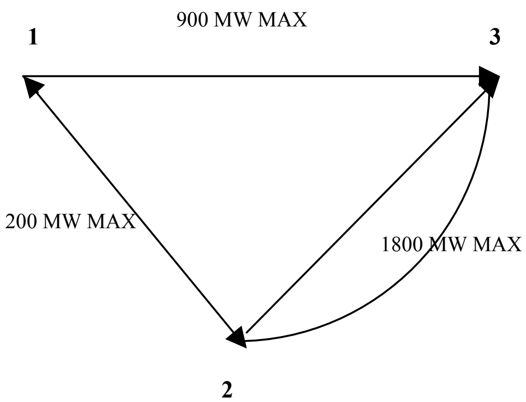
$$\gamma = b_{12} \qquad \lambda = p_{12} \qquad \zeta = \gamma / p_{12} = b_{12} / p_{12}$$

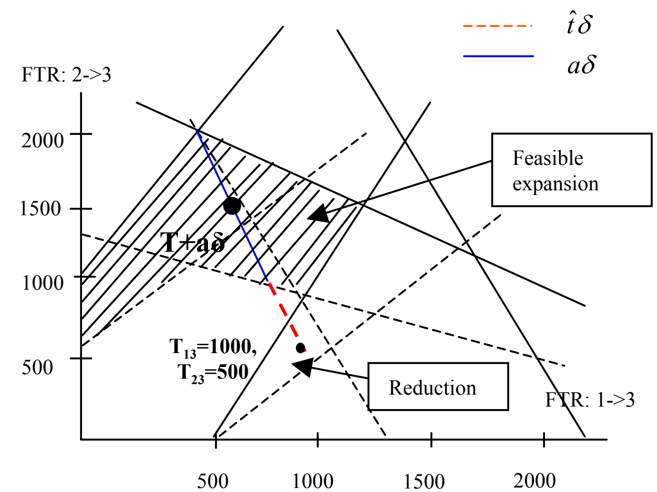
Three-Node Network





Three-Node Network





Conclusions

- Internalization of possible negative externalities caused by potential expansion is possible according to the rule proposed by Hogan: allocation of FTRs before (proxy FTRs) and after (incremental FTRs) the expansion is in the same direction and according to the feasibility rule
- In the Bushnell and Stoft (1997) example, the investor will have to take FTRs with a negative value
- Requires that FTRs are used by each agent as a perfect hedge for their net load. No one will then benefit from an expansion that reduces welfare
- Our mechanism implicitly achieves this last property but through the use of proxy awards

Conclusions

- A bi-level programming model for allocating long-term FTRs along with transmission expansion has been provided
- Incremental FTR awards are allocated according to investor preferences and depend on the initial partial allocation of FTRs and network topology before and after expansion
- Investment protocol: a proxy award is the best use of the grid along the same direction
- LTFTRs are efficient under non-lumpy marginal expansions of the transmission network, and lack of market power
- Establish a rule in practice for drawing a line between merchant and regulated investment