Allocating the cost of transmission investment in the New Zealand electricity market

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Outline

- Background of transmission pricing:
  - Purpose of transmission pricing in electricity markets.
  - Proposals for transmission pricing in New Zealand.
  - How does the beneficiaries-pay SPD charge method work?
- Equilibrium models with charges on Ricardian rents.
  - Deterministic Cournot setting.
  - Oligopoly supply function equilibrium.
  - Perfect competition supply function equilibrium.
- Supply function equilibria with beneficiaries-pay transmission pricing.
  - Definition of 'benefits'.
  - Uniform demand shock example.
  - Welfare analysis.
- An alternate proposal.
  - Option value of the grid.
  - Pricing flow within SPD.
- 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.

Locational marginal pricing

In the NZEM, electricity is priced at the margin.

If all generation and demand is at the same location, this would mean that the price everyone pays or is paid for power is the same, and equal to the cost of the most expensive generator.

With a transmission grid, this concept extends to locational marginal prices.

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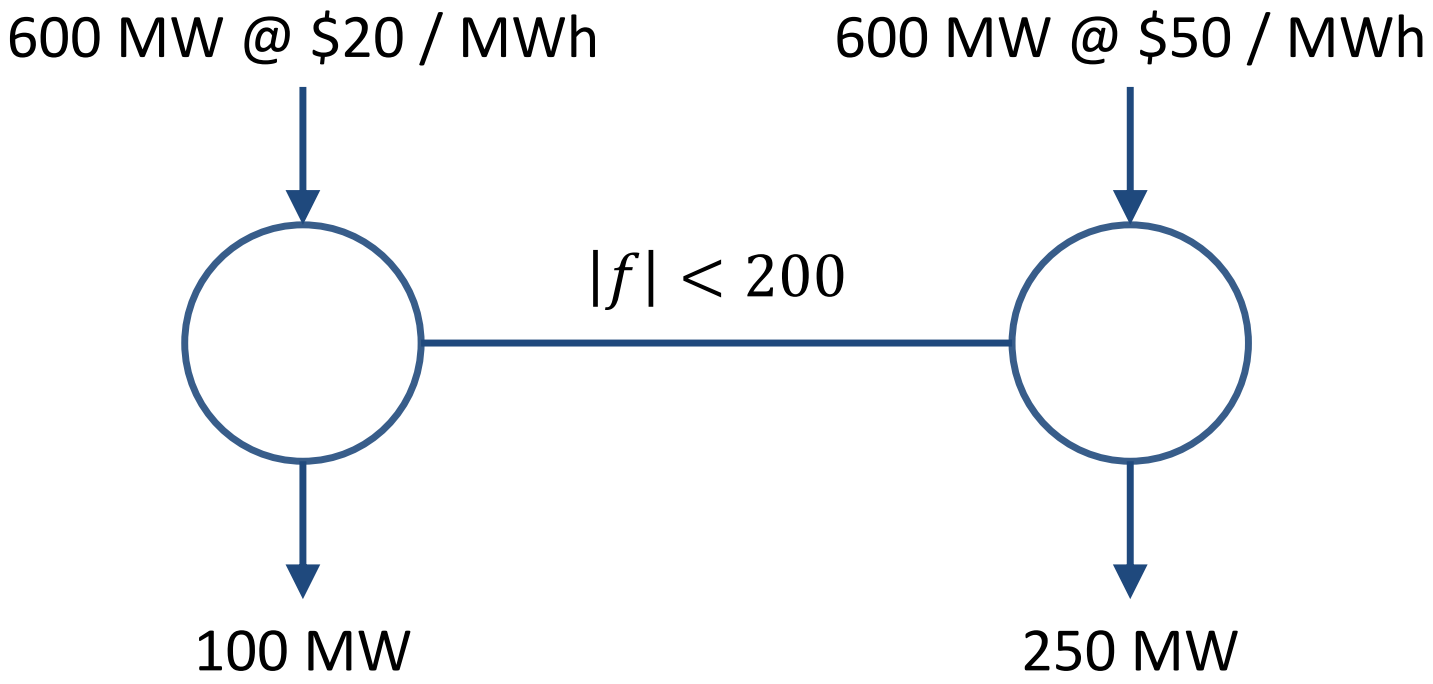

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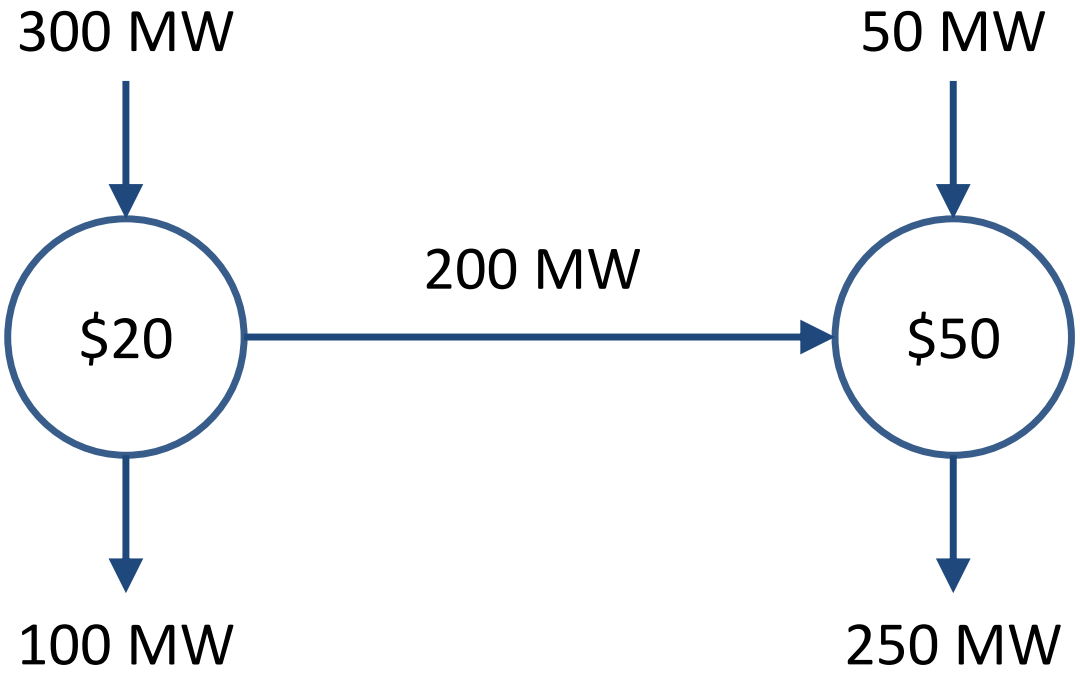

Total payments from consumers: $14500.
Total payments to generators: $8500.

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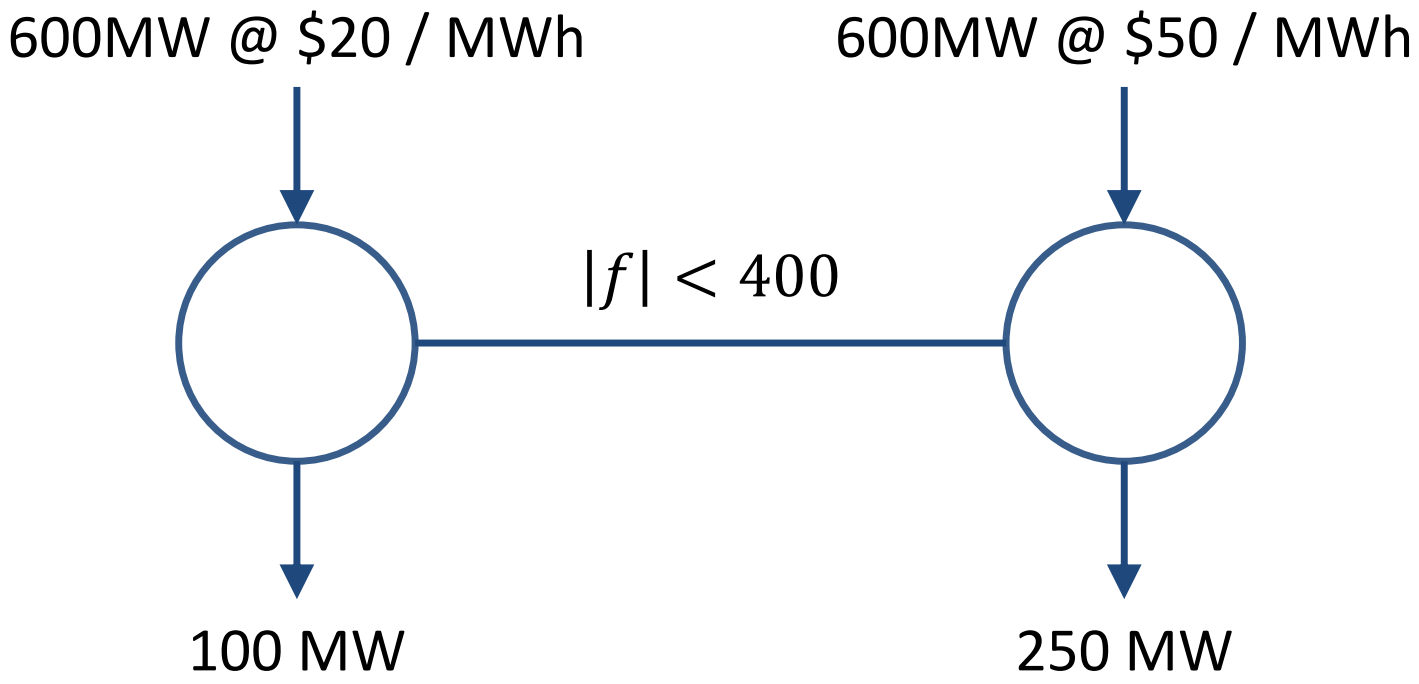

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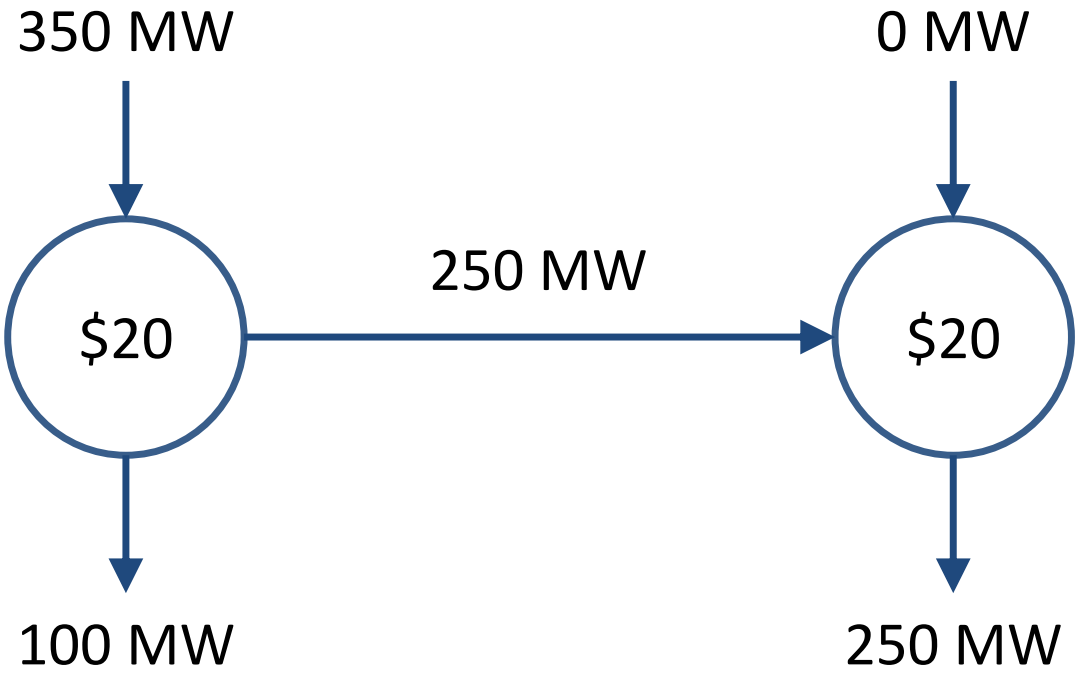


Total payments from consumers: $7000.
Total payments to generators: $7000.

Purpose of Transmission Pricing

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.

However, there are several practical complications with this approach, particularly:

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

For these reasons, congestion rentals are insufficient to pay for investment in the transmission grid.

Goal of Transmission Pricing

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.

However, these costs should be designed so as to promote both static and dynamic efficiency.

In particular, once a line is built it is desirable that:

- the line be used, thereby reducing fuel consumption;
- the charging mechanism sends the right (locational) price signals.

Transmission Pricing Methodologies

Various forms of transmission pricing have been applied:

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

There has been significant research into transmission cost allocation. For example:

- Joskow, P. & Tirole, J. (2005). Merchant Transmission Investment. *Journal of Industrial Economics*, 53(2), 233-264.
- Hogan, W. (2011). Transmission benefits and cost allocation, May 31. JFK School of Government, Harvard University.
- Littlechild S.C. & Skerk C.J. (2008). Transmission expansion in Argentina 1: The origins of policy. *Energy Economics*, 30, 1367-1384.

Transmission Pricing Proposals in New Zealand

Transmission pricing has been debated and discussed in New Zealand since the market was first established in 1996.

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

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

These are viewed by the Electricity Authority (EA) as not being:

- adaptive;
- cost reflective;
- efficient.

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

New Zealand electricity grid.[1]

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

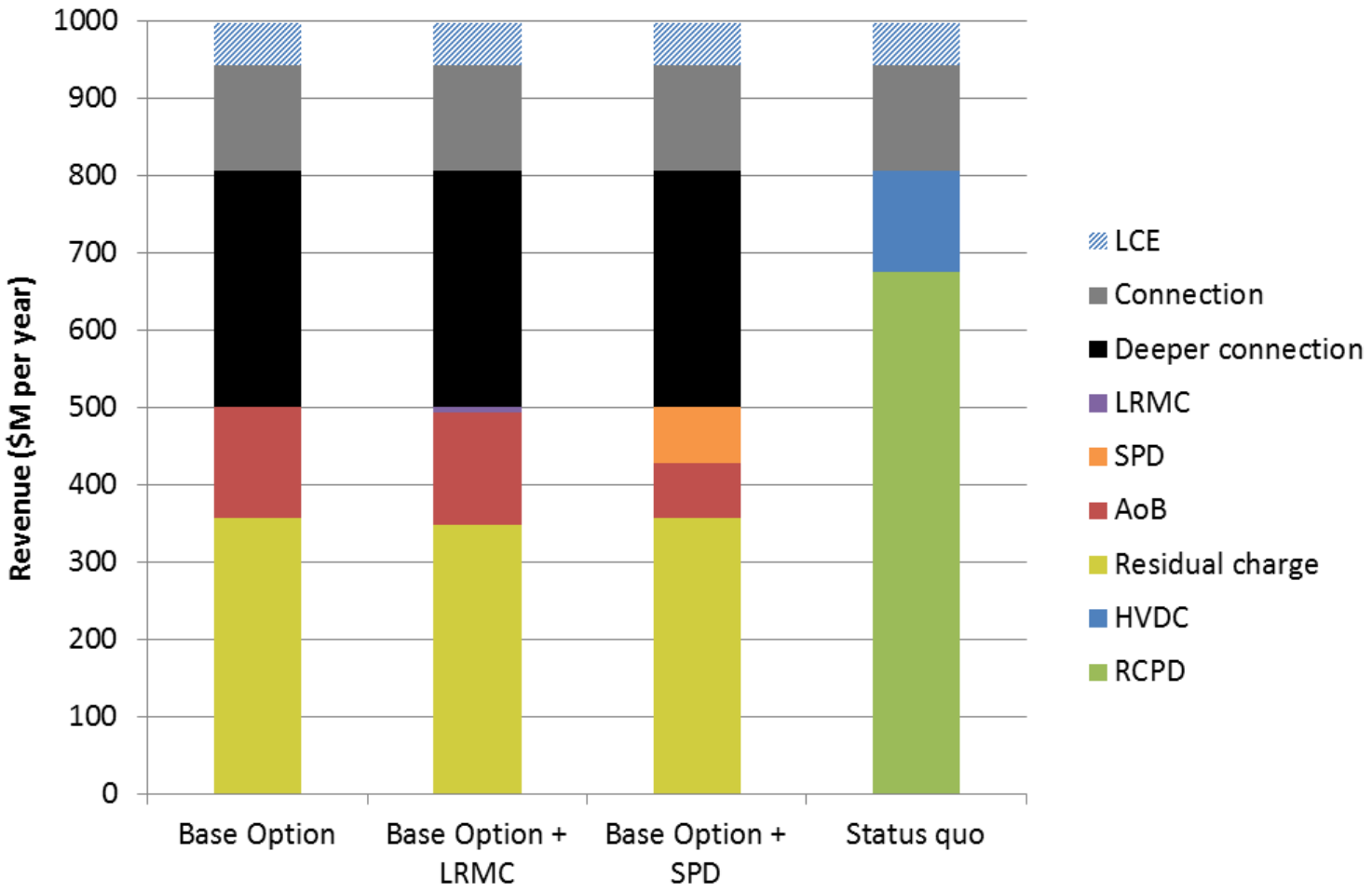
Transmission Pricing Proposals in New Zealand

In the Electricity Authority's latest TPM consultation document from June this year, a base package of charges were put forward to recover costs of transmission assets. This included:

- connection charge;
- deeper connection charge;
- area of benefit charge;
- residual charge.

One of the options is to also include a charge based on benefits, as computed from offers, with and without the grid asset. This is referred to as the SPD charge.

Estimated revenue from each charge



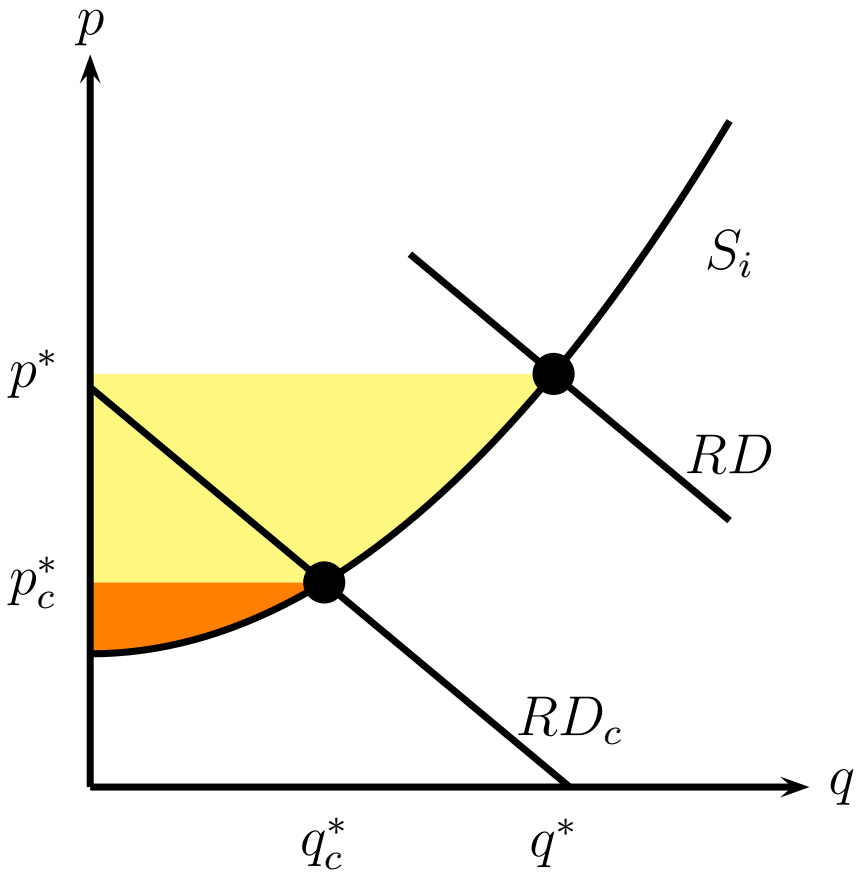
Revenue collected under proposals.[2]

[2] Electricity Authority; Transmission pricing methodology review: TPM options. 16 June 2016.

SPD Charge Methodology

The SPD charge is allocated based on the perceived benefits to market participants.

For a generator, these perceived benefits are computed based on the change in their infra-marginal or Ricardian rents, given their offer stack. 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:

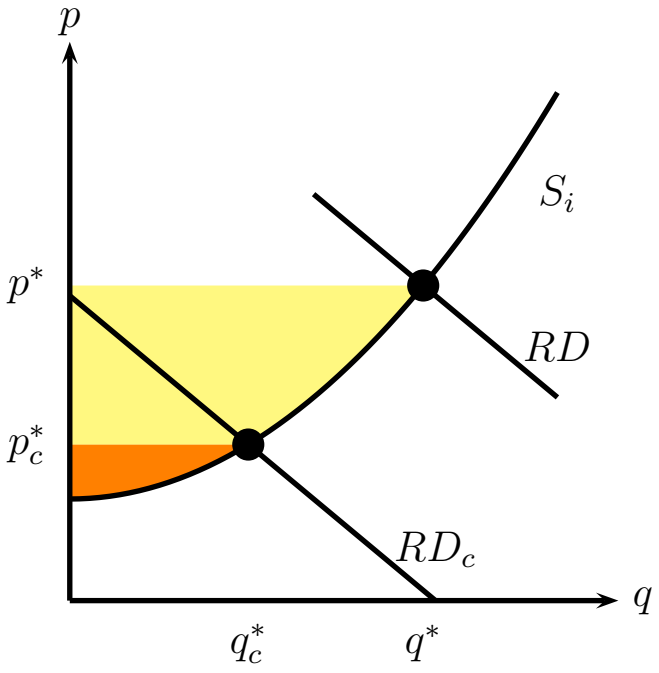
- with known demand, generators can avoid charges altogether;
- with uncertain demand, a firm must balance its incentive to minimize the transmission charge against the incentive to maximize its profit in the current period.

Charge on Ricardian Rents

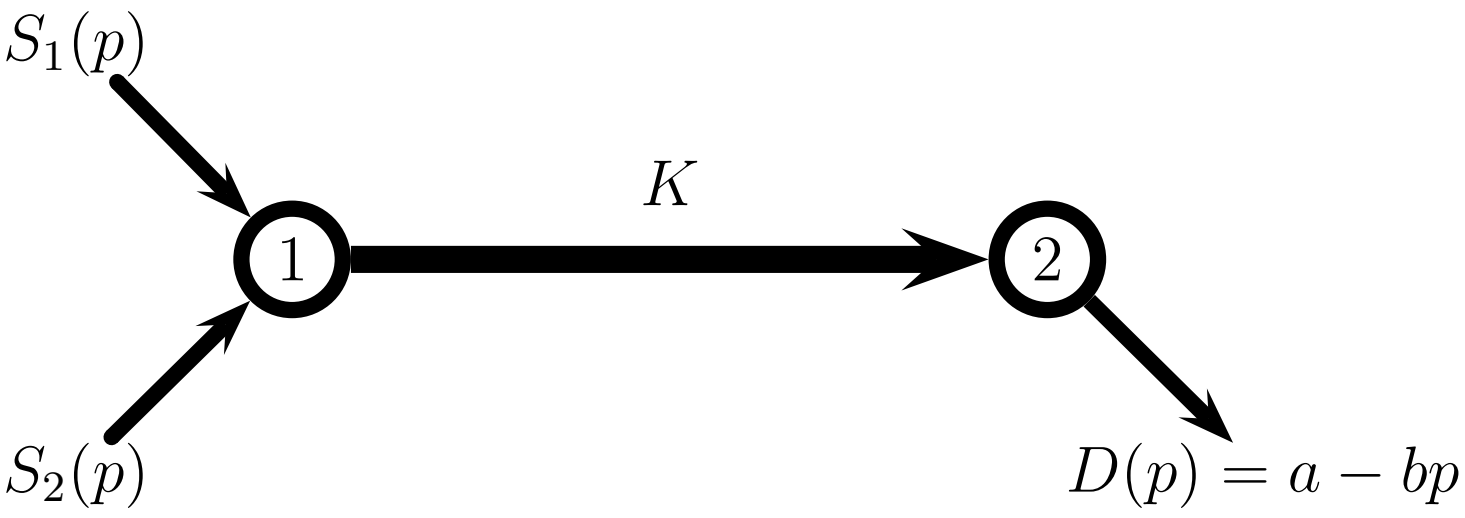
We will initially present a model whereby a charge is simply applied in proportion to the Ricardian rents of a generator (rather than to the benefits).

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 known demand.



Cournot Duopoly Model



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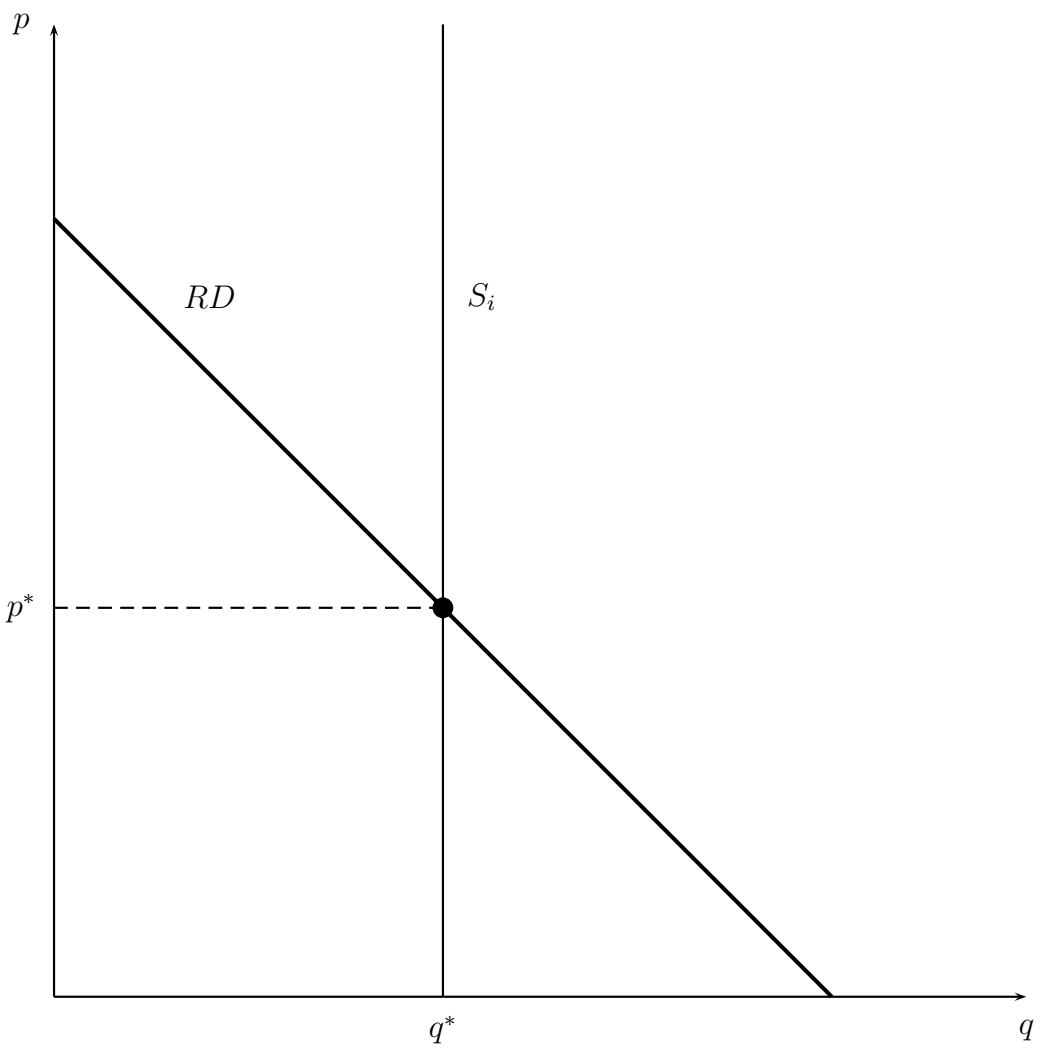

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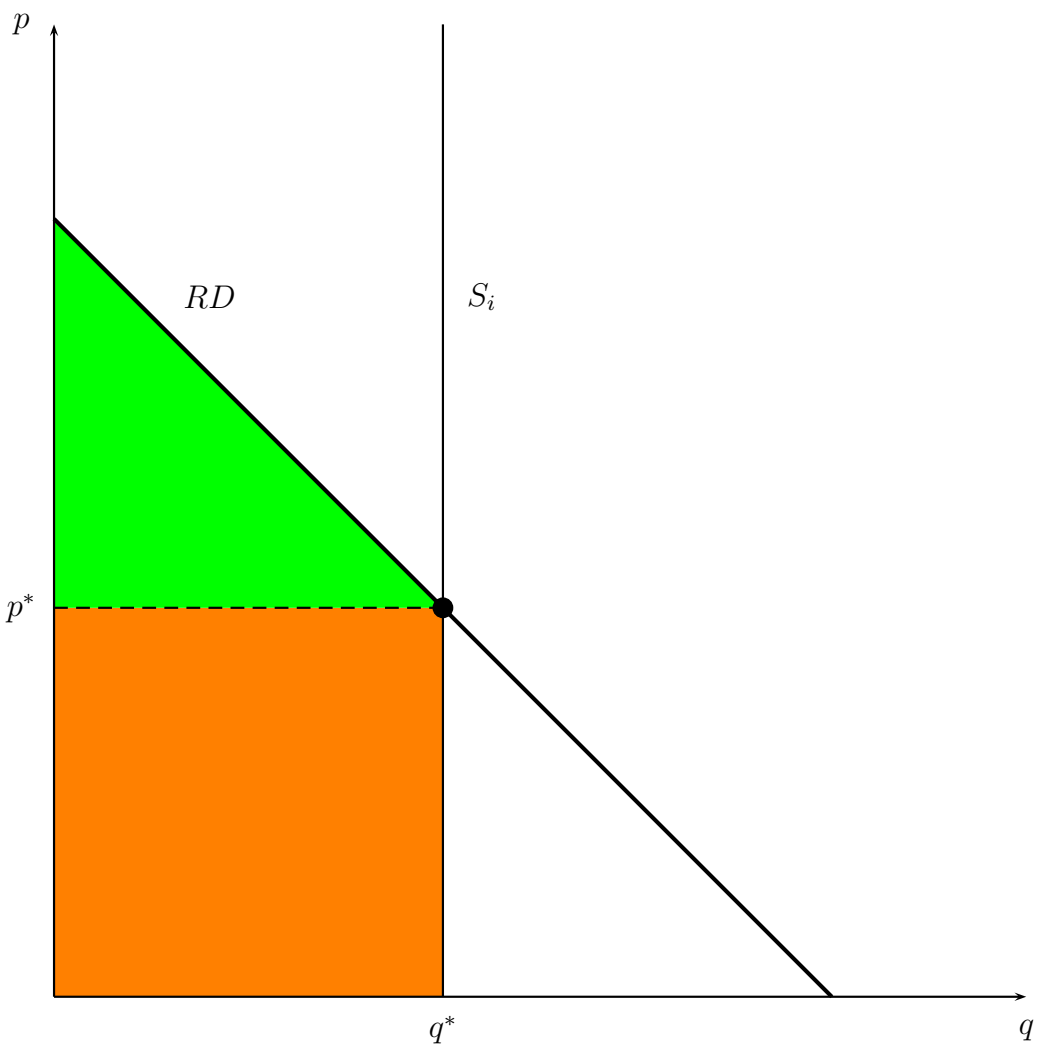
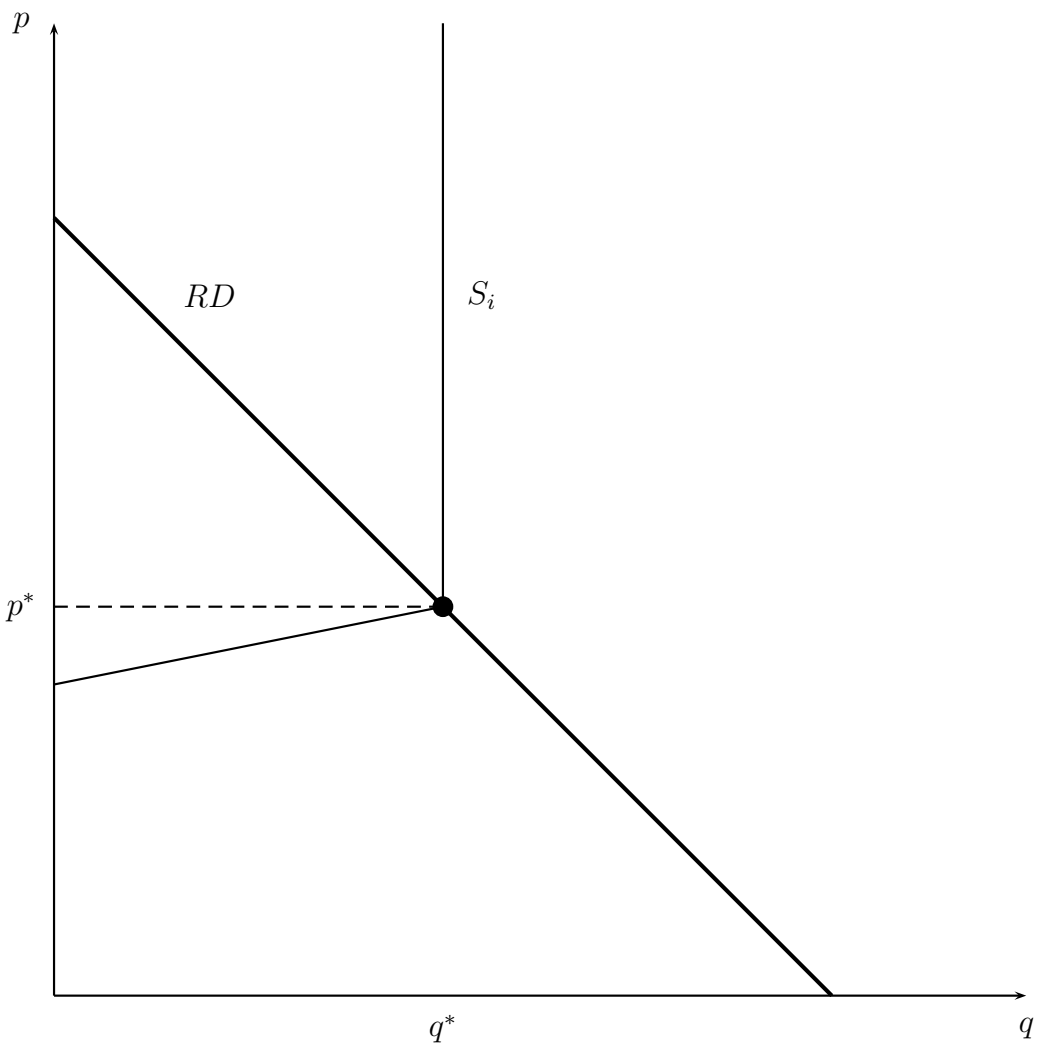


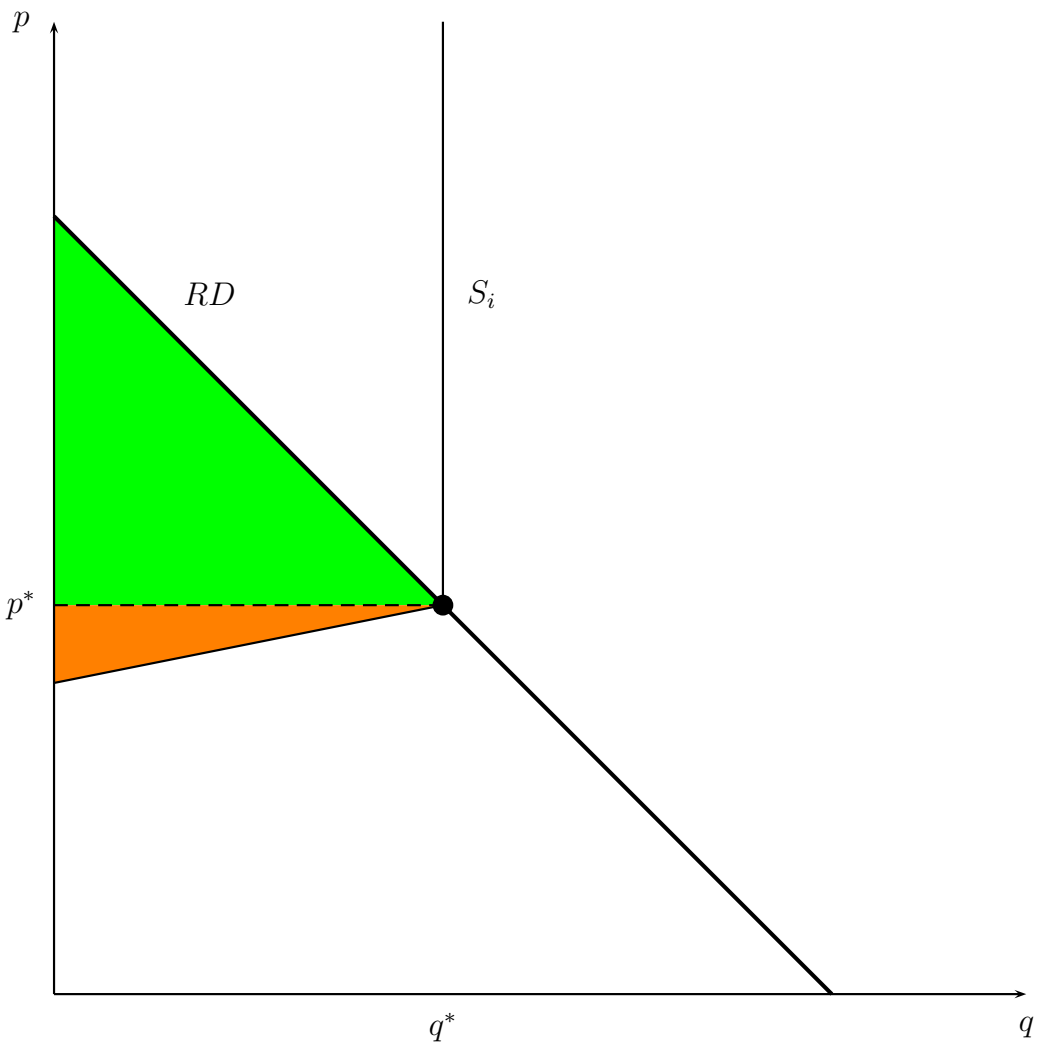
Charge on Ricardian Rents

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.

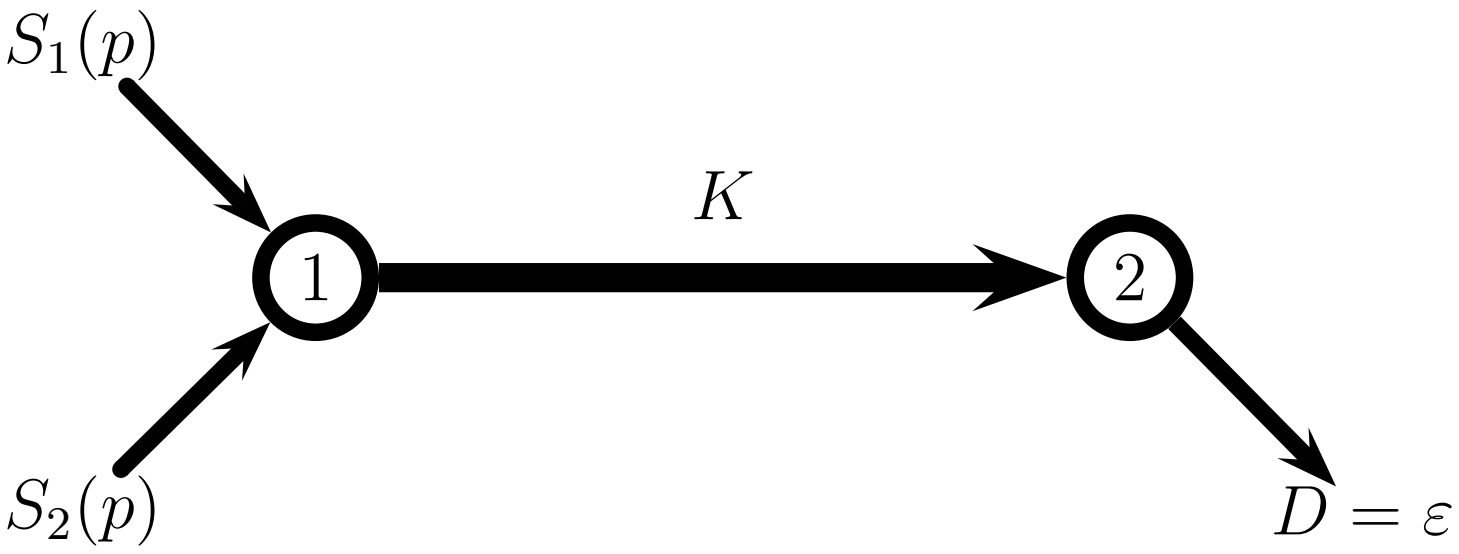


Implications for SPD Charge transmission pricing

- 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

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

where c is the marginal cost, $\overline{p}$ is the price cap, and $\psi(q,p)$ is the market distribution function (the probability that an offer of q MW at price p will not be fully dispatched). Finally, ψ_q and ψ_p denote partial derivatives of ψ with respect to q and p, respectively.[3]

The first-order optimality condition (Euler-Lagrange):

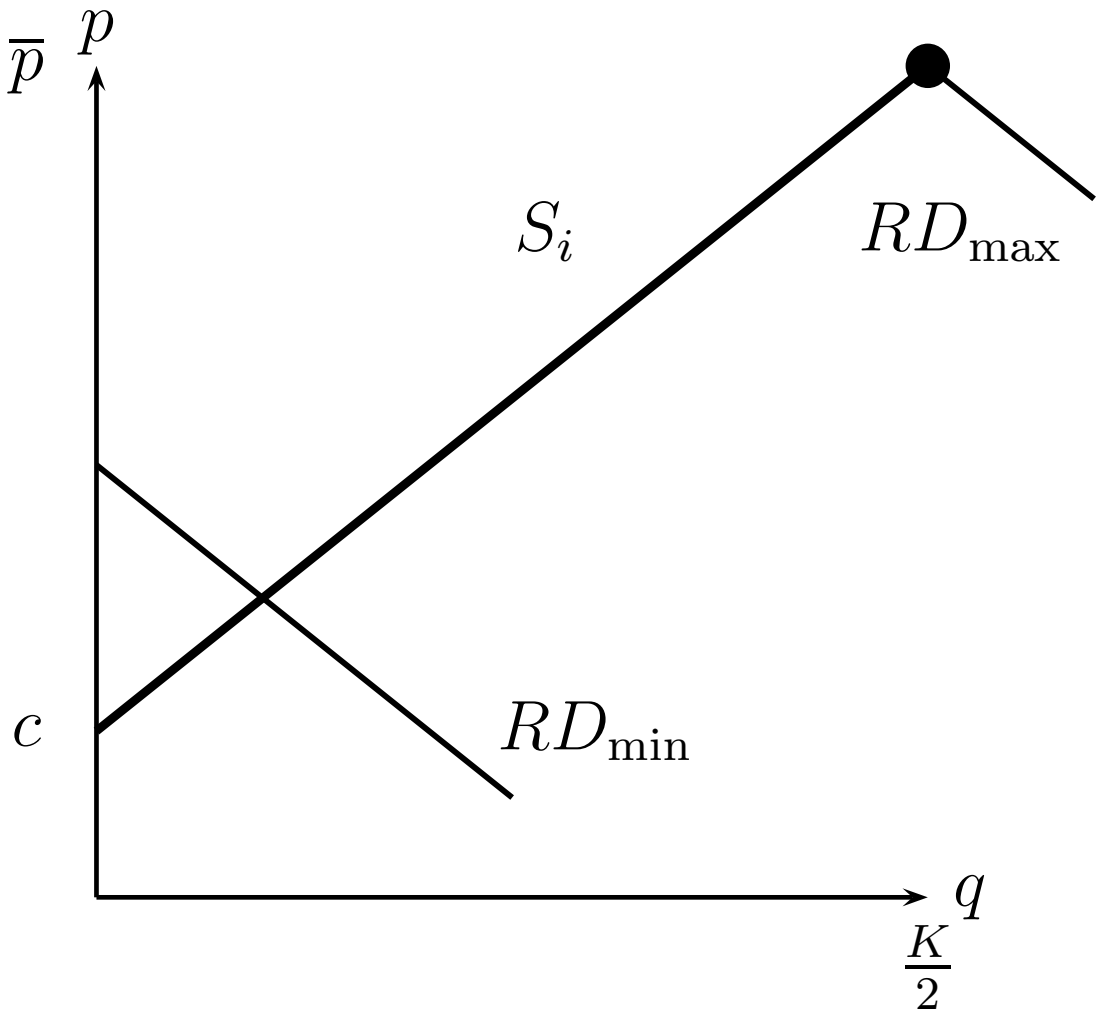
$$Z(q,p) = (p-c)\,\psi_p - q\psi_q = 0$$

gives rise to a system of differential equations.

The SFE for each firm is linear in a duopoly with inelastic demand; the offers hit the price-cap at the line capacity.

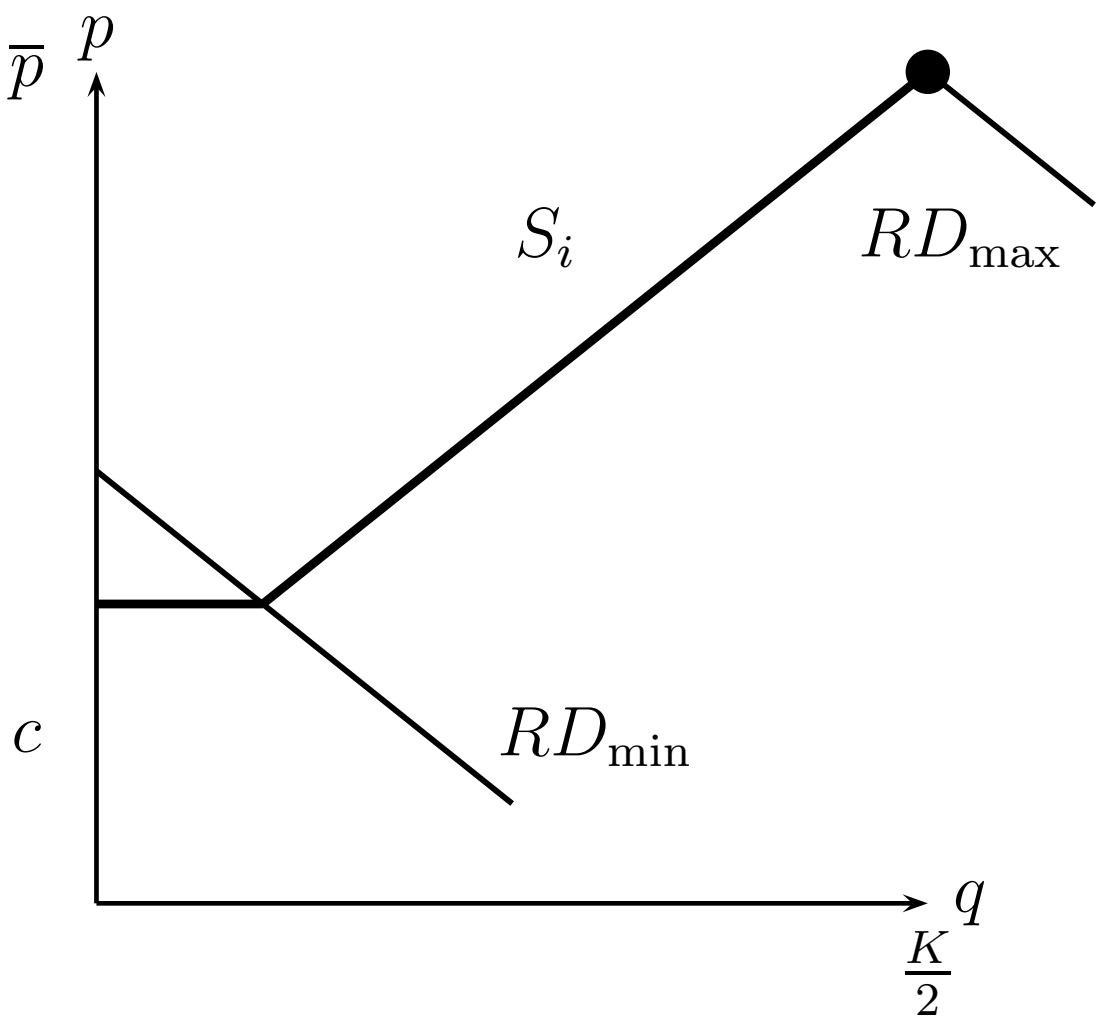
[3] Anderson, E.J. & Philpott, A.B. (2002). Optimal offer construction in electricity markets. *Mathematics of Operations Research*, 27, 82-100.

Incentives to mark-up



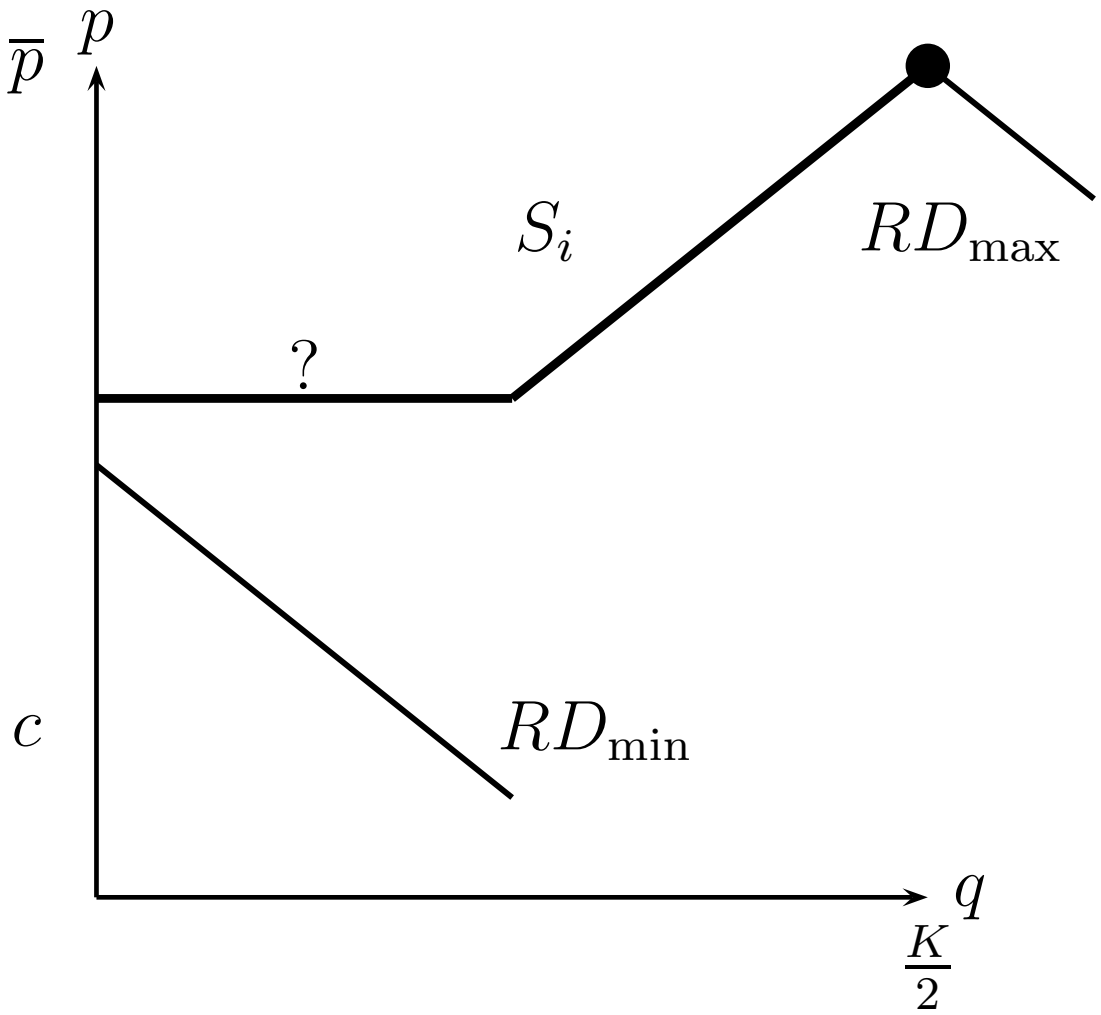
What might happen with a charge on Ricardian rents? Suppose that $\alpha = 25\%$ of perceived producer profits is charged to fund transmission investment.

Marking up in response to the charge – undispatched segment



A gradient discontinuity in undispatched part of curve is fine.

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 your offer quantity, q, and the other generator's supply function $S_2(p)$, the probability of not being fully dispatched is:[4]

$$\begin{aligned}\psi(q,p) &= \Pr\left[\varepsilon < q + S_2(p)\right] \\ &= \left(q + S_2(p)\right)/\overline{\varepsilon}\end{aligned}$$

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

[4] 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

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

for the symmetric SFE.

This is a first-order linear ODE which can be solved using an integrating factor to give

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

where k is a constant of integration that can be chosen to satisfy an endpoint condition.

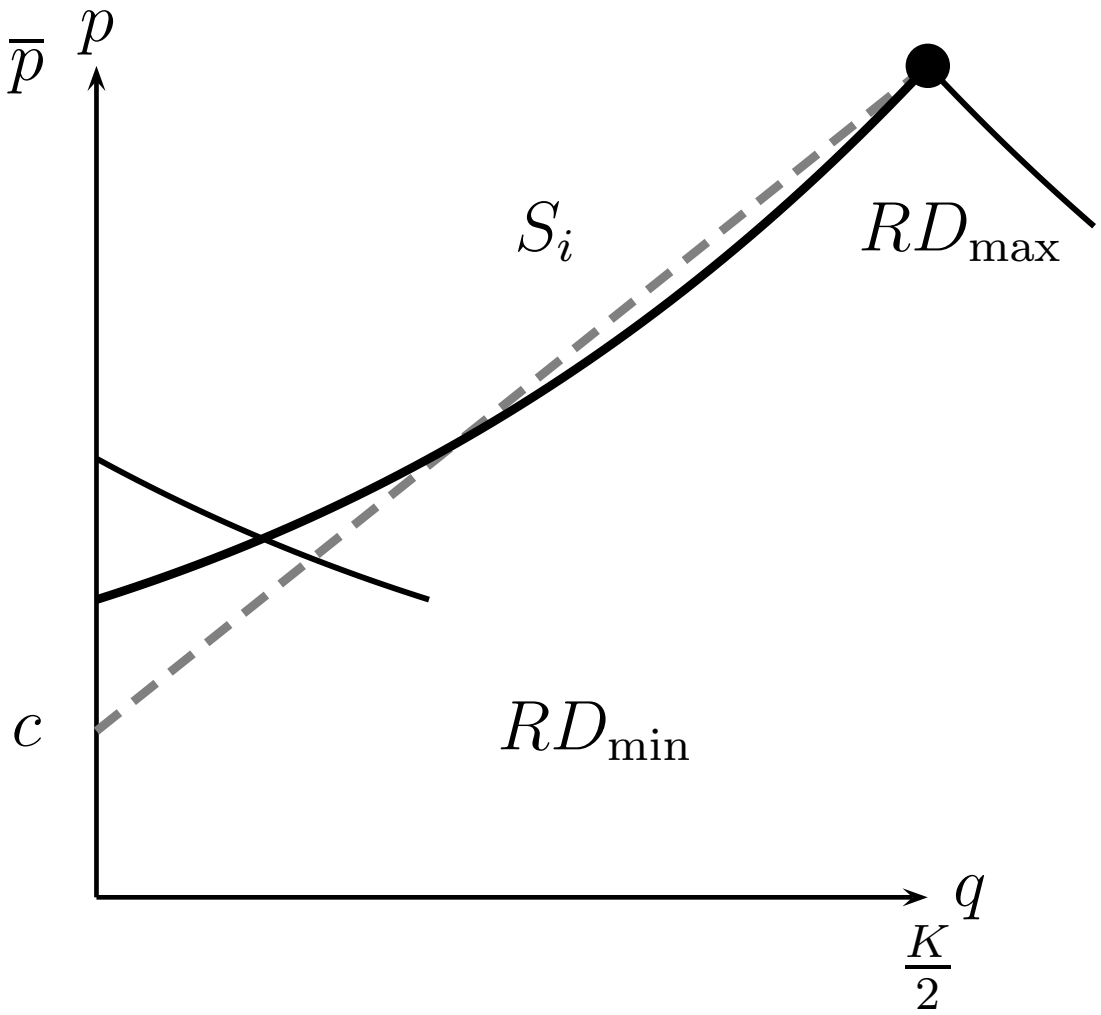
Since we assume that the line capacity is smaller than the highest levels of demand, this yields the unique endpoint condition

$$S(\overline{p}) = K/2,$$

for which no profitable deviation is possible.[5]

[5] 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.

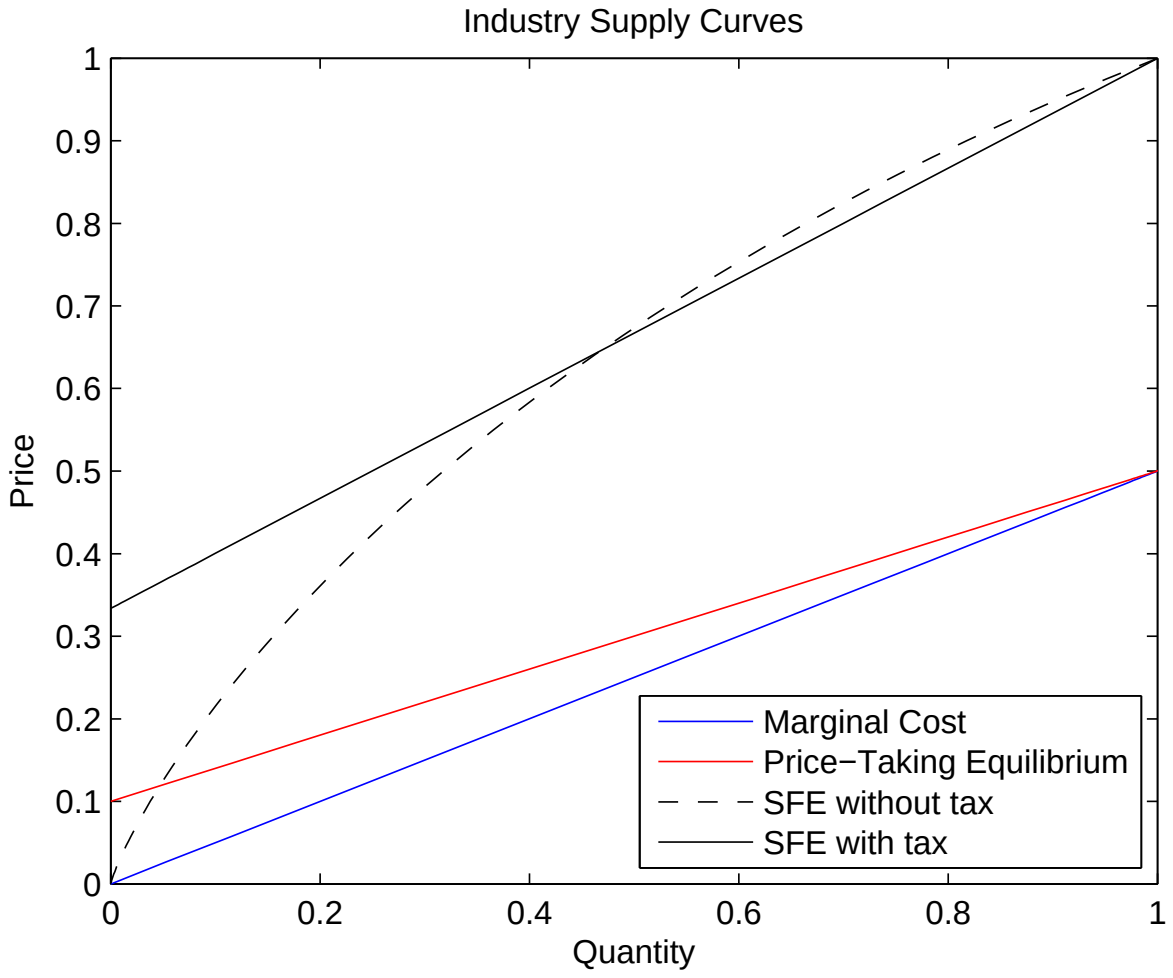
Incentives for firms competing under Perfect Competition

The previous example shows how strategic firms will alter their bids in response to a charge, in equilibrium.

One question is whether the firm's ability to mark up is due to the firms' market power. With constant marginal costs, firms that are price takers will not receive any Ricardian rents, so there is no incentive to mark-up.

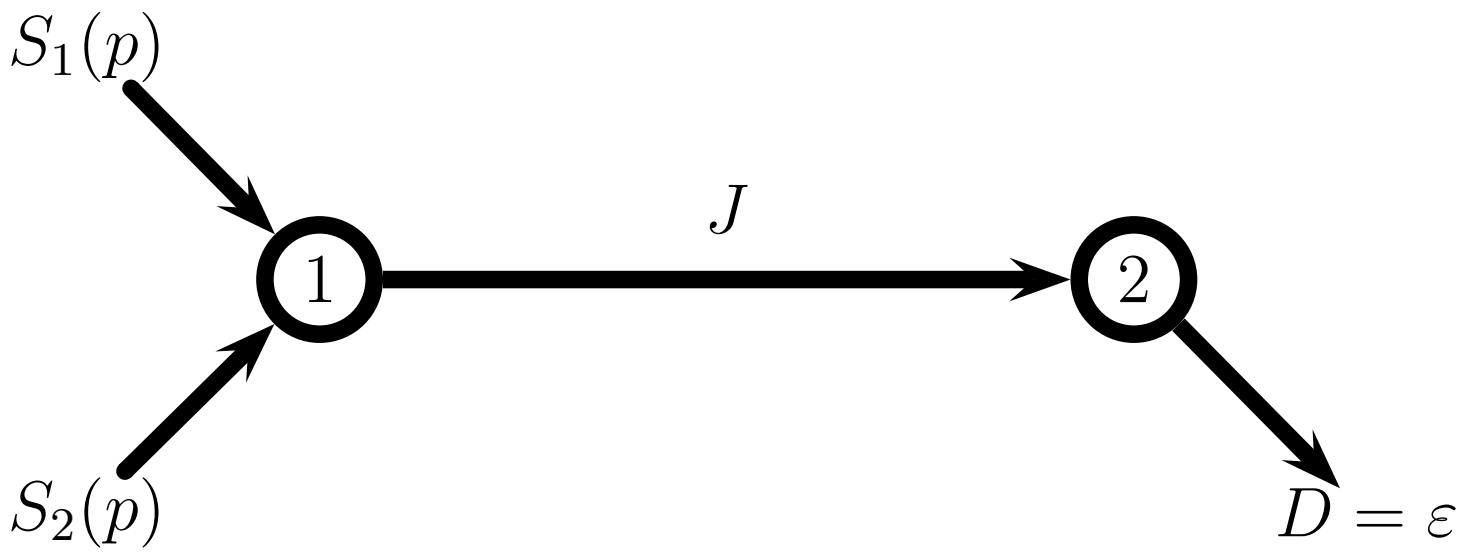
However, in the case where there firms have linear marginal costs, we find that price takers will mark-up their offer curve to avoid the charge.

Incentives for firms competing under Perfect Competition



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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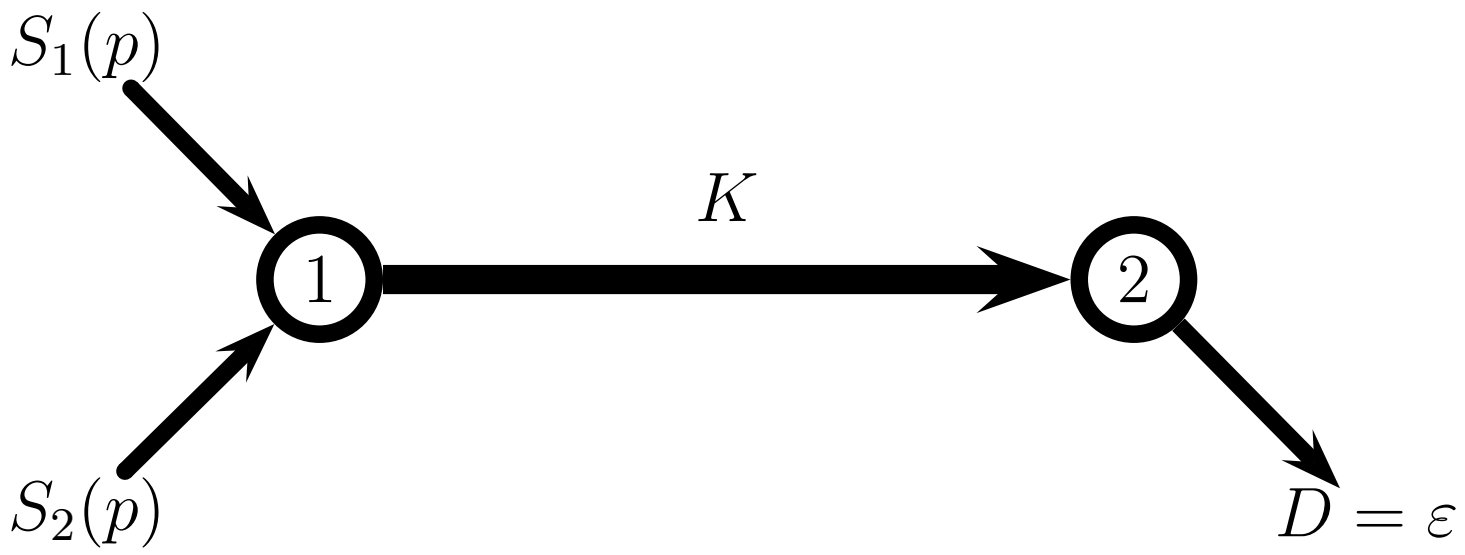
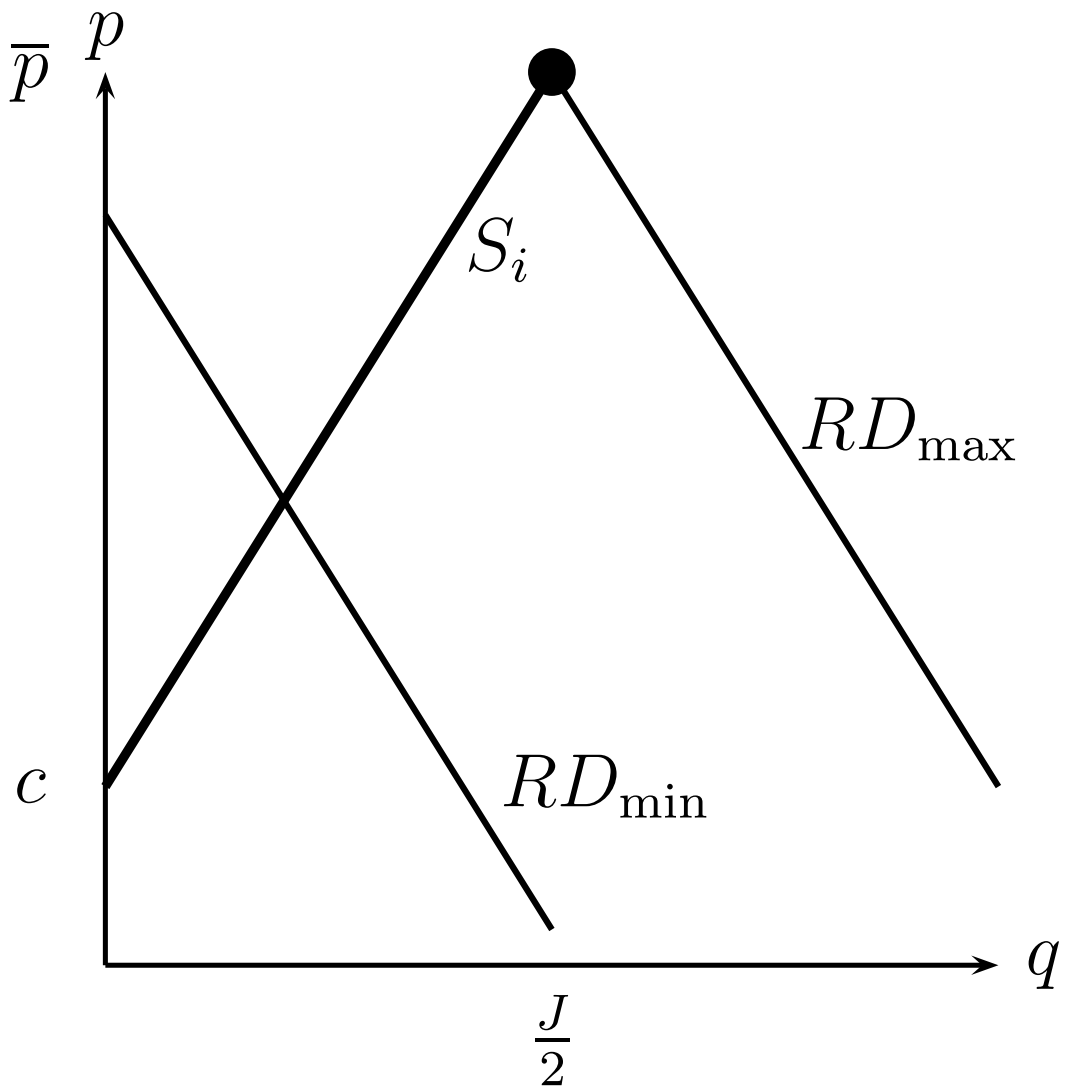


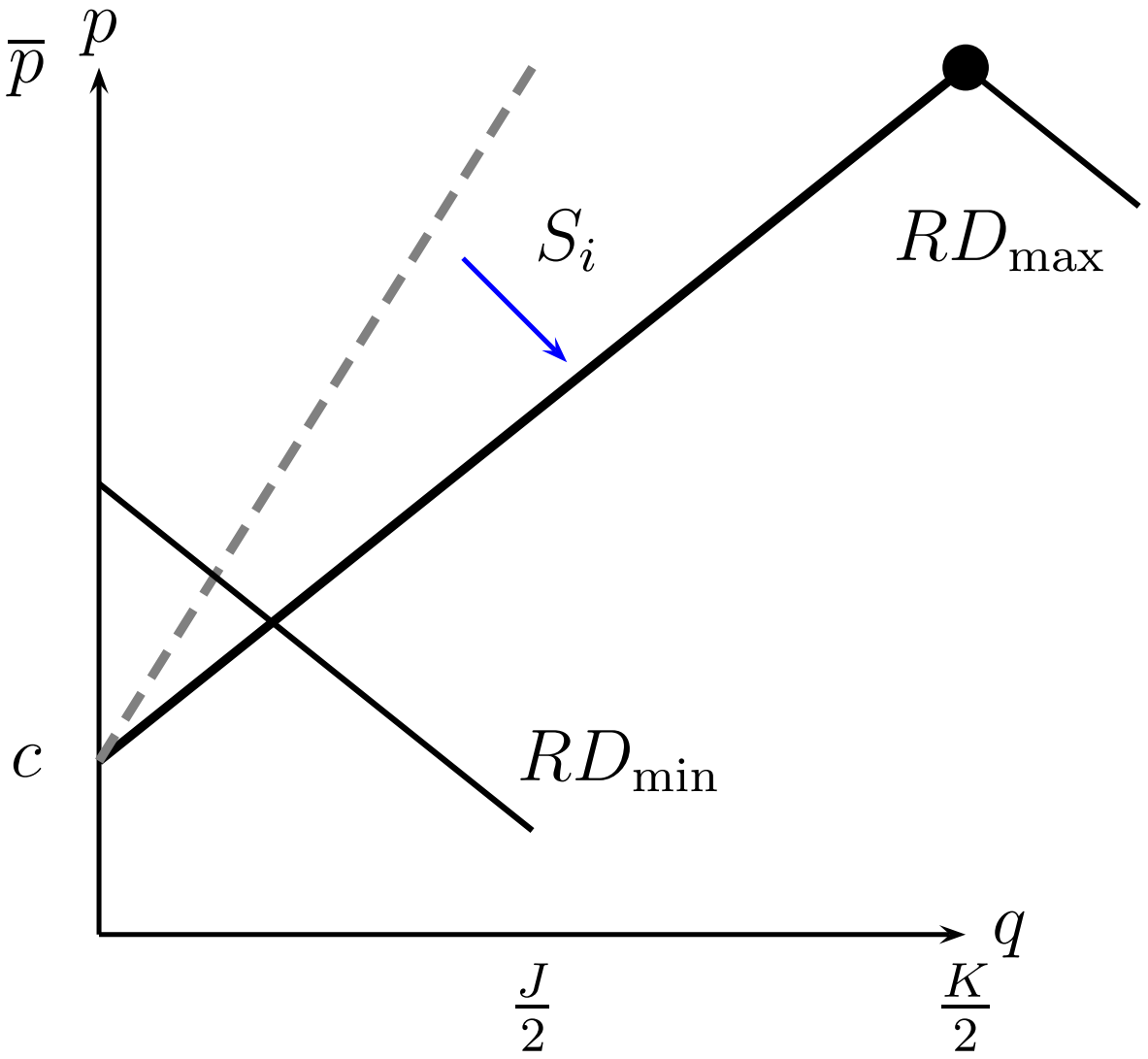
$\varepsilon \sim U[\underline{\varepsilon}, \bar{\varepsilon}]$

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)



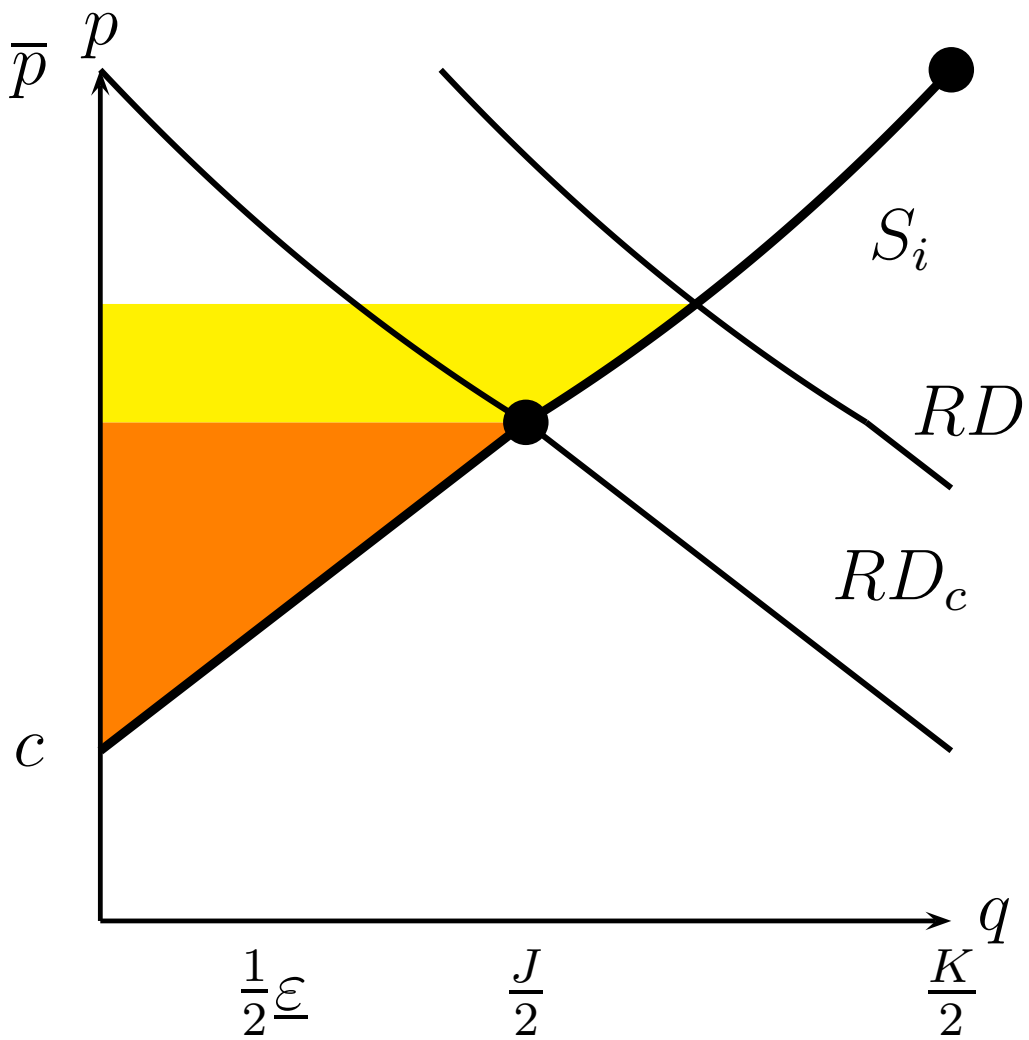
Duopoly SFE with expanded line (no charge)



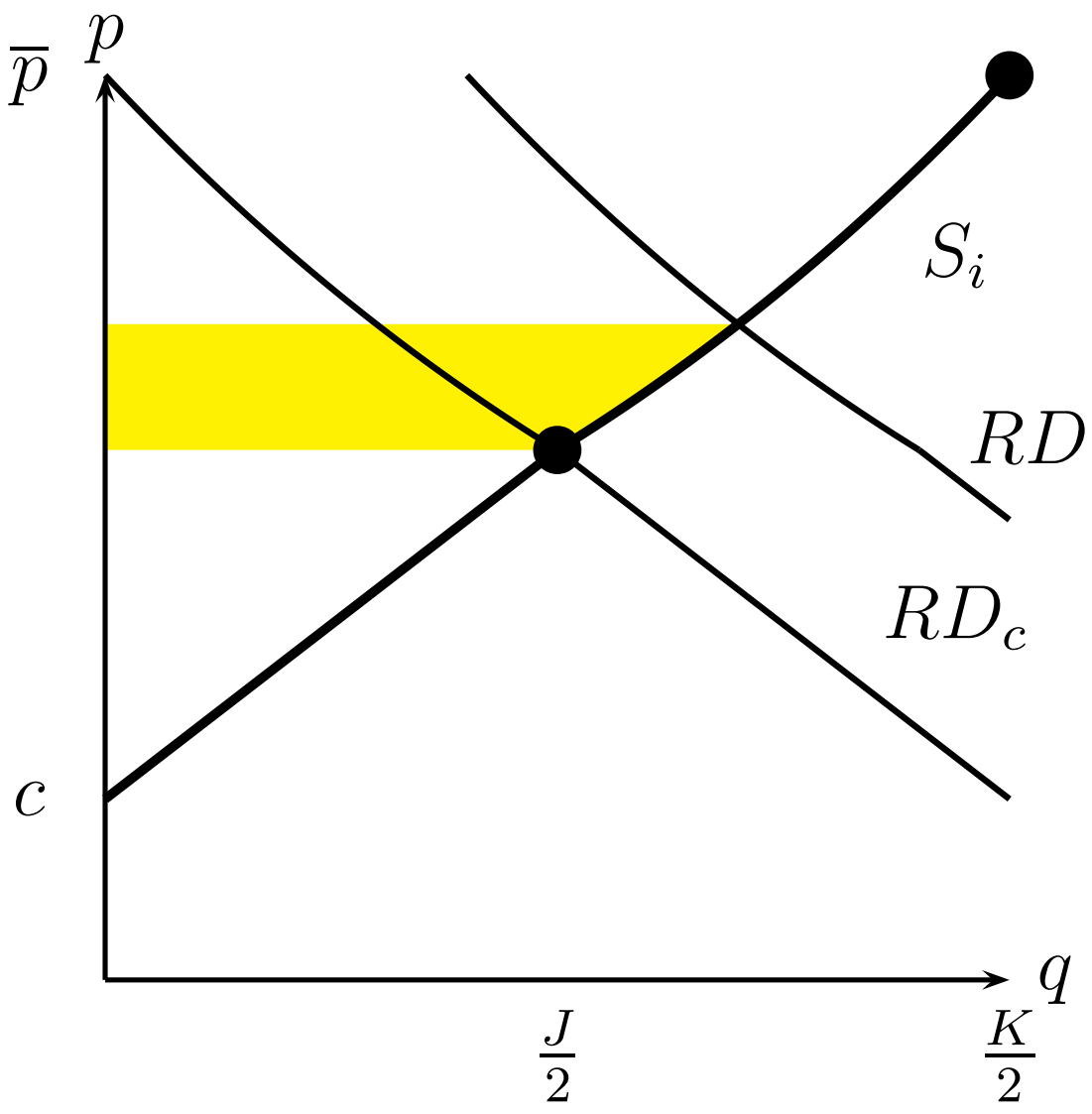
Larger capacity gives a flatter curve (more competitive). The SPD-methods, assumes that the offer stays the same – this would not be a valid assumption in this case.

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.

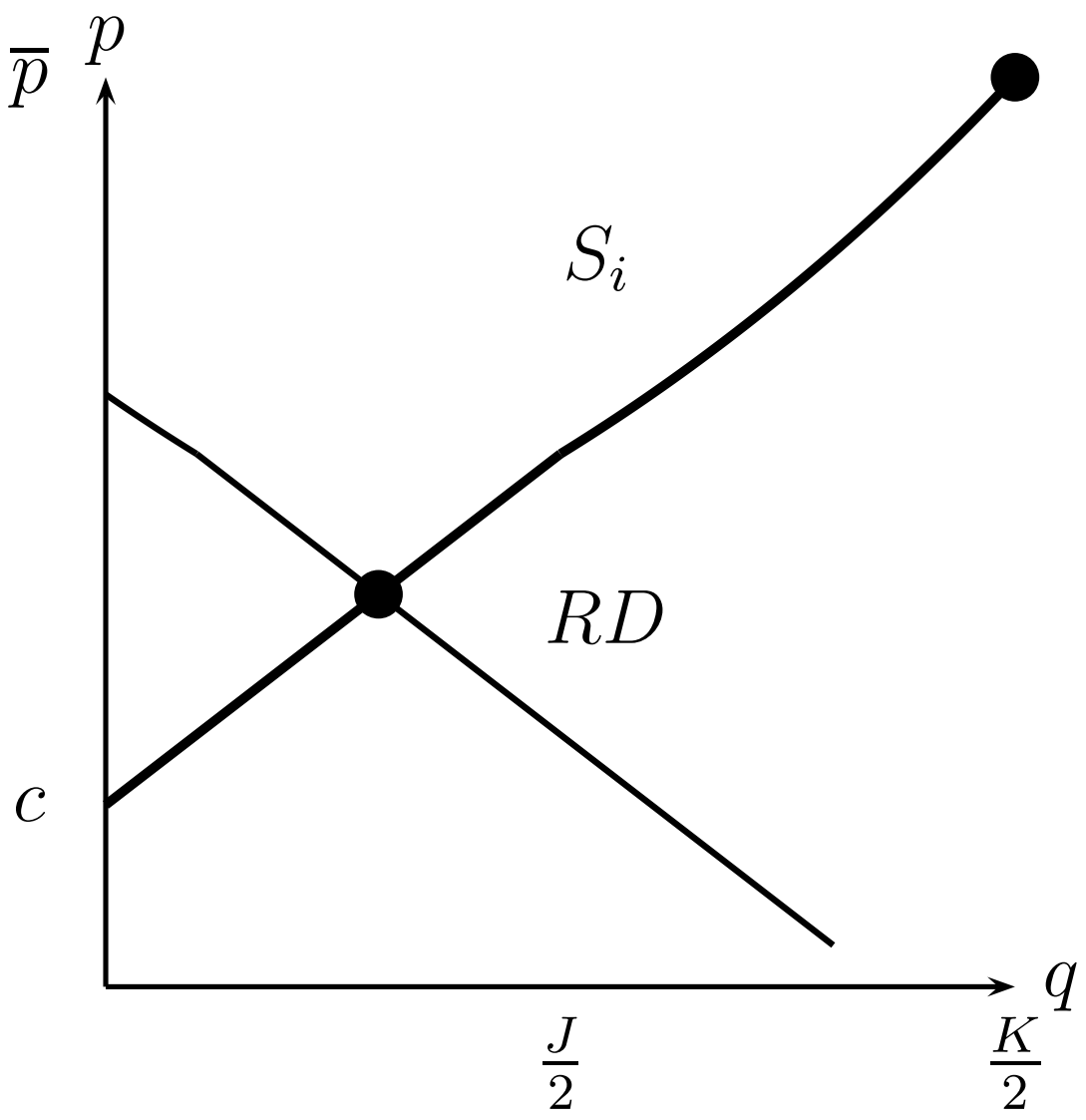


Charge on benefit from expanded line (dispatch $> \frac{J}{2}$)



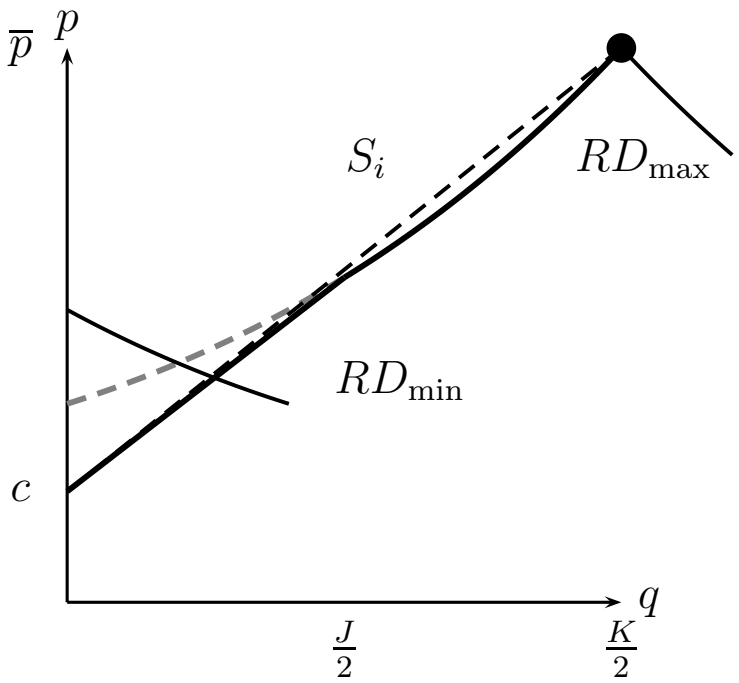
The charge will be based on this area (which depends on the realisation of the demand shock).

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).

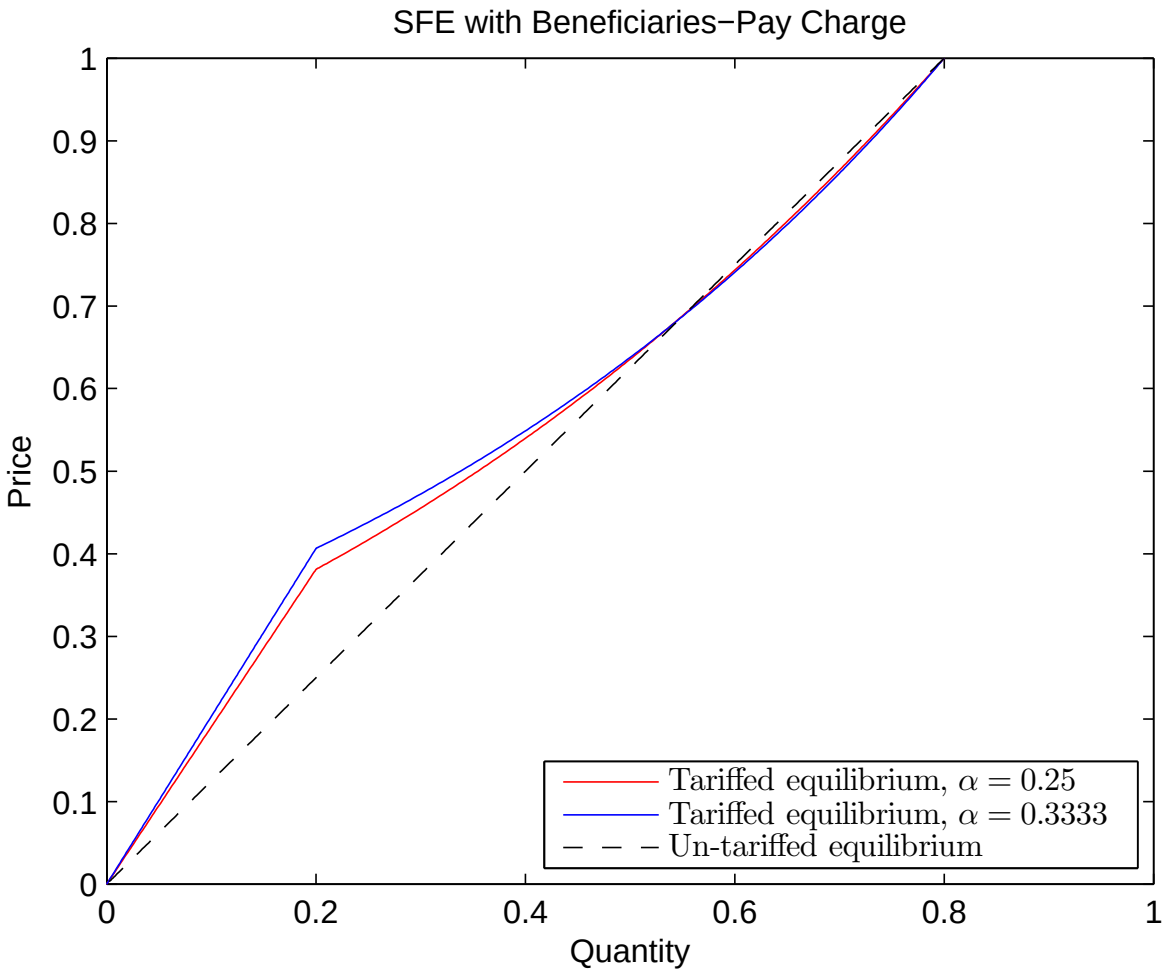
For quantities greater than $\frac{J}{2}$, the equilibrium curve matches the curve where the charge was applied to total perceived surplus.

Illustrative Example

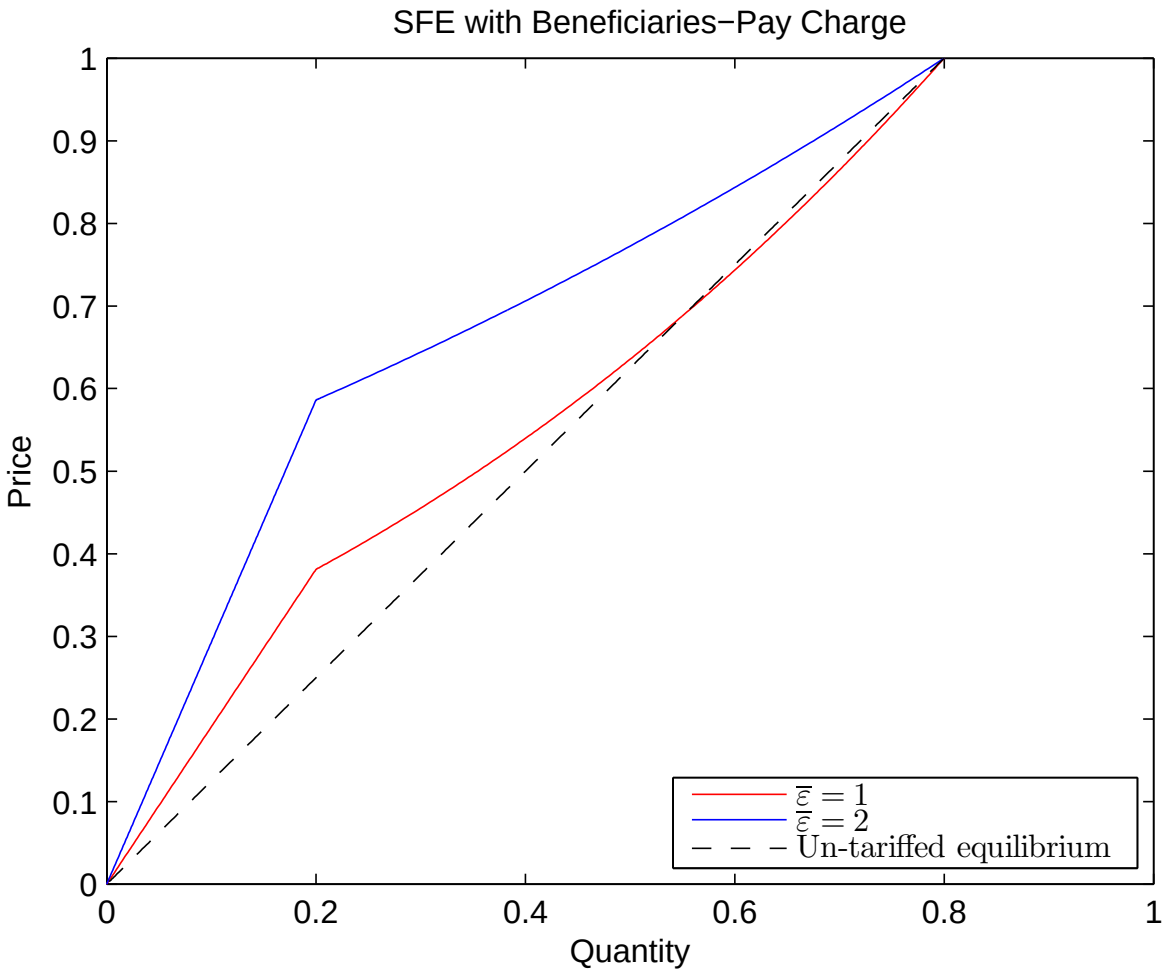
Consider a duopoly, over a network as shown earlier.

- 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.



SFE depends on the max demand shock



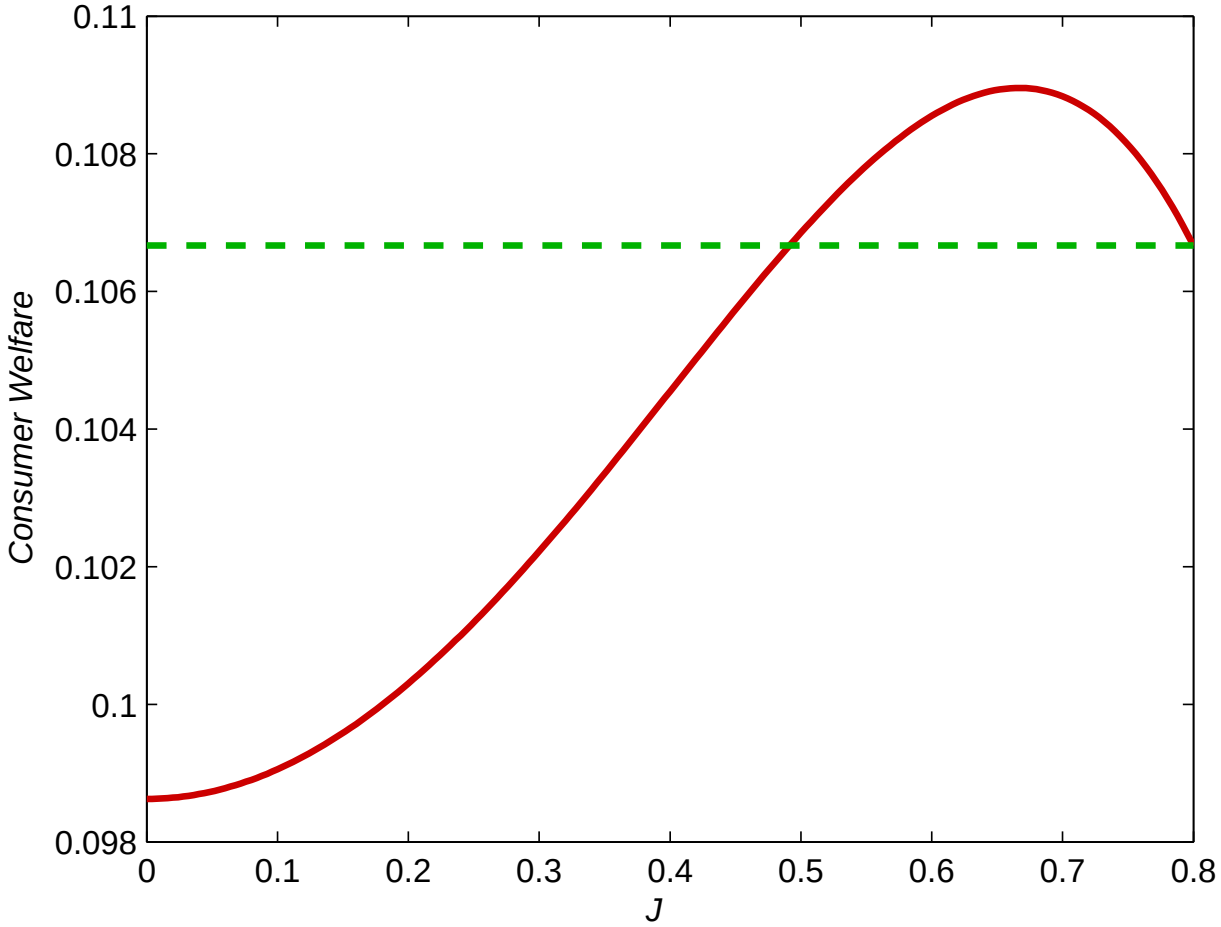
Welfare Calculations

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.

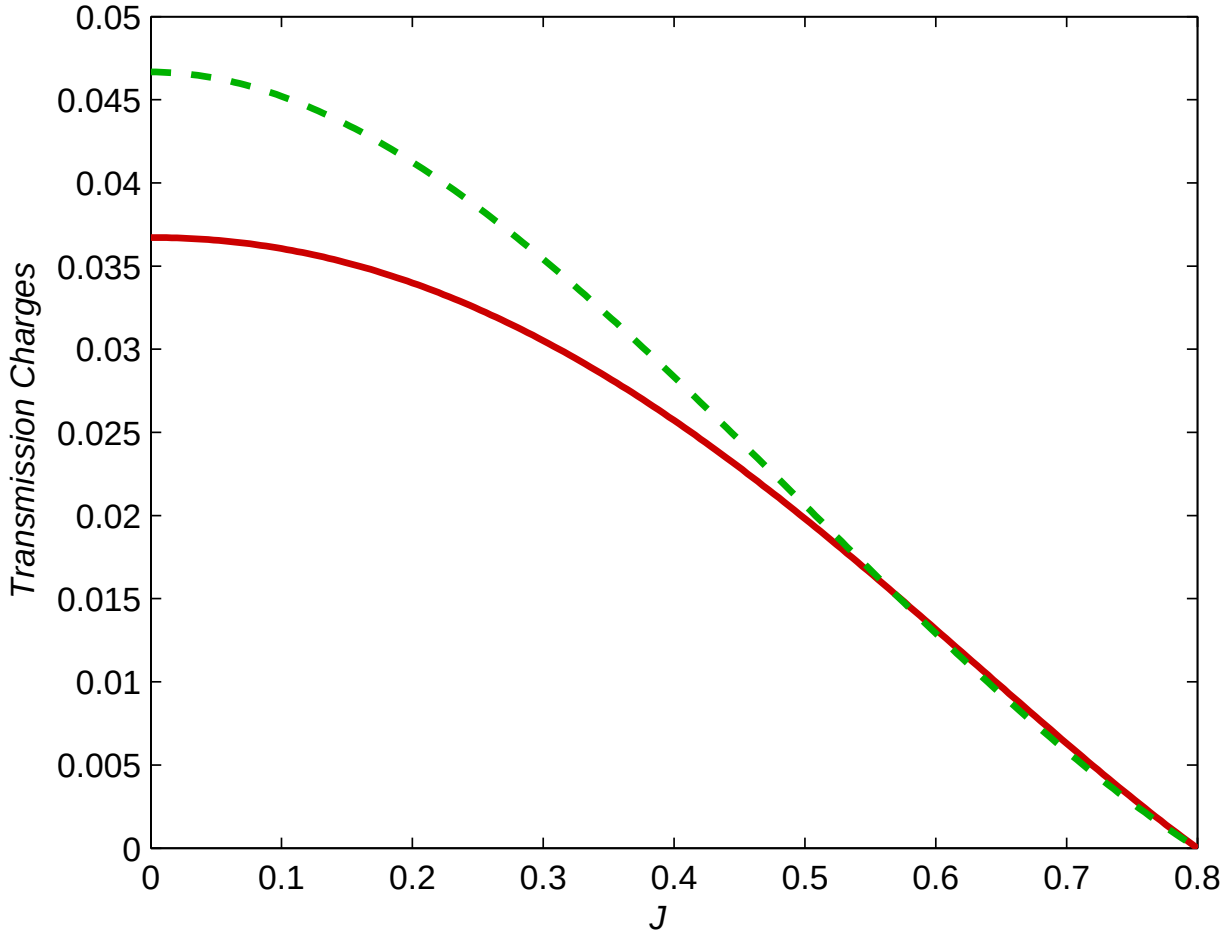
CS is the consumer surplus, TS is total surplus, and Π^U and Π^T are the untaxed and taxed per-firm profits, respectively.

Consumer welfare comparison



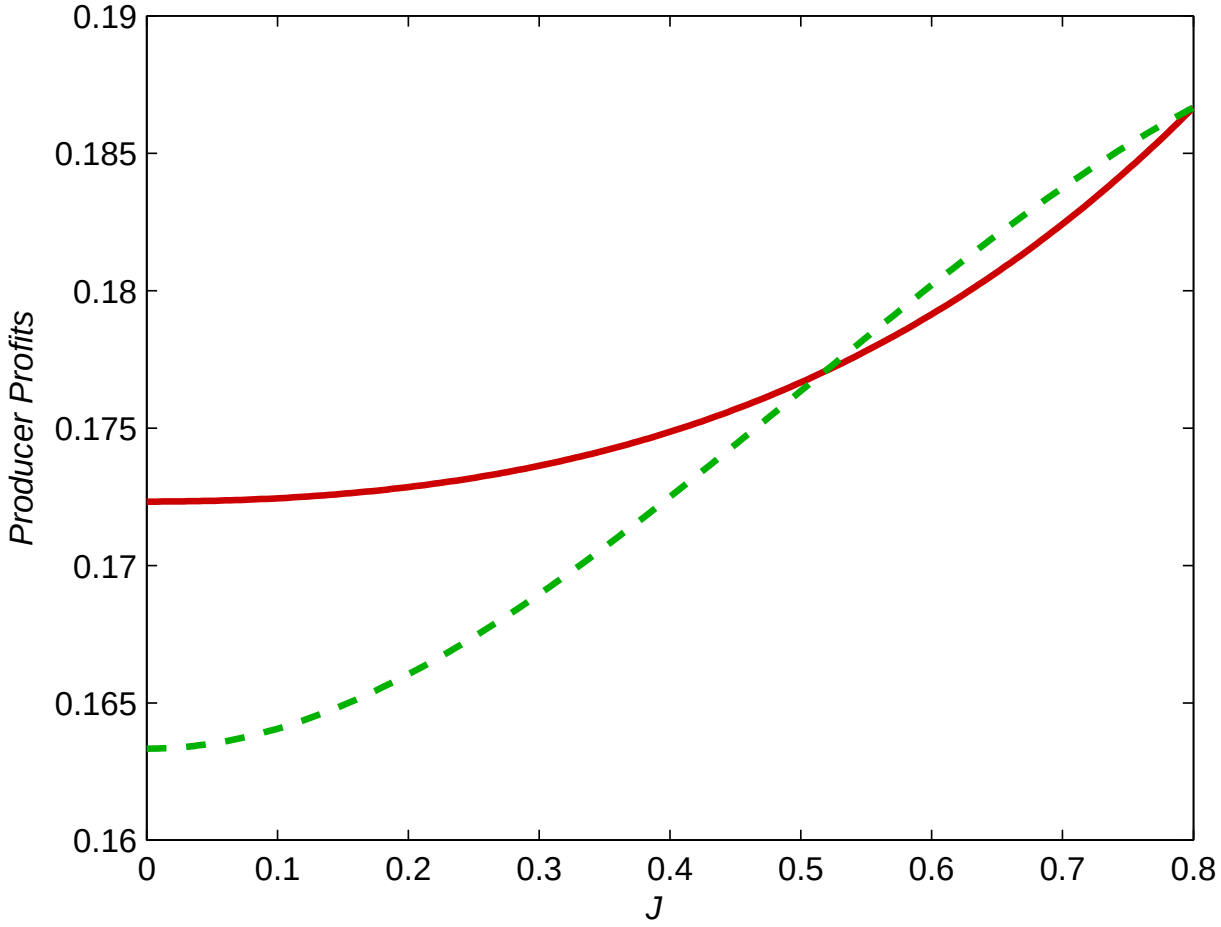
When $J < 0.5$ the expected consumer welfare drops as the firms try to avoid the charge; otherwise the consumers are better off.

Generator transmission charges comparison



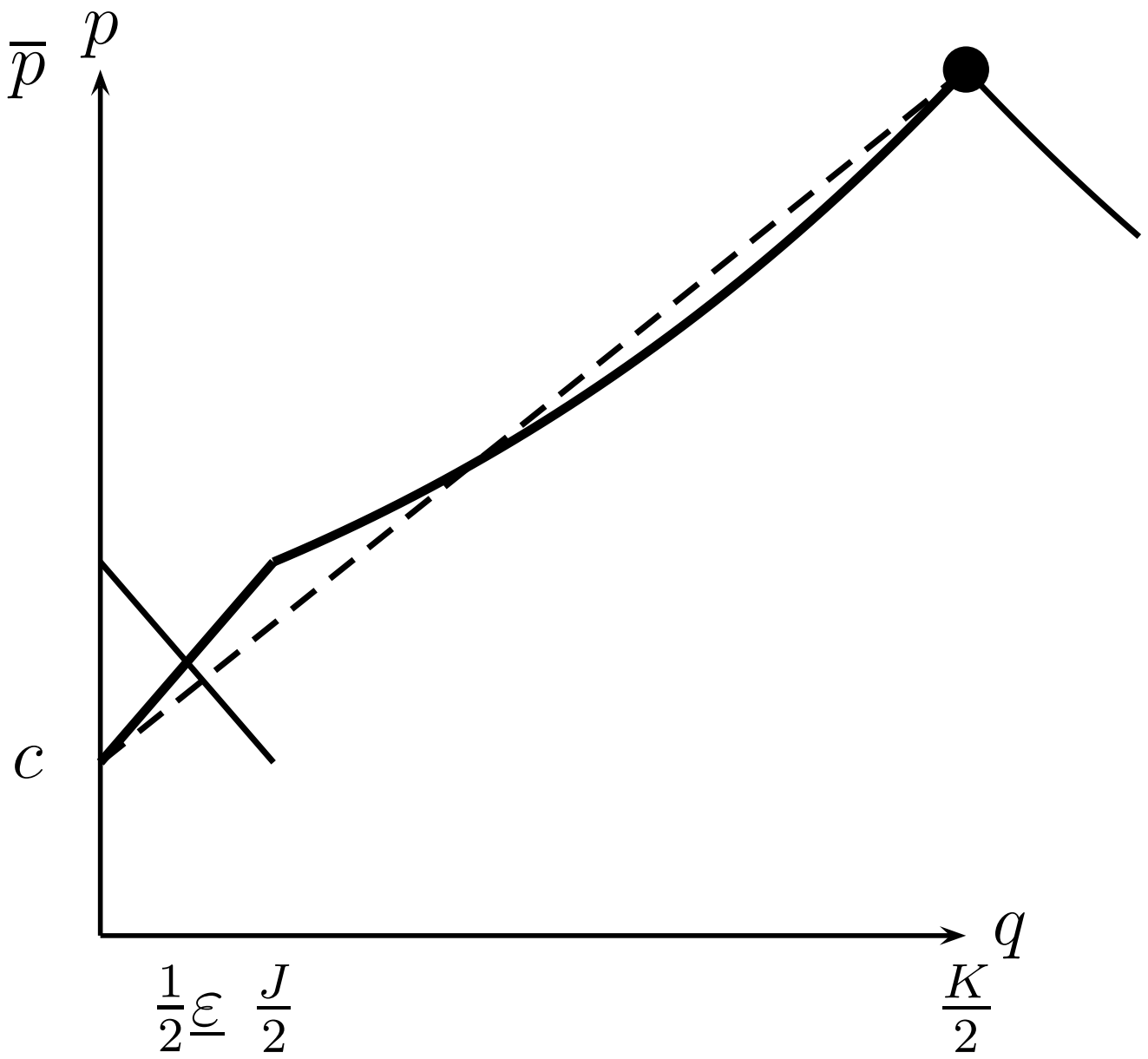
When $J < 0.58$ the expected charge drops as the firms change their behaviour; interestingly, the firms end up paying a slightly higher charge for small increases in line size.

Producer surplus comparison (after transmission charge)

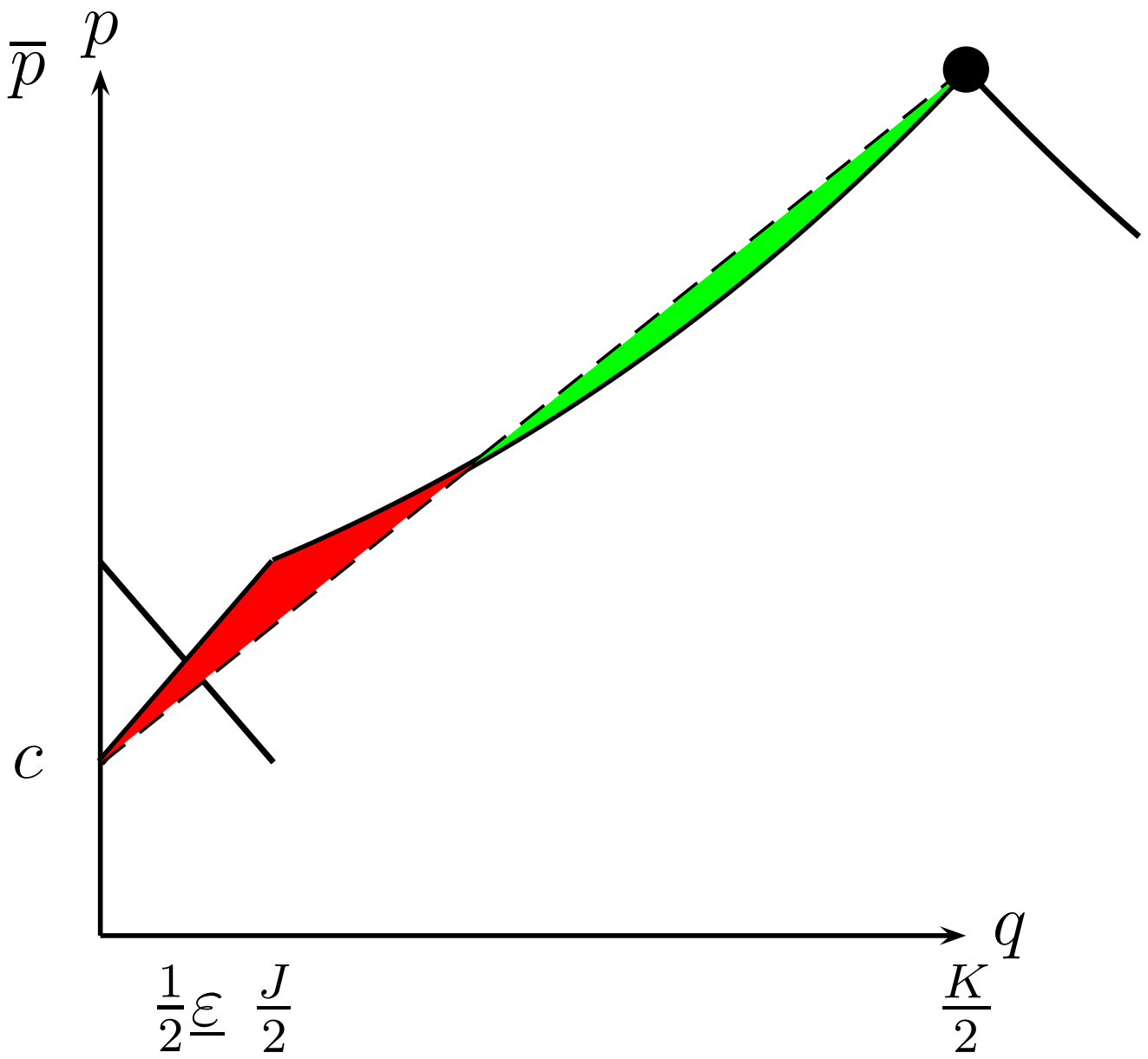


When $\frac{J}{K} < 0.52$ the expected producer surplus increases as the firms try to reduce the charge paid. For smaller line upgrades the producers are worse off.

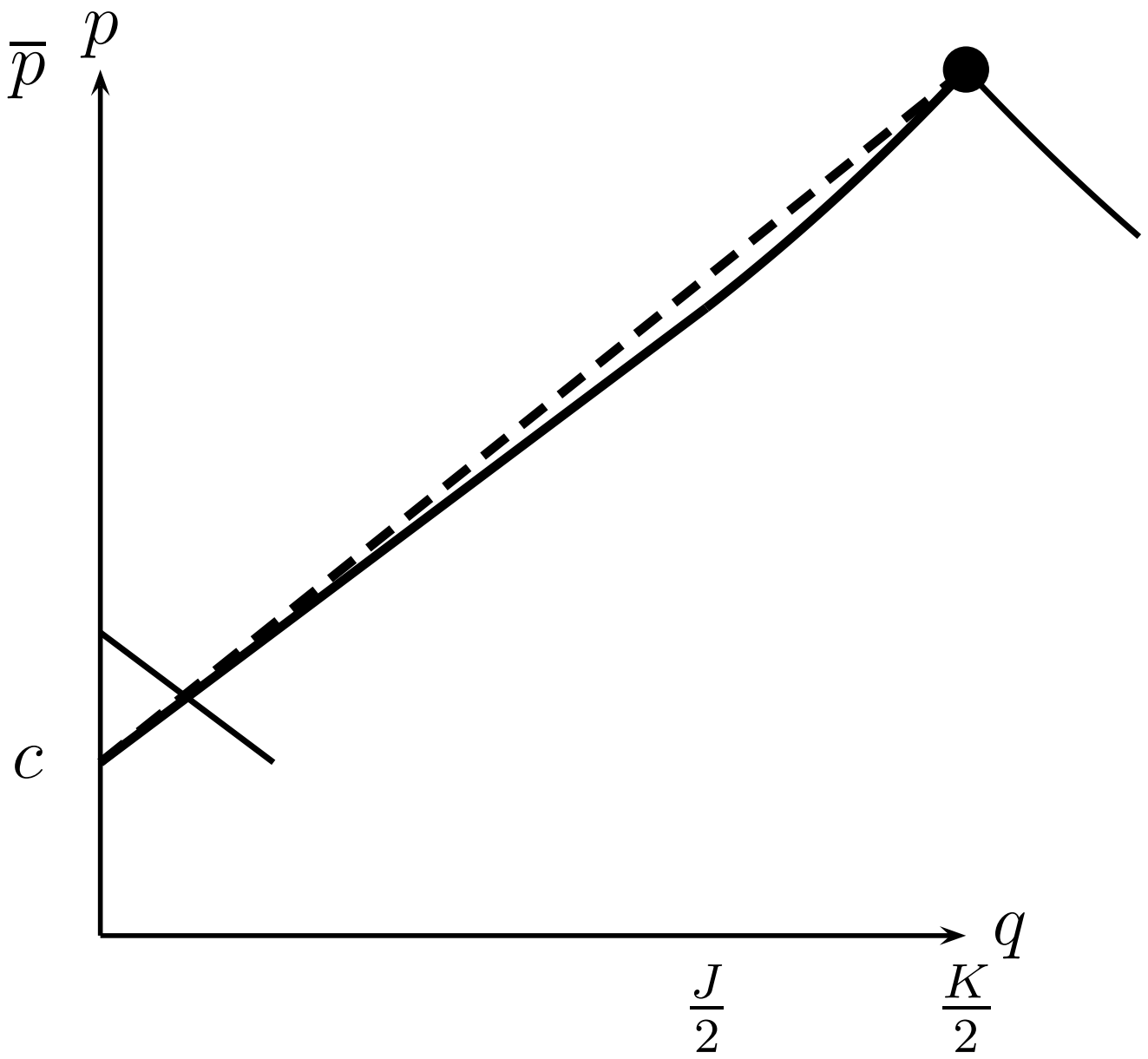
Overall markup depends on magnitude of expansion



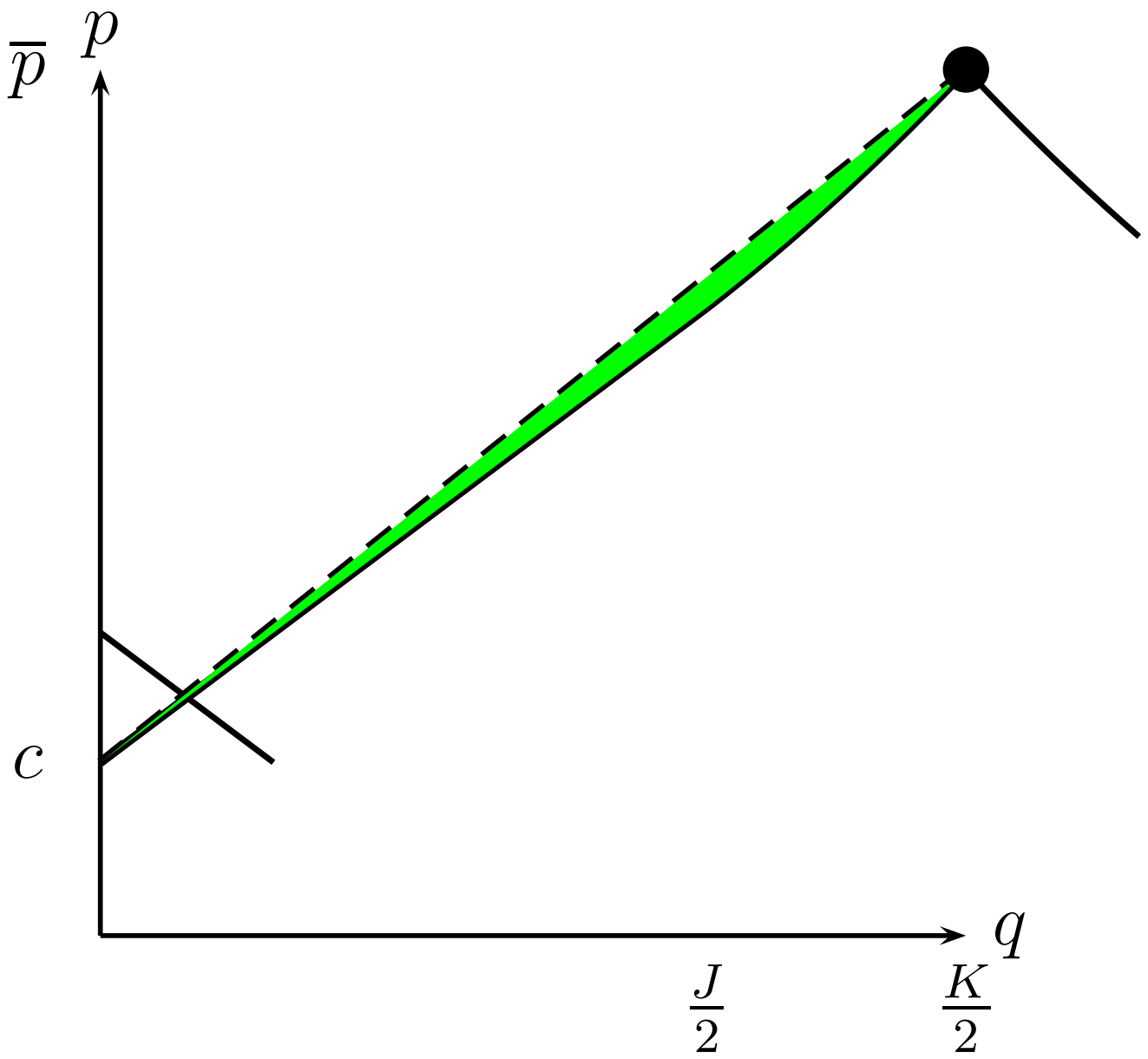
Overall markup depends on magnitude of expansion



Overall markup depends on magnitude of expansion



Overall markup depends on magnitude of expansion



Summary

- If the charge is a small % of the benefits, the equilibrium is close to the uniform price SFE.
- There is a greater incentive to mark up the lower part of curve; exacerbated when the probability of lost load increases.
- Competitiveness depends on size of transmission capacity expansion.
- These equilibria are valid so long as $\alpha < \frac{1}{2}$.

An enduring pricing methodology

One of the major issues facing electricity industries around the world is the increasing penetration of distributed generation, such as solar power for residential uses.

If users are not appropriately charged for the value of the transmission (i.e. its option value as well as for the energy delivered), then as holdholds rely less and less on energy from the grid. The fixed cost of transmission is bourne by fewer and fewer consumers, causing them to also purchase solar panels. This is termed a death spiral in economics; and can lead to stranded assets.

By charging market participants for the option value associated with using the grid, participants will either need to disconnect, and face lower reliability or contribute to the costs of the grid through the purchase of this option - even if no power is consumed.

When charging for transmission it is important to get this balance correct, in order to send the right pricing signal to electricity consumers.

Incorporating transmission charges within SPD

We wish to find a way to incorporate a beneficiaries pays scheme without:

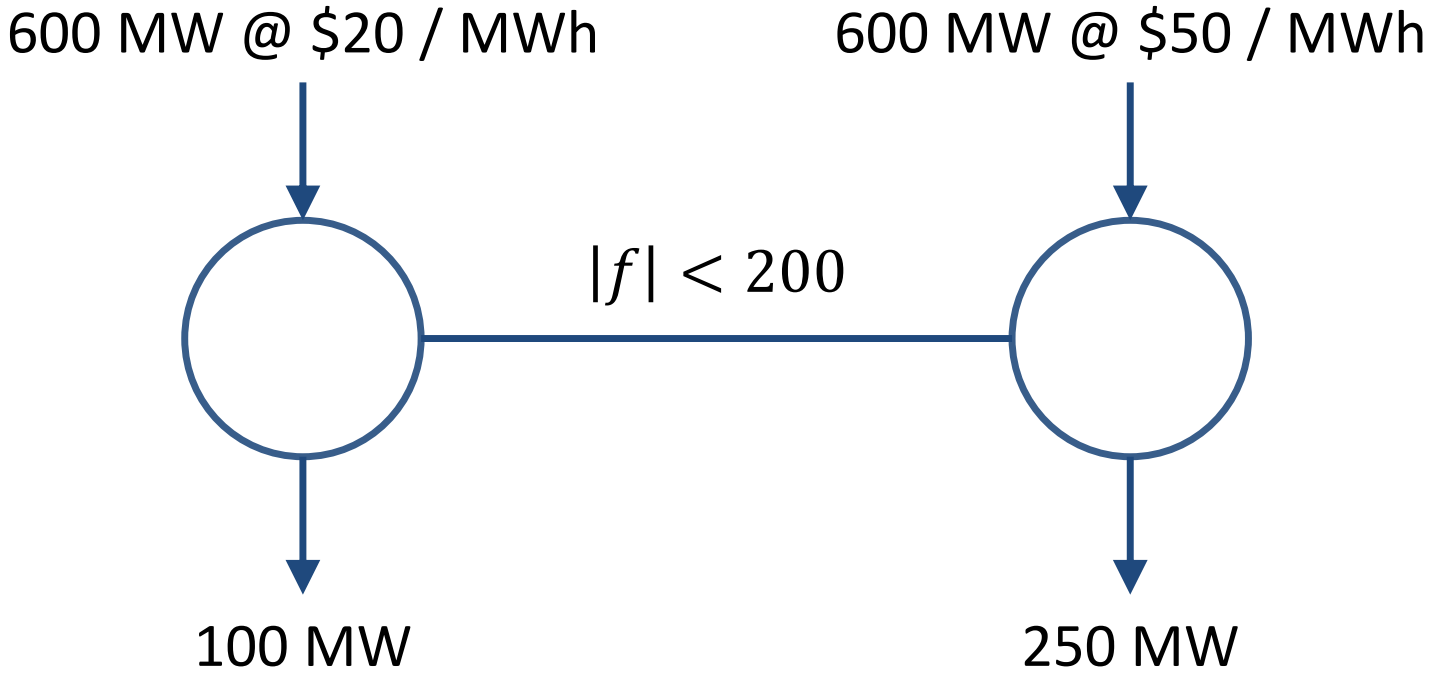
- estimating benefits in advance (the Area of Benefit charge); or
- providing incentives for firms to misrepresent their benefits (the SPD method).

The method we propose involves pricing the use of transmission directly within SPD, and follows the same principles of the workable competition model we use in the spot market.

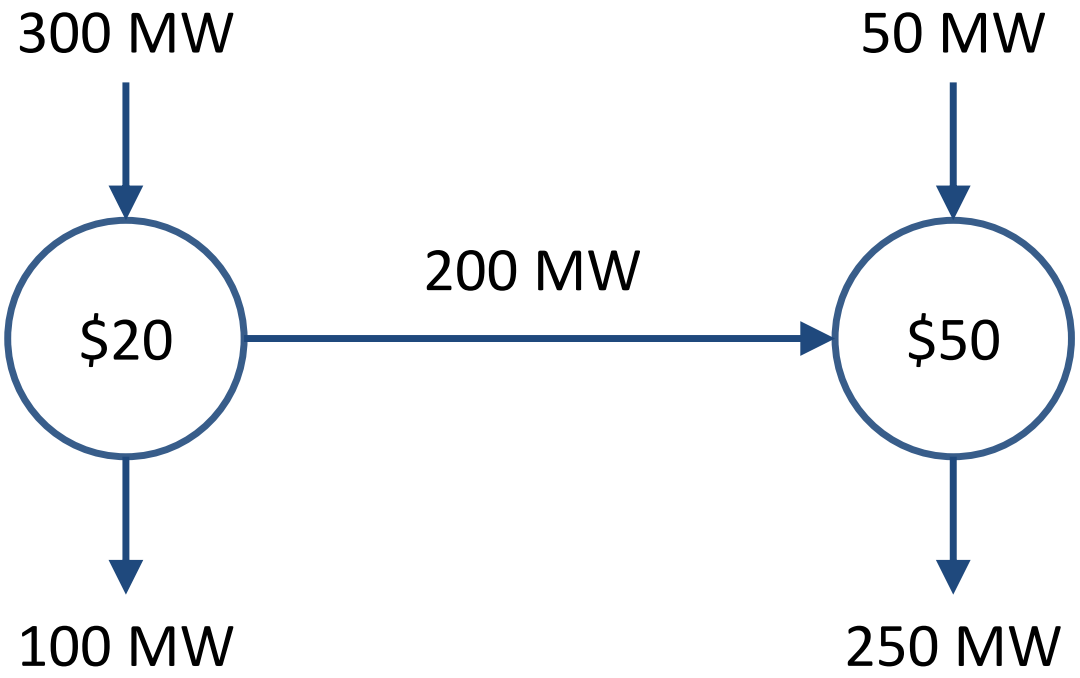
Although this may have a distortionary effect on short-term price signals, we feel that this approach is valid for two reasons:

- the benefits that accrue to users of the line are on a $ / MWh basis;
- the lumpy nature of investments means that the current marginal price signal is not all that matters in long-term decision making.

Example: pricing flow within SPD (low demand)

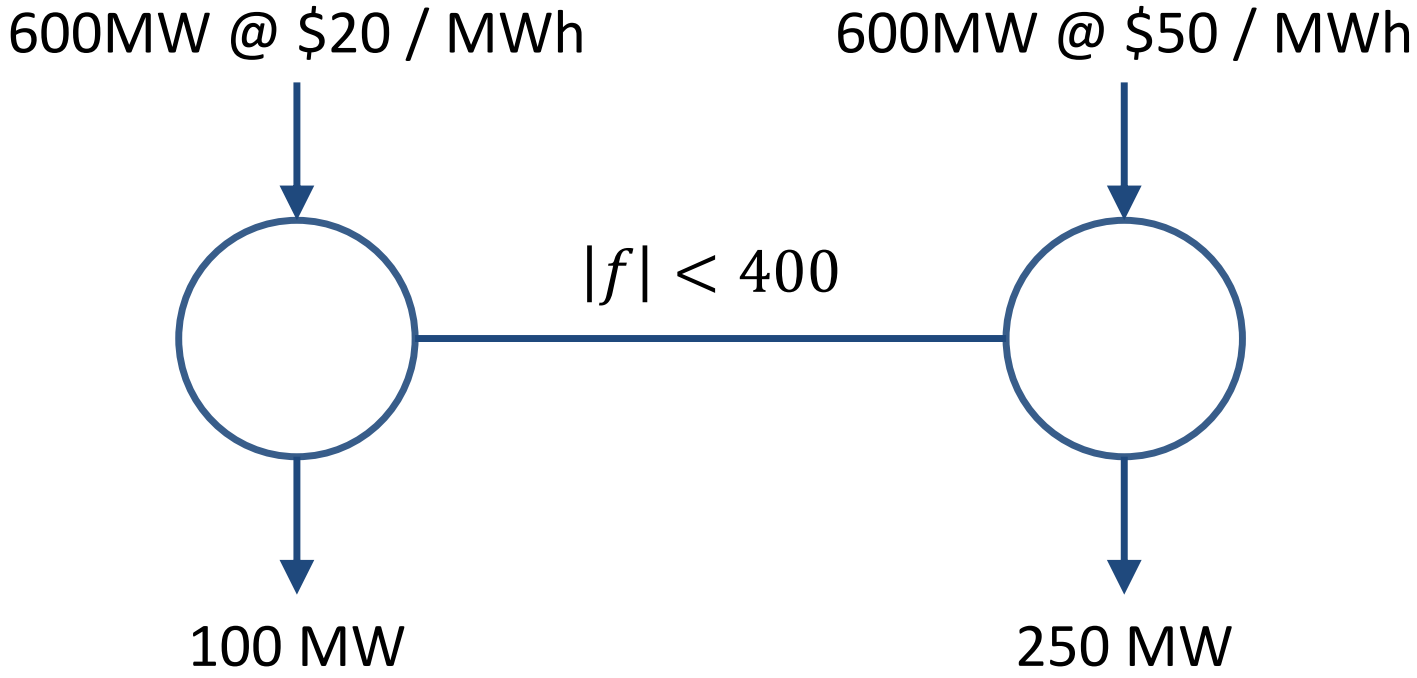


Example: pricing flow within SPD (low demand)

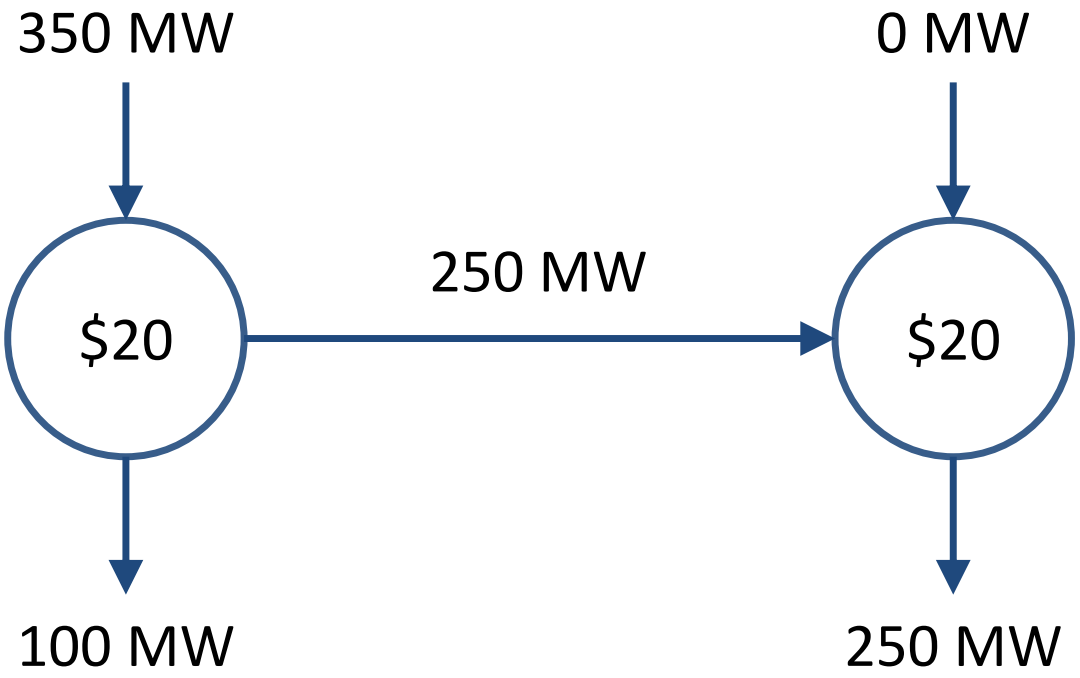


Payment from: consumer A: $2000; consumer B: $12500.
Payment to: generators A: $6000; generator B: $2500.
Congestion rents: $6000.

Example: pricing flow within SPD (low demand)

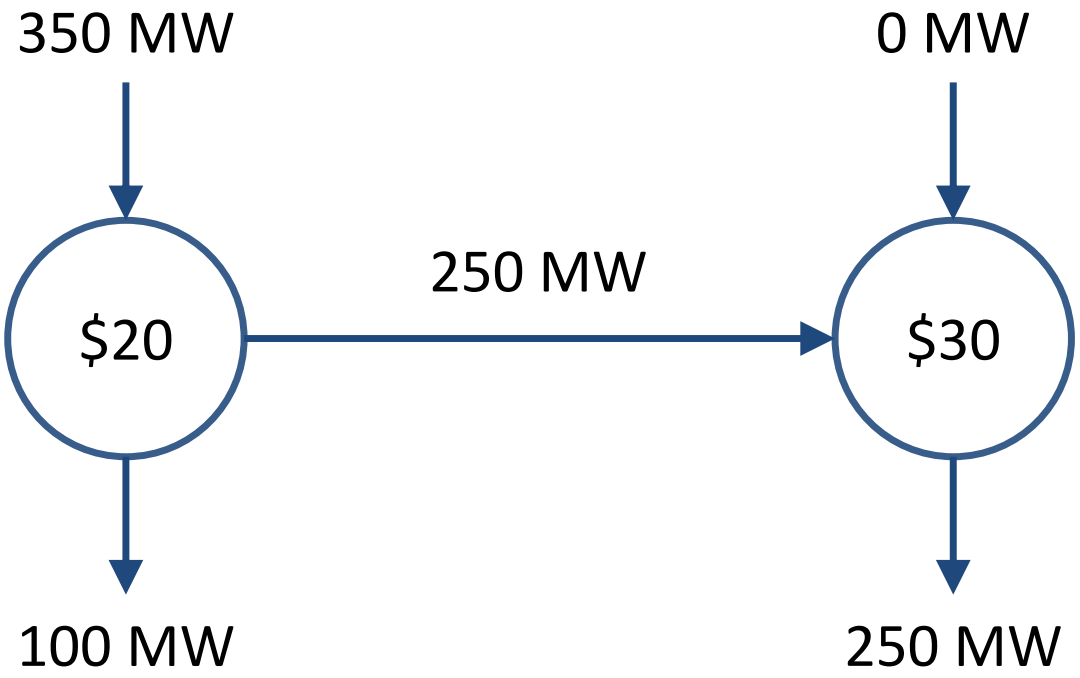


Example: pricing flow within SPD (low demand)



Payment from consumer A: $2000; consumer B: $5000.
Payment to generators A: $7000; generator B: $0.
Congestion rents: $0.

Example: pricing flow within SPD (low demand)



Payment from consumer A: $2000; consumer B: $7500.
Payment to generators A: $7000; generator B: $0.
Congestion rents: $2500.

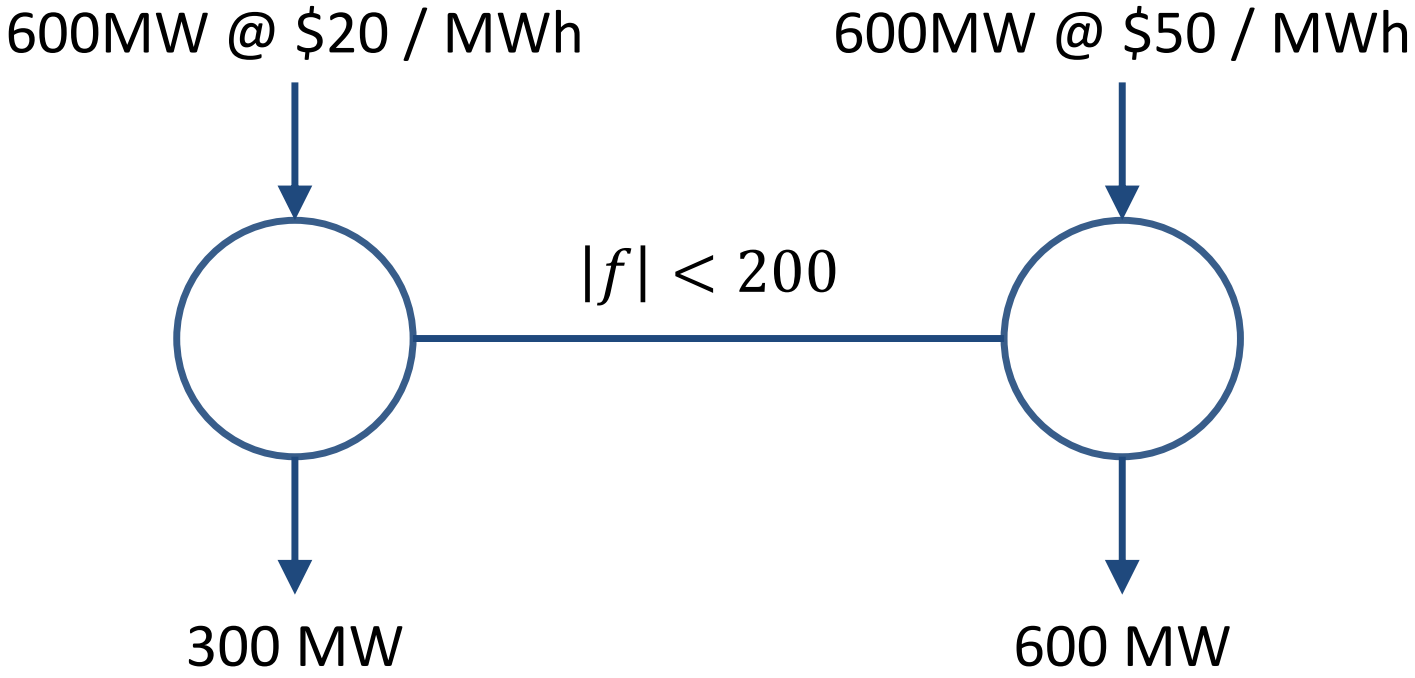
Here we have applied a marginal cost of $10 /MWh for sending flow along the line.

Example: pricing flow within SPD (low demand)

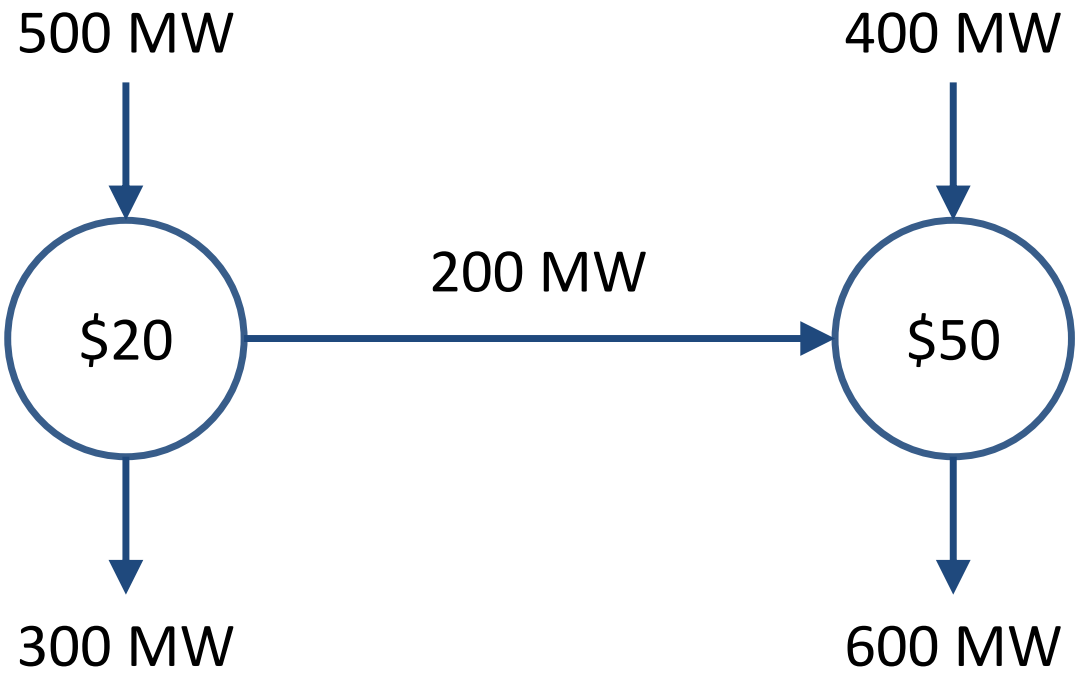
	No Charge		$10 / MWh
	200MW	400MW	400MW
Producer A	$0	$0	$0
Producer B	$0	$0	$0
Consumer A	$8000	$8000	$8000
Consumer B	$12500	$20000	$17500
Congestion Rents	$6000	$0	$2500
Total Welfare	$26500	$28000	$28000

Note: consumers value electricity at $100 / MWh, and generators are offering at marginal cost.

Example: pricing flow within SPD (high demand)

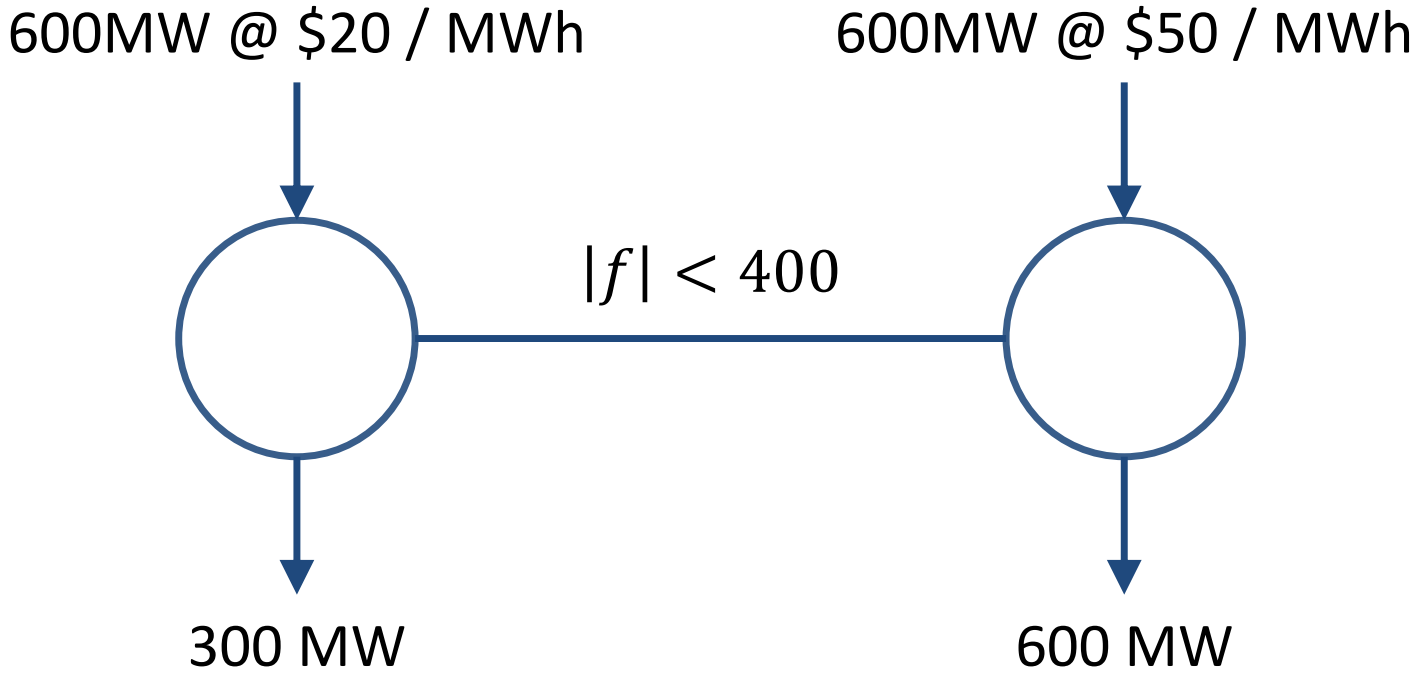


Example: pricing flow within SPD (high demand)

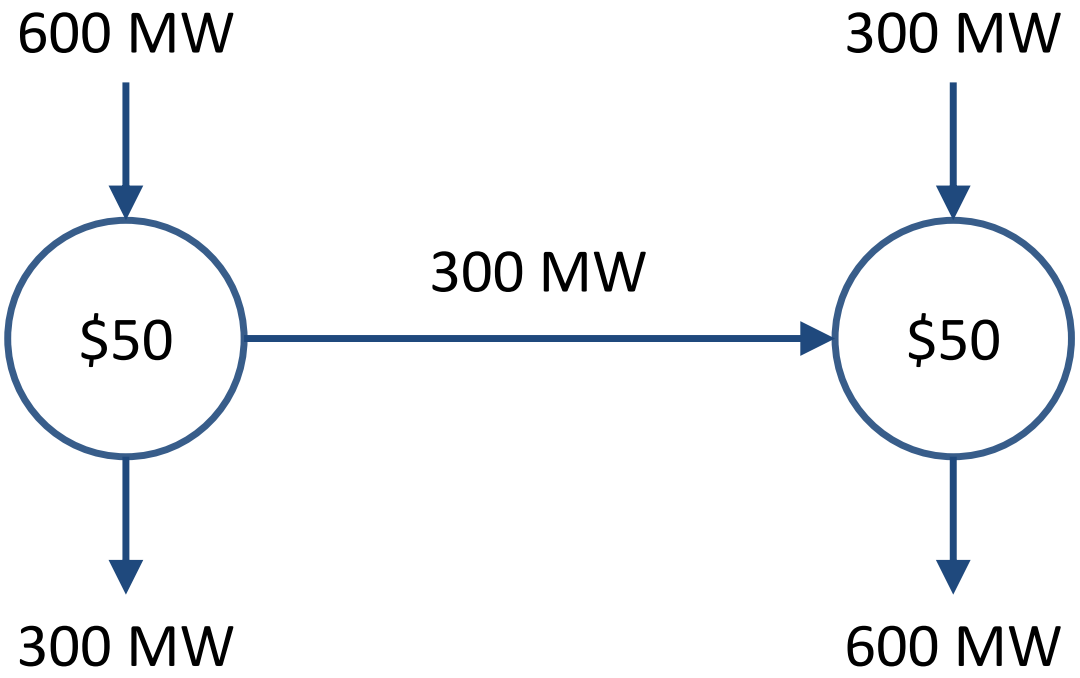


Payment from: consumer A: $6000; consumer B: $30000.
Payment to: generators A: $10000; generator B: $20000.
Congestion rents: $6000.

Example: pricing flow within SPD (high demand)

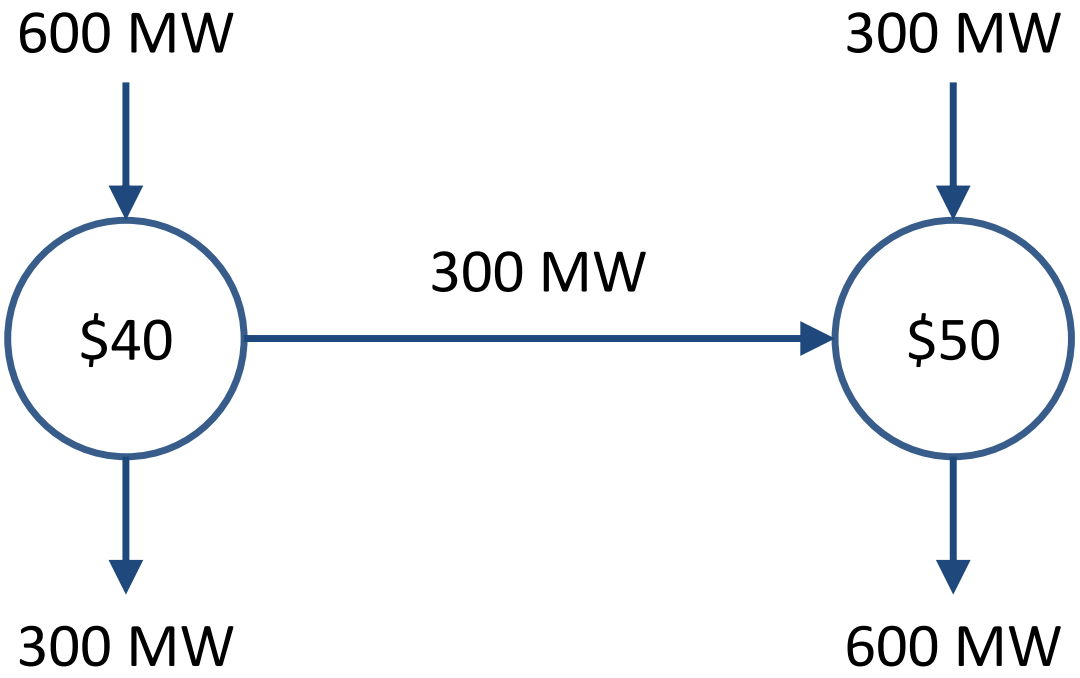


Example: pricing flow within SPD (high demand)



Payment from consumer A: $15000; consumer B: $30000.
Payment to generators A: $30000; generator B: $15000.
Congestion rents: $0.

Example: pricing flow within SPD (high demand)



Payment from consumer A: $12000; consumer B: $30000.
Payment to generators A: $24000; generator B: $15000.
Congestion rents: $3000.

Here we have applied a marginal cost of $10 / MWh for sending flow along the line.

Example: pricing flow within SPD (high demand)

	No Charge		$10 / MWh
	200MW	400MW	400MW
Producer A	$0	$18000	$12000
Producer B	$0	$0	$0
Consumer A	$24000	$15000	$18000
Consumer B	$30000	$30000	$30000
Congestion Rents	$6000	$0	$3000
Total Welfare	$60000	$63000	$63000

Note: consumers value electricity at $100 / MWh, and generators are offering at marginal cost.

Conclusions

- Demand uncertainty diminishes incentives to mark up offer stacks to conceal profits.
- A charge based on benefits does not give incentive to mark-up at the low end of the offer stack, since it is the difference in perceived profits that is taxed.
- Interestingly, with small-medium line expansions we found that generator competition would increase due to the charge, and in fact consumer surplus and the total charge collected from generators would increase.
- For large line increases, consumer welfare decreased as firms marked up the low-quantity end of their curve to minimize their transmission charge. For this reason we do not recommend the SPD charge be implemented.
- Our alternate proposal of integrating the transmission charge is much simpler and transparent and delivers beneficiaries-pay outcomes.

Further Research / Work in Progress

- Supply function equilibrium modelling of asymmetric firms (e.g. firms at either end of a potentially constrained line). Here upstream firms receive benefits and downstream firms, disbenefits.
- Explore the nature of the supply function equilbria when the 2nd order optimality conditions for $Z(q, p) = 0$ are not satisfied.
- Investigate the viability of the auction for options to use the transmission grid.

Thanks for your attention.

Any Questions?