Transmission charging and market distortion

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IPAM workshop, UCLA

January 13, 2016

Outline

- Background of transmission pricing:
  - Merchant transmission.
  - Volume versus peak charges.
  - Beneficiaries-pay SPD charge method.
- Equilibrium models with charges on Ricardian rents.
  - A Cournot model.
  - Supply function equilibrium.
  - Price-taking agents.
- Supply function equilibria with beneficiaries-pay transmission pricing.
  - Definition of "benefits".
  - Example with uniform demand shock.
  - Welfare analysis.
- Conclusions.

What is the value/cost of a transmission grid?

The transmission grid provides a number of different benefits:

- reliability;
- competition benefits;
- short-run efficiency;
- the ability to access electricity when needed.

The cost of a transmission line is mainly in its construction, and there are large economies of scale. The cost of using the line is near $0 / MWh.

Merchant transmission investment?

Typically, the transmission grid is operated as a regulated monopoly, where investments in the grid are made to improve the overall social welfare of the system.

In economic theory, locational marginal prices should deliver congestion rentals to the grid operator to fund investment in the grid. Would like these to provide ex-ante incentives for market-like investments.

Practical complications[1]

- the price signal is valid at the margin, whereas investment in transmission is "lumpy" and future focused;
- transmission investment takes place to improve security and reliability as well as real-time power delivery.

So congestion rentals alone are insufficient to pay for what is deemed required investment in the transmission grid. Leads to a cost recovery problem.

[1] Joskow, P. & Tirole, J. (2005). Merchant Transmission Investment. *Journal of Industrial Economics*, 53(2), 233-264.

Cost recovery

Transmission pricing seeks to recover the costs of transmission investment from market participants, namely:

- distribution network owners (on behalf of their customers);
- directly connected consumers (large industrials);
- generators.

These costs should be designed so as to promote both static and dynamic efficiency.

In particular, if a line has been built it is desirable that:

- the line be used to reduce short-run (fuel) costs;
- the charging mechanism does not distort efficient locational price signals.

Transmission pricing methodologies

- MISO (postage stamp rates, 80% to load 20% to generators);
- PJM (investment costs are collected from those deemed to benefit from the investment).[2]
- Argentina (affected market participants approve, and users pay).[3]

[2] Hogan, W.W. (2011). Transmission benefits and cost allocation, May 31. JFK School of Government, Harvard University.

[3] Littlechild S.C. & Skerk C.J. (2008). Transmission expansion in Argentina 1: The origins of policy. *Energy Economics*, 30, 1367-1384.

New Zealand electricity grid.[4]

[4] Ministry for the Environment; http://www.mfe.govt.nz/publications/rma/national-environmental-standards-electricity-transmission-activities-introduction

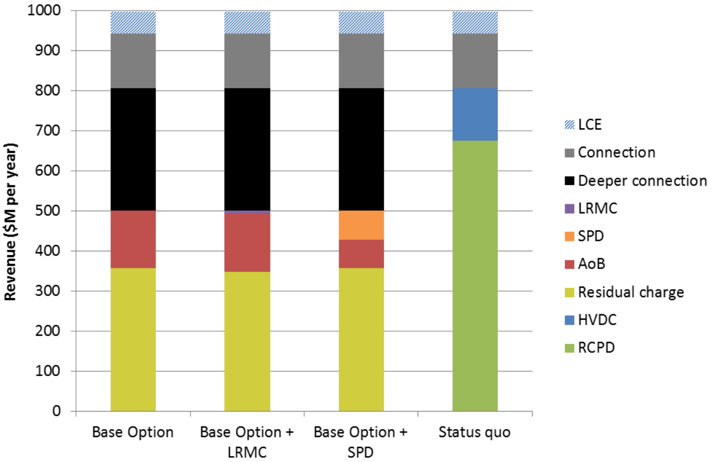
Transmission pricing proposals in New Zealand

Currently the transmission pricing methodology (TPM) has three main charges:

- connection charge ($130m);
- HVDC charge ($150m);
- interconnection charge ($630m).

A market-based (or market-like) approach is being sought, where the beneficiaries of the investment pay.

Estimated revenue from each charge



Revenue collected under proposals.[5]

[5] Electricity Authority; Transmission pricing methodology review: TPM options. 16 June 2015.

What should users pay for?

Debate over users of the grid avoiding regional coincident peak demand (RCPD) charges by load shifting. Inflexible participants advocate:

- less emphasis on peak-load charging (RCPD).
- more emphasis on charging by volume (deep connection and SPD charges).

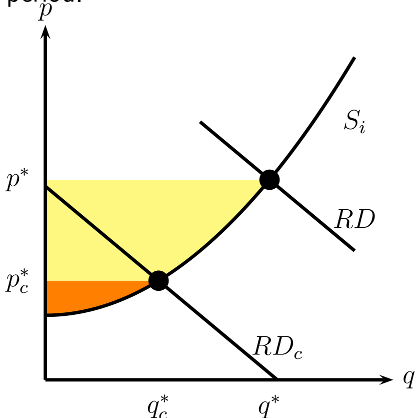
But volume-based charges are clearly distortionary. We are interested in understanding these distortions. We focus on the SPD charge.

SPD = "Schedule Price Dispatch" the DCOPF dispatch software. The benefits of an asset are computed using two runs of the software, with and without the asset.

SPD Charge methodology

The SPD charge is equal to a proportion α of the perceived benefits of a line expansion to market participants, where α is chosen to recover the required amount.

For a generator, these perceived benefits are computed by SPD based on the change in their infra-marginal or Ricardian rents, given their supply curve offer. This benefit will be computed for every trading period.



Incentive to conceal perceived benefits

One of the concerns of this approach is that generators and other market participants may be able to conceal their perceived benefits by changing their offer.

This could lead to inefficiency in the dispatch model as well as shifting the burden of paying for the transmission asset onto those market participants who cannot or do not behave strategically.

We will show that:

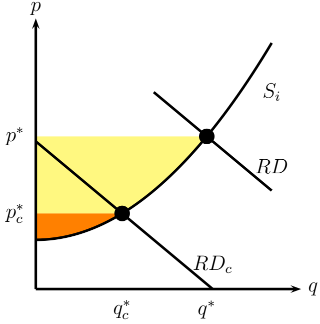
- with known demand, generators can avoid charges altogether;
- with uncertain demand, a firm must balance its incentive to minimize the transmission charge against the incentive to maximize its profit in the current period.

Charge on Ricardian Rents

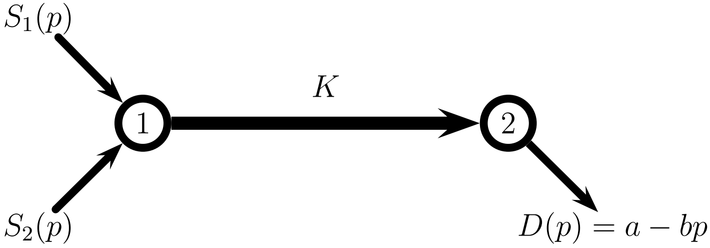
We will initially present a model whereby a charge is simply applied in proportion to the Ricardian rents of a generator (rather than to the benefits).

This is simpler to model, however, we will later see that it still has much in common with the charge on benefits.

To illustrate some of the incentives to avoid the charge, we will first consider the change in behaviour of a Cournot agent with deterministic demand.

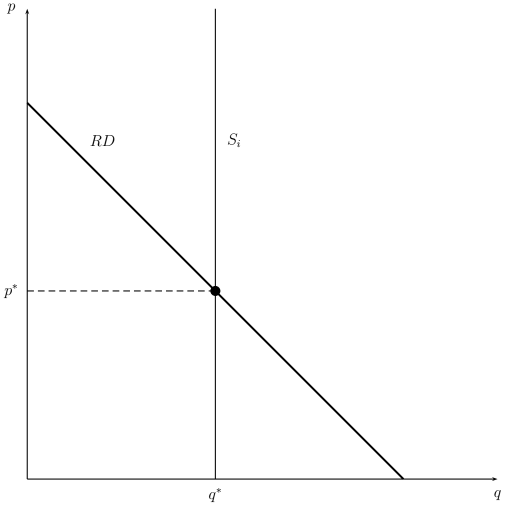


Cournot duopoly model

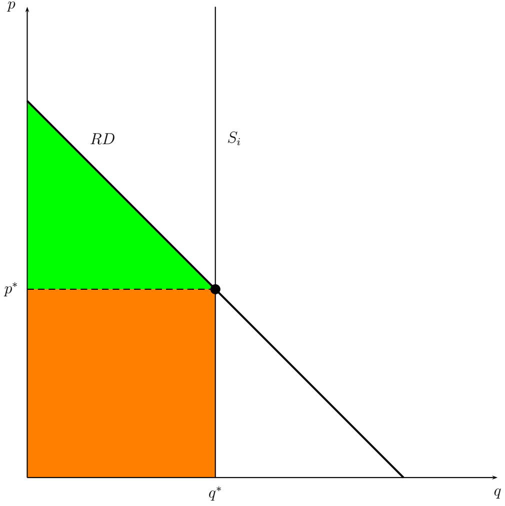


Cournot players offer supply curves $S_i(p) = q_i$

Cournot duopoly model

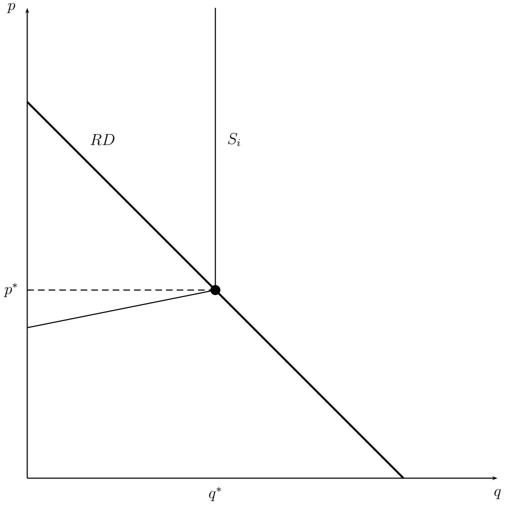


Cournot duopoly model



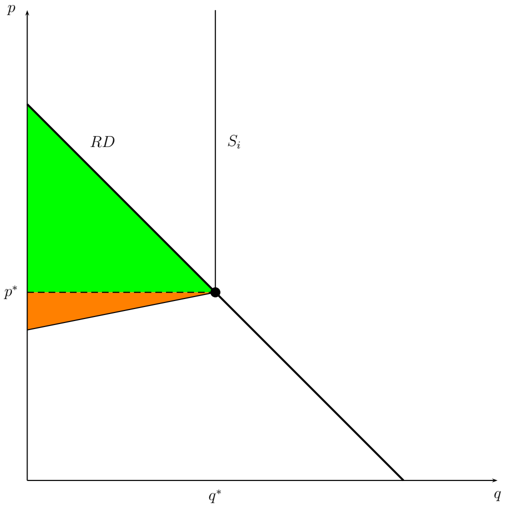
Charge on Ricardian rents

A small portion $\alpha < \frac{1}{2}$ of perceived producer surplus is taxed. Generators respond by marking up below the dispatch quantity (which has no effect of the dispatch point).



Charge on Ricardian rents

Strategic producer benefits are hidden. Price taking generators and consumers are less able to conceal their benefits, leaving them with a larger share of the transmission charges.

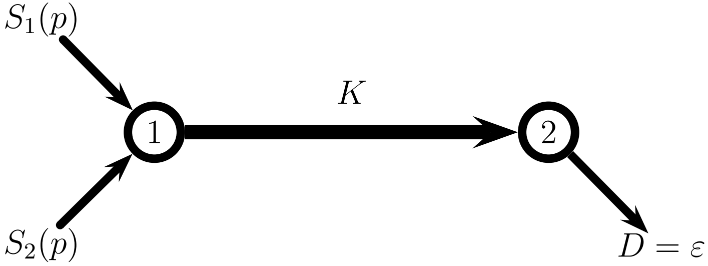


Implications for SPD Charge transmission pricing

- In this model, producers can 'hide' all of their producer surplus and thus not have to contribute to the cost of the grid investment.
- However, this result relies on the demand (curve) being known in advance.
- What happens under more realistic assumptions about demand uncertainty?

Supply function equilibrium model

Now consider the same network, but now demand at node 2 is uncertain (but no longer elastic).



$\varepsilon \sim U[\underline{\varepsilon}, \bar{\varepsilon}]$

Profit maximization by suppliers

Generators try to maximize their profit functional

$$\Pi = \int_S q(p-c)d\psi(q,p) = \int_c^{\overline{p}} (p-c)q(\psi_p + q'\psi_q)\, dp.$$

- c is the marginal cost; $\overline{p}$ is the price cap,
- $\psi(q,p)$ is the market distribution function[6] (the probability that an offer of q MW at price p is not fully dispatched).
- ψ_q and ψ_p are the partial derivatives of ψ.

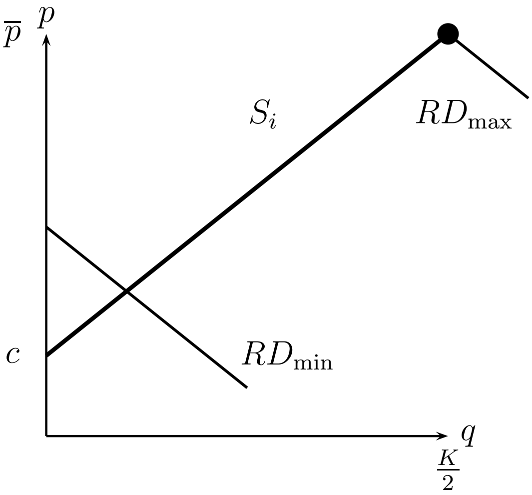
First-order optimality conditions (Euler-Lagrange)

$$Z(q,p) = (p-c)\psi_p - q\psi_q = 0$$

yields a system of differential equations. In symmetric duopoly this is a single o.d.e. that has solution of a linear supply curve through $(c,0)$ and $(\overline{p}, \frac{K}{2})$

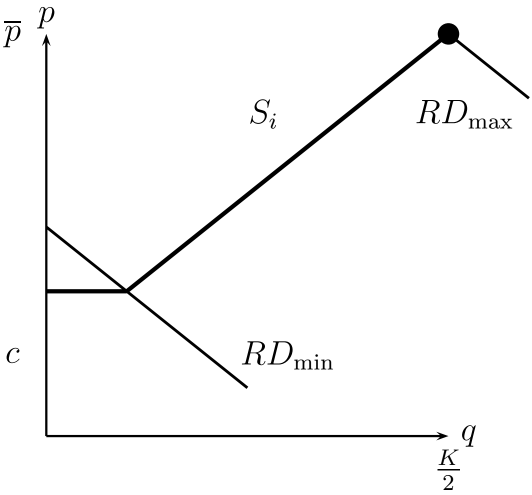
[6] Anderson, E.J. & Philpott, A.B. (2002). Optimal offer construction in electricity markets. *Mathematics of Operations Research*, 27, 82-100.

Incentives to mark-up



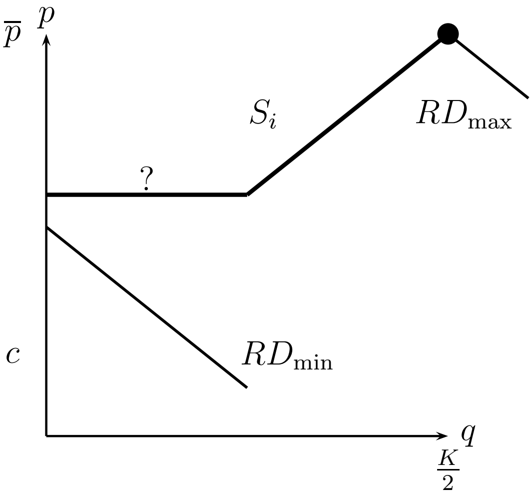
What might happen with a charge on Ricardian rents? Suppose that $\alpha = 25\%$ of perceived producer profits is charged to fund transmission investment.

Marking up in response to the charge – undispatched segment



A gradient discontinuity in any undispatched part of offer curve is OK.

Marking up in response to the charge – dispatched region



What about further up the curve, in the part that is sometimes dispatched?

Duopoly SFE with a charge on perceived benefits

New profit functional

$$\Pi = \int_c^{\overline{p}} (p-c)q(\psi_p + q'\psi_q) - \alpha q(1-\psi)\,dp.$$

First-order optimality condition becomes

$$Z(q,p) = (p-c)\psi_p - (1-\alpha)q\psi_q - \alpha(1-\psi) = 0.$$

$$\Rightarrow \quad \hat{Z}(q,p) = (p-c)\frac{\psi_p}{\psi_q} - (1-\alpha)q - \alpha\frac{1-\psi}{\psi_q} = 0.$$

Given offer quantity, q, and other generator's supply function $S_2(p)$, the probability of not being fully dispatched is:[7]

$$\psi(q,p) = \Pr[\varepsilon < q + S_2(p)] = (q + S_2(p))/\overline{\varepsilon}$$

$$\hat{Z}(q,p) = (p-c)S_2'(p) - (1-\alpha)q - \alpha\overline{\varepsilon} + \alpha(q + S_2(p)).$$

[7] So long as $q + S_2(p) \leq K$, otherwise the probability is 1.

Duopoly SFE with a charge on perceived benefits

If we set $q(p) = S_2(p) = S(p)$, then the condition $\hat{Z}(q, p) = 0$ gives first-order linear ODE

$$S'(p) = \frac{(1-3\alpha)}{p-c} S(p) + \frac{\alpha\bar{\varepsilon}}{p-c}$$

for the symmetric SFE.

General solution is

$$S(p) = A(p-c)^{1-3\alpha} - \frac{\alpha\bar{\varepsilon}}{1-3\alpha},$$

.

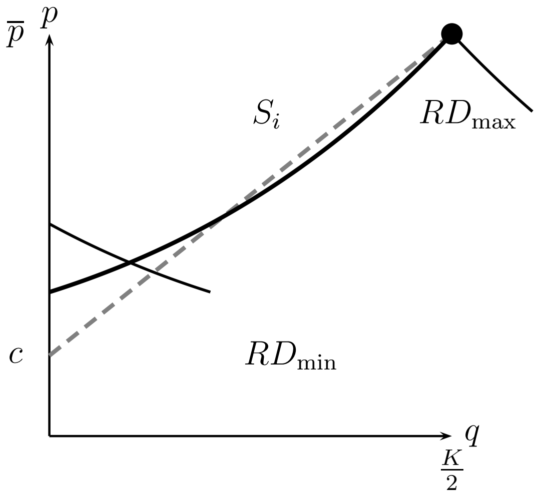
Since we assume that the line capacity is smaller than the highest levels of demand, A is determined by endpoint condition

$$S(\bar{p}) = \frac{K}{2},$$

(otherwise profitable deviation is possible).[8]

[8] Holmberg, P. (2008). Unique supply function equilibrium with capacity constraints. *Energy Economics*, 30(1), 148-172.

Equilibrium after charge applied



In order to avoid the tax, the firms, in equilibrium, mark-up their offer prices for low quantities, but may also mark-down as they approach the line capacity.

Price-taking agents

Market distribution function $\psi(q,p)$ for a price-taking agent is $\psi(p) = \Pr(P < p)$. Each producer seeks to maximize

$$\Pi = \int_0^{\overline{p}} (pq - C(q))\,\frac{d\psi}{dp} - \alpha q\,(1 - \psi(p))\;dp.$$

Euler-Lagrange condition is

$$\begin{aligned} Z^A &= (p - C'(q))\,\psi_p - (1-\alpha)\psi_q - \alpha\,(1-\psi) \\ &= (p - C'(q))\,\frac{d\psi}{dp} - \alpha\,(1-\psi) = 0. \end{aligned}$$

Symmetric equilibrium from industry supply curve

Assume inelastic demand ε with density f and c.d.f. F. Assume n symmetric generators with total supply Q. [9]

$$nS(p) = Q(p) = \varepsilon.$$

$$\psi(p) = \Pr(P < p) = F(\varepsilon) = \Pr(Q(P) < Q(p)) = F\left(Q(p)\right).$$

$$\frac{d\psi}{dp} = f(Q)\frac{dQ}{dp}$$

Industry cost function C_I has derivative at $Q = nq$ defined by $C_I'(Q) = C'(q)$. Thus

$$Z = (p - C'(q))\frac{d\psi}{dp} - \alpha\left(1 - \psi(p)\right) = 0.$$

$$(p - C_I'(Q))\, f\left(Q\right)\frac{dQ}{dp} - \alpha\left(1 - F\left(Q\right)\right) = 0.$$

[9]related model in Frederico & Rahman (2003). Bidding in an electricity pay-as-bid auction. *J. Regulatory Economics*, 24(2), 175-211.

Price-taking example

Two identical firms with

$$C(q) = q^2$$

Industry cost function is

$$C_I(Q) = \frac{1}{2}Q^2.$$

If demand shock is uniform on $[0, 1]$, ordinary differential equation for industry curve $Q(p)$ is

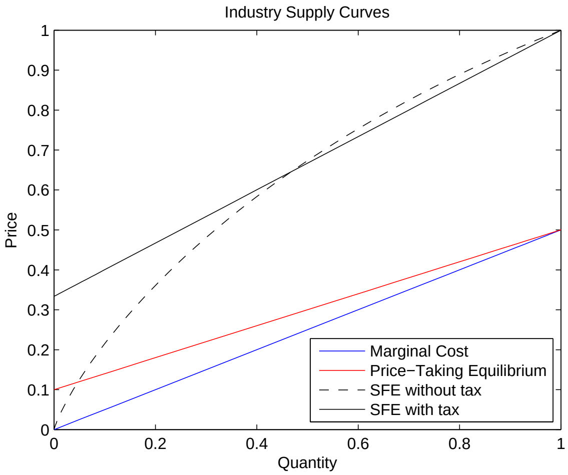
$$(p - Q)\frac{dQ}{dp} = \alpha(1 - Q), \qquad Q(1) = 1$$

$$Q(p) = (1 + \alpha)p - \alpha.$$

So each agent offers

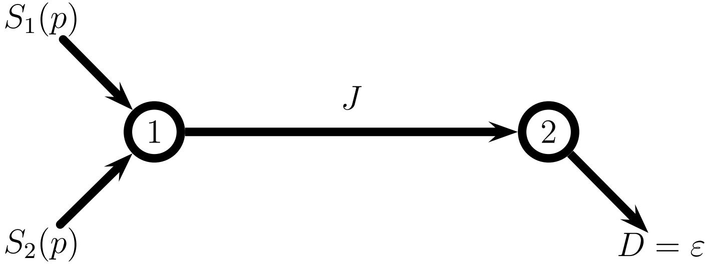
$$S(p) = \frac{(1 + \alpha)}{2}p - \frac{\alpha}{2}$$

Incentives for price-taking firms



Charge on benefit from expanded line

The SPD Charge method does not apply a charge based on the entire producer surplus, only based on the difference in Ricardian rents compared to some counterfactual.



$\varepsilon \sim U[\underline{\varepsilon}, \bar{\varepsilon}]$

This counterfactual is the state of the network prior to any line upgrade.

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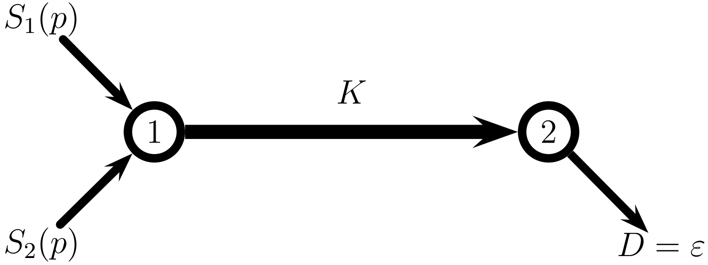
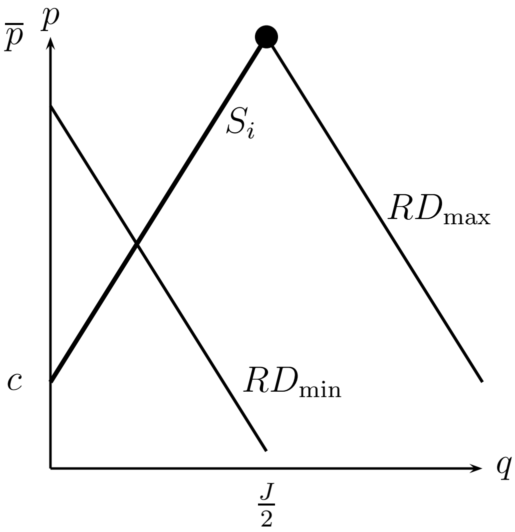


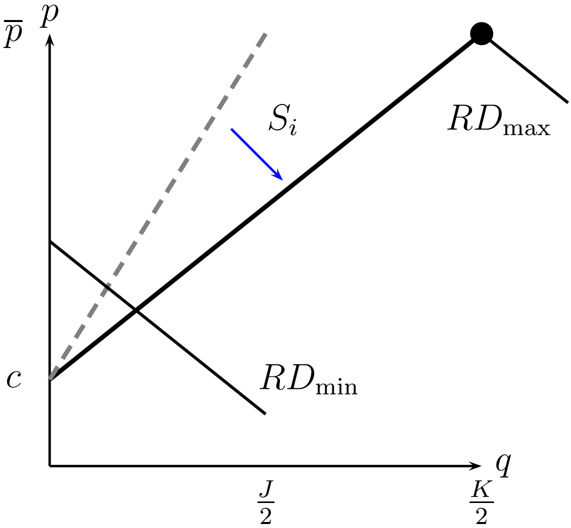
$$\varepsilon \sim U[\underline{\varepsilon}, \bar{\varepsilon}]$$

After the line upgrade we have the following network; the size of the line has increased from J to K.

Duopoly SFE with low-capacity line (no charge)



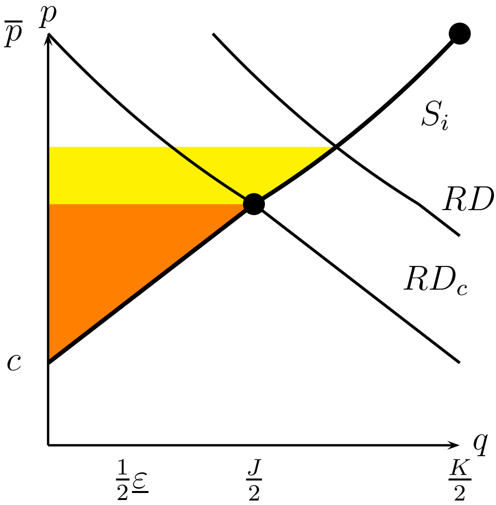
Duopoly SFE with expanded line (no charge)



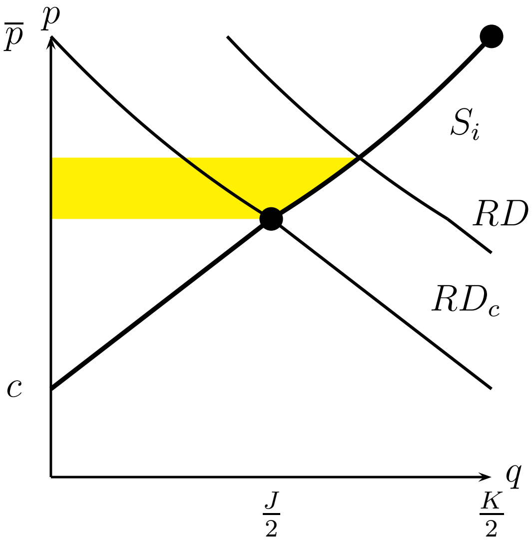
Larger capacity gives a flatter curve (more competitive). The SPD-method assumes that the offer stays the same – this would not be a valid assumption in this case.

Tariff on benefit from expanded line (dispatch $> \frac{J}{2}$)

Rather than paying a charge on the full producer surplus, the transmission charge is a proportion of the benefit accruing due to the increased line capacity.

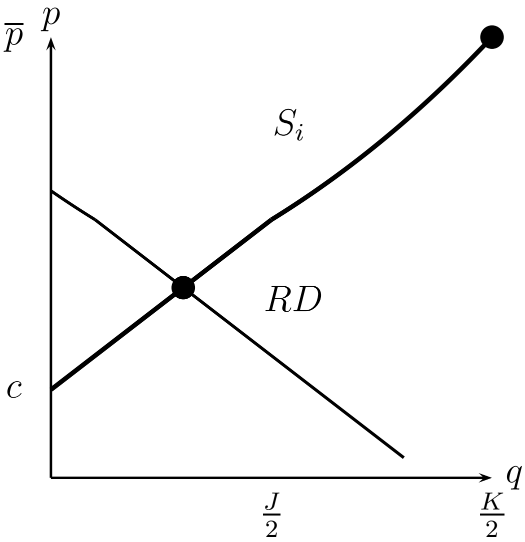


Charge on benefit from expanded line (dispatch $> \frac{J}{2}$)



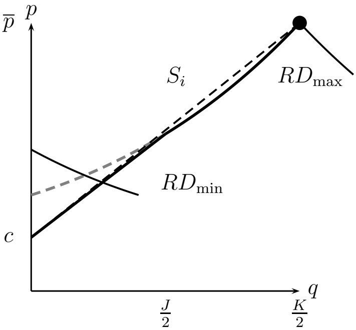
The charge will be based on this area (which depends on the realization of the demand shock).

Charge on benefit from expanded line (dispatch $\leq \frac{J}{2}$)



For dispatch below $\frac{J}{2}$, the actual and counterfactual dispatch points are the same, so there is no charge.

Equilibrium offer curve (charge on benefit)



For quantities below $\frac{J}{2}$, the equilibrium offer curve is straight, since there is no charge payable in this region (and it does not affect the perceived benefit).

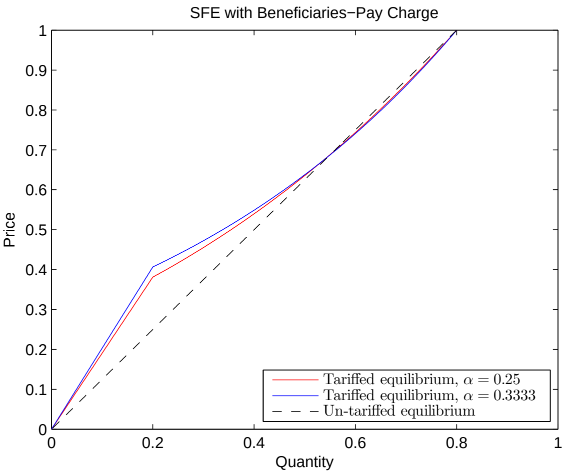
For quantities greater than $\frac{J}{2}$, the equilibrium curve matches the curve where the charge was applied to total perceived surplus.

Illustrative example

Consider a duopoly, over a network as shown earlier.

- The initial capacity of the transmission line is $J = 0.2$, and the line is expanded to $K = 0.8$.
- The marginal cost of both generators is $c = 0$, and there is a price-cap in the market of 1.
- The demand at node 2 is random, and uniformly distributed between $\underline{\varepsilon} = 0$ and $\bar{\varepsilon} = 1$.
- Firms are charged $\alpha = 25\%$ of their benefits.

SFE depends on the proportion of benefits charged.



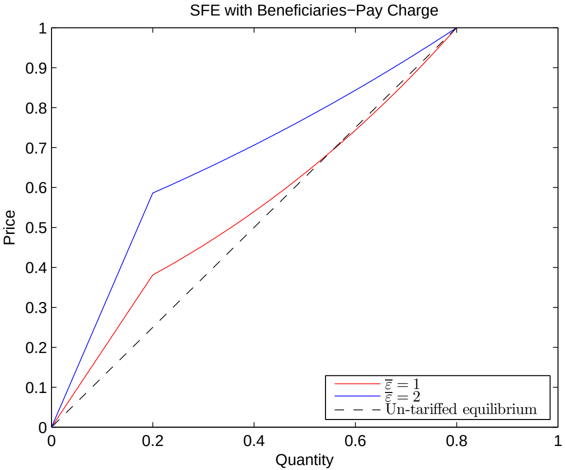
Welfare calculations

Curve	α	CS	Π^U	Π^T	Tax per firm	TS
S	0.25	0.1067	0.1067	0.0833	0.0233	0.32
S'	0.25	0.1003	0.1098	0.0887	0.0211	0.32

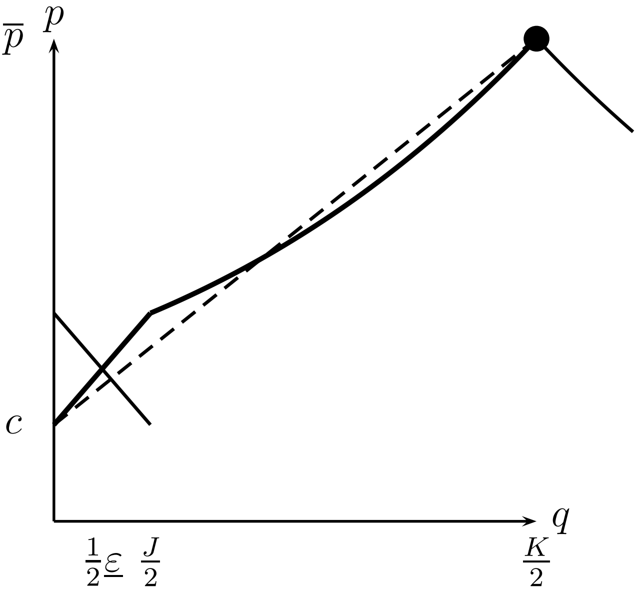
Table 1: Benefits and taxes with a charge on line-expansion benefits.

- S is the SFE offer assuming $\alpha = 0$,
- S' is the SFE offer with $\alpha = 0.25$,
- CS is the consumer surplus,
- TS is total surplus,
- Π^U and Π^T are untaxed and taxed per-firm profits.

SFE depends on the max demand shock



Overall markup depends on magnitude of expansion



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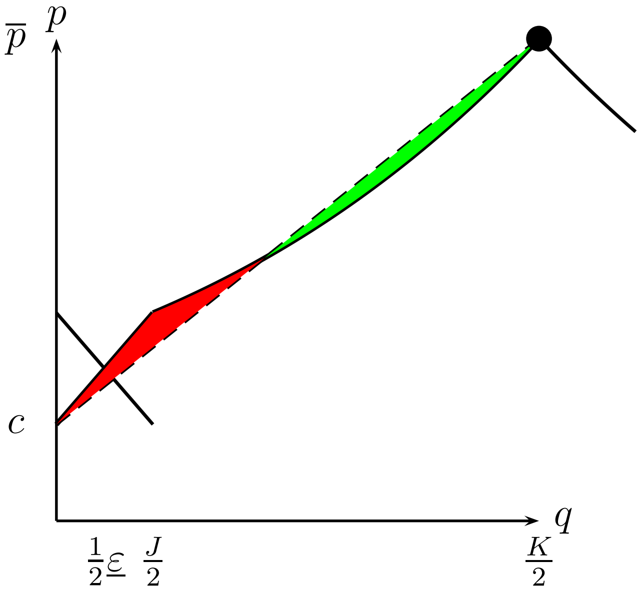

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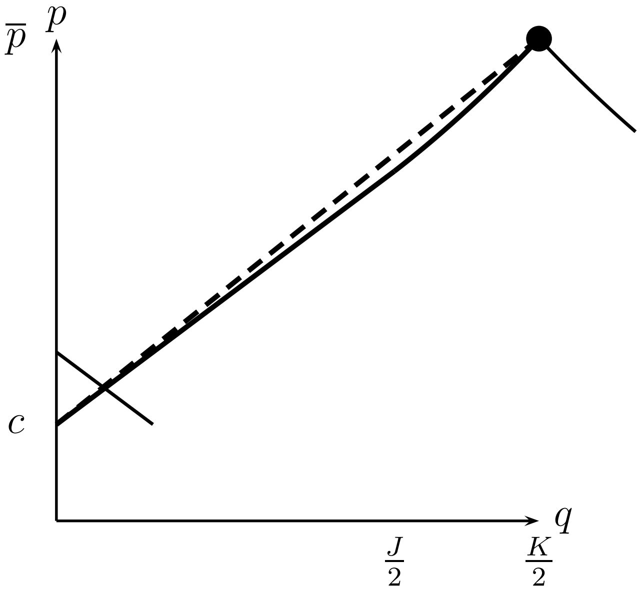

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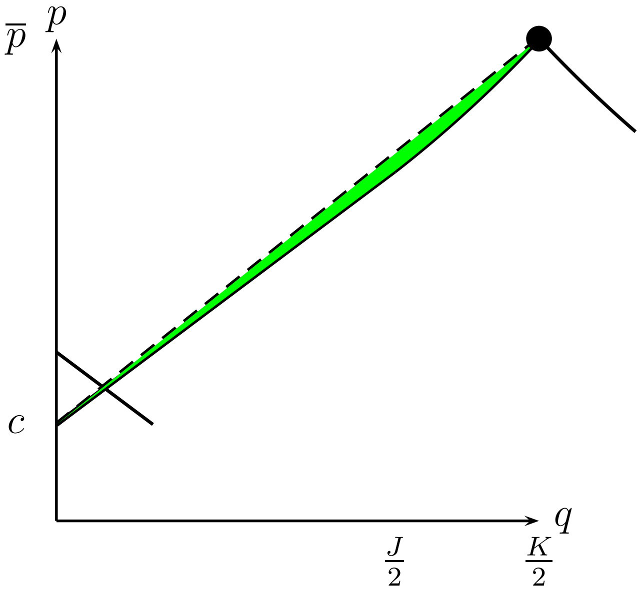
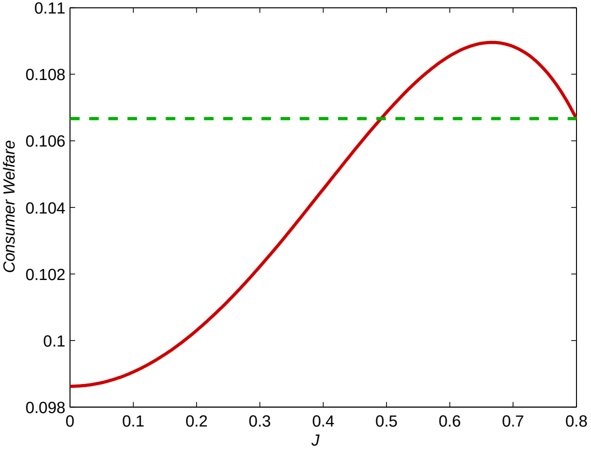
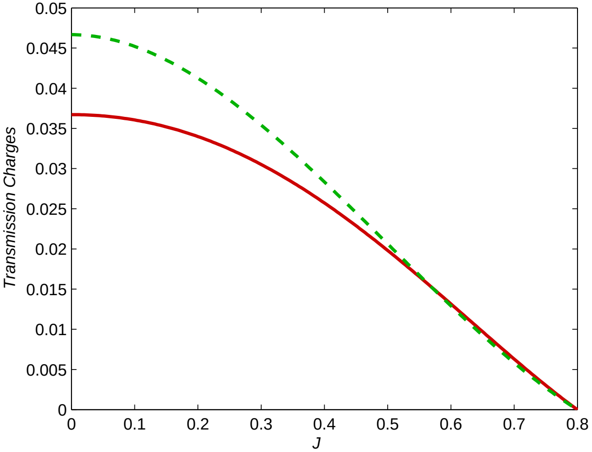


Consumer welfare comparison



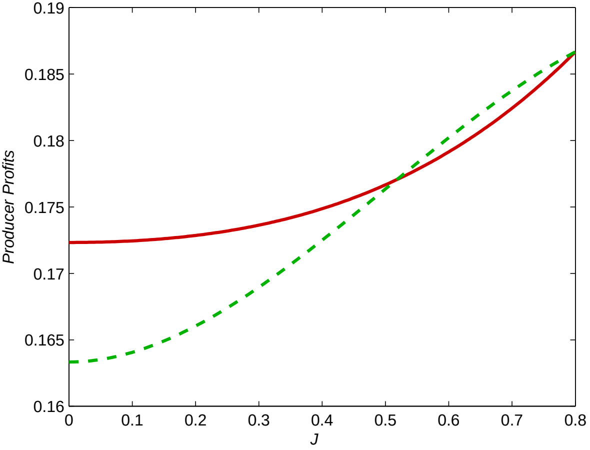
When $J < 0.5$ the expected consumer welfare drops as the firms try to avoid the charge; otherwise the consumers are better off.

Generator transmission charges comparison



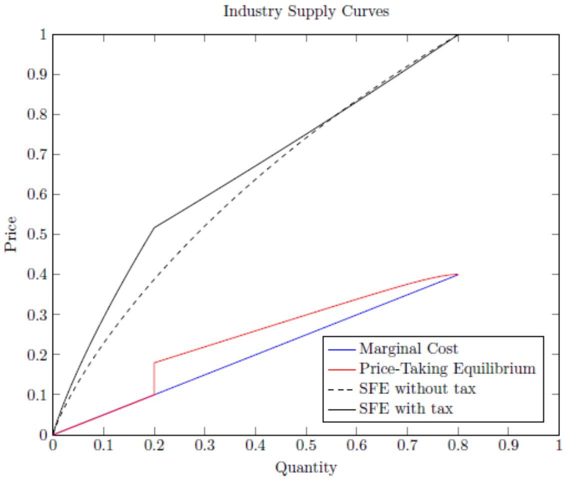
When $J < 0.58$ the expected charge drops as the firms change their behaviour; interestingly, the firms end up paying a slightly higher charge for small increases in line size.

Producer surplus comparison (after transmission charge)



When $\frac{J}{K} < 0.52$ the expected producer surplus increases as the firms try to reduce the charge paid. For smaller line upgrades the producers are worse off.

Comparison with perfect competition



Variance of demand shock affects outcomes

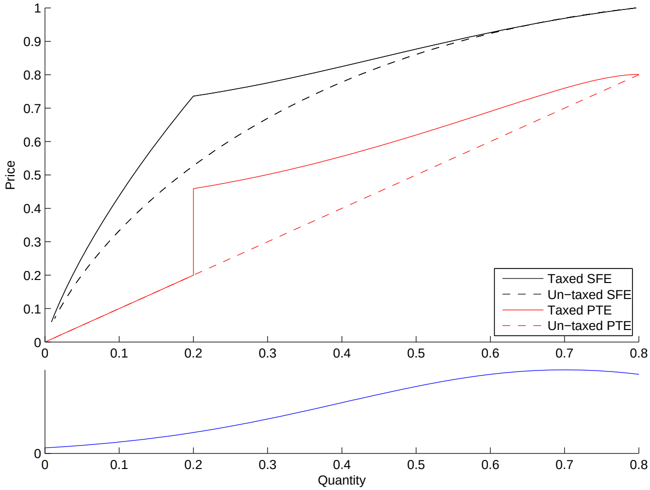


Figure 1: Equilibrium solution for example with normally distributed $\varepsilon \sim N(0.7, 0.2)$.

Reducing variance of demand destroys equilibrium

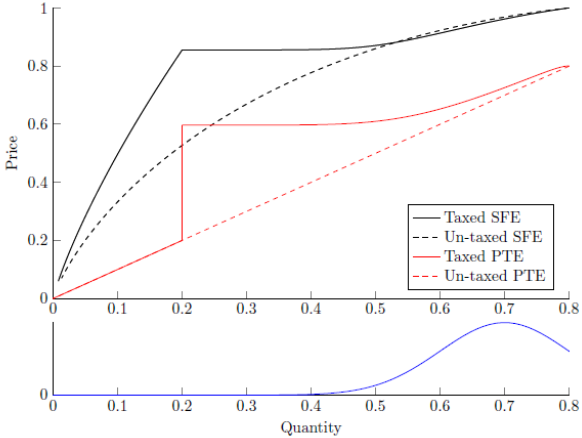


Figure 2: First-order solution for example with normally distributed $\varepsilon \sim N(0.7, 0.1)$.

Remarks

- If the charge is a small % of the benefits, the equilibrium is close to the uniform price SFE.
- Incentive to mark up the lower part of curve increases with probability of lost load and decreases with variance of demand shock.
- Competitiveness depends on size of transmission capacity expansion.
- Example equilibria are valid only if $\alpha < \frac{1}{2}$.

Conclusions

- Demand uncertainty reduces incentives to mark up offer curves to conceal perceived profits.
- A charge based on benefits does not give an incentive to mark-up at the low end of the offer curve, since it is the difference in profits from counterfactual that is taxed.
- With small-medium line expansions we found that generator competition would increase due to the charge, and consumer surplus and the total charge collected from generators would increase.
- For large line increases, consumer welfare decreases as firms mark up the low-quantity end of their curve to minimize their transmission charge.
- The SPD charge is retrospective. Related deep connection charges use flow tracing ex-post to allocate costs. Both give incentives to offer strategically in the spot market. A simpler alternative is to price the use of transmission directly within the dispatch software. Is this more or less distortionary than current proposals?

Thanks for your attention.

Any Questions?