

# horizontal subcontracting and intermittent power generation

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# a paradox

intermittent energy sources

- *increase* the need for flexible back-up facilities to ensure security of supply



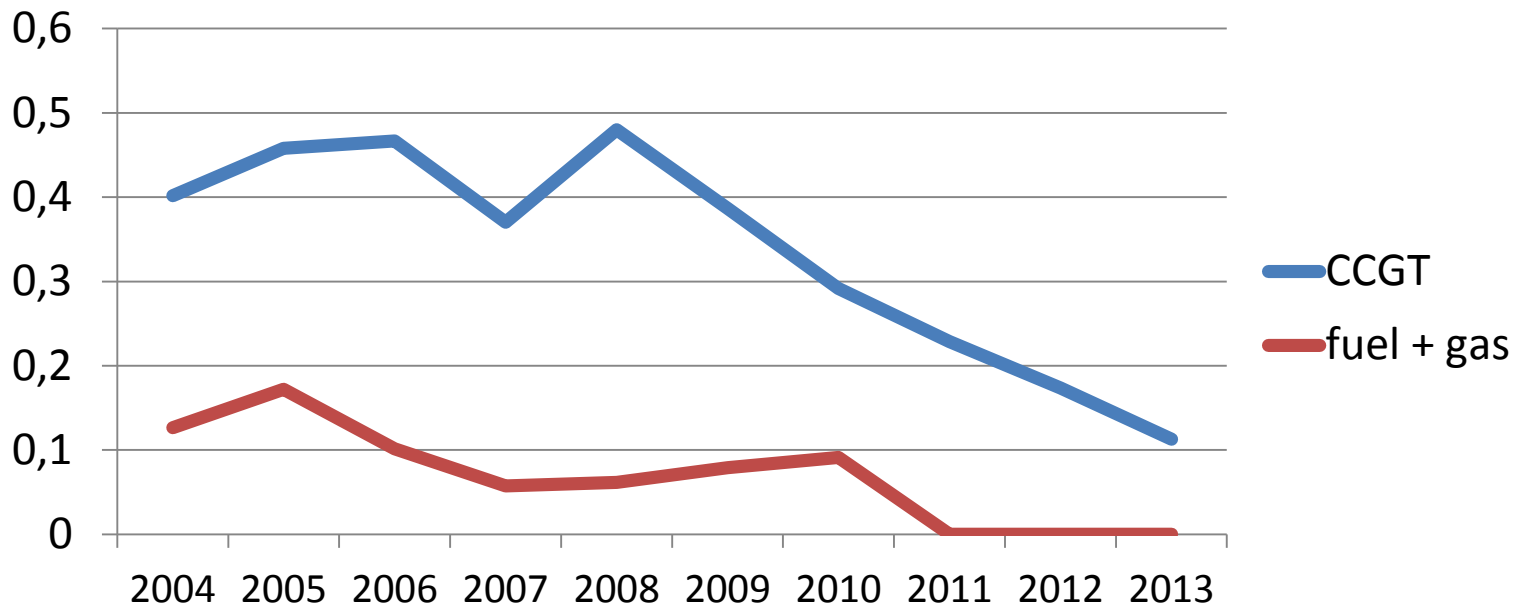
- *reduce* the #hours of operation (capacity factor) of conventional capacity
- *decrease* conventional plant profitability

# examples

- 1 MW of wind power removes only 0.2-0.3 MW of reliable energy sources (US)

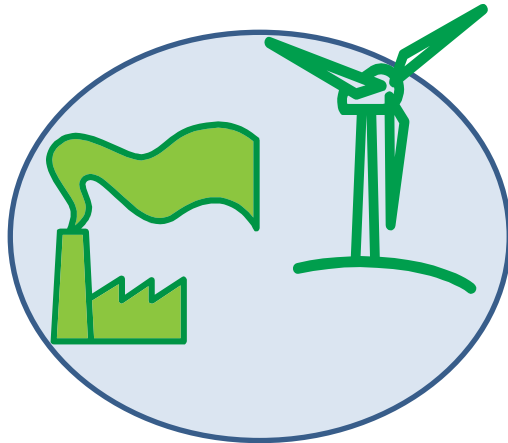
# examples

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- capacity factors (Spain)

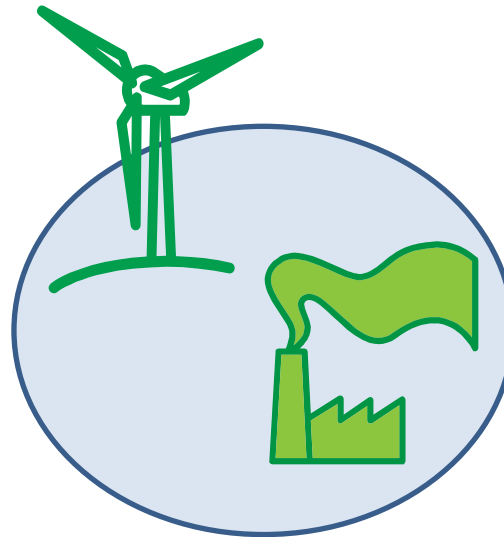


# reliable and intermittent sources

firm  $i$

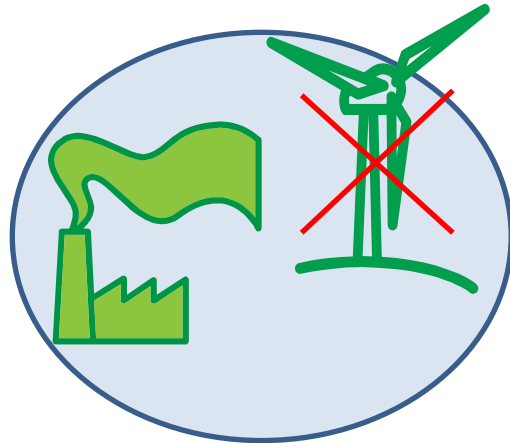


firm  $j$

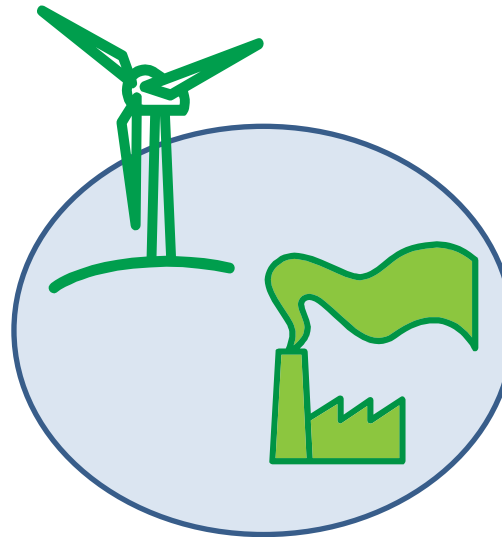


# reliable and intermittent sources

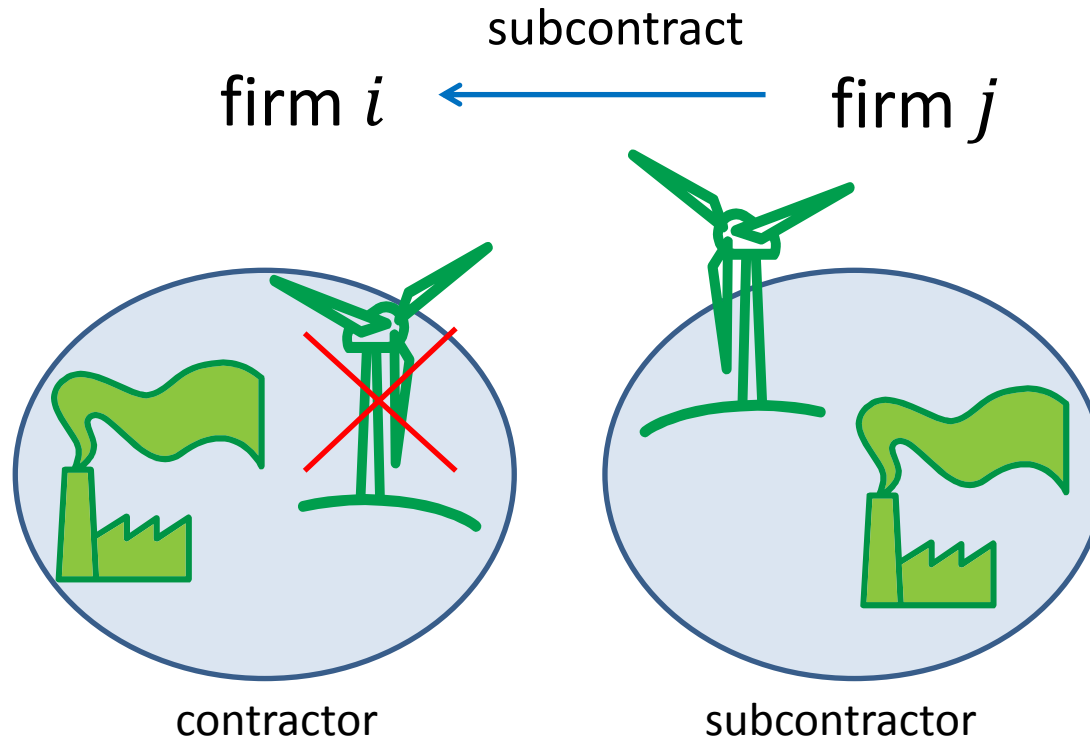
firm  $i$



firm  $j$



# horizontal subcontracts!



firms gain from outsourcing conventional generation to the wind-abundant rival

# what's new?

- literature : Kamien et al. (1989), Spiegel (1993)
  - gains from subcontracting
  - the subcontracting terms alter equilibrium behavior

*subcontracting literature:* +

- option contracts to increase industry profits
- idle capacity avoids hold-up by the subcontractor
- welfare comparison: Bertrand, Cournot, collusion

*power markets literature:*

- plant profitability underestimates firms' willingness to invest: conventional plants *need not* be used to increase profits



# the model

- symmetric duopoly
- two production technologies
  - intermittent, zero marginal cost
  - expensive back-up:  $TC = 0.5\beta q^2$
- two-stage game
  - stage 1: competition for customers  
market demand  $Q = 1 - P$
  - stage 2: °nature reveals weather conditions  
°subcontracting

# stage 2: nature reveals state

- $\alpha$  = prob. wind-abundant  $\Rightarrow$  **firm-intermittency**
- $\rho$  = prob. both firms have identical generation conditions  
 $\Rightarrow$  **system intermittency**

# stage 2: nature reveals state

- $\alpha$  = prob. wind-abundant  $\Rightarrow$  **firm-intermittency**
- $\rho$  = prob. both firms have identical generation conditions  $\Rightarrow$  **system intermittency**

		firm $j$	
		$w$	$\bar{w}$
firm $i$	$w$	$0.5(-1 + 2\alpha + \rho)$	$0.5(1 - \rho)$
	$\bar{w}$	$0.5(1 - \rho)$	$0.5(1 - 2\alpha + \rho)$

# stage 2: gains from subcontracting

Firm  $j$

		$w$	$\bar{w}$
Firm $i$	$w$	0	$TC(q_j)$
	$\bar{w}$	$TC(q_i)$	$TC(q_i) + TC(q_j)$ $-2TC(0.5(q_i + q_j))$

# stage 2: gains from subcontracting

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1. efficient subcontracts
2. seller appropriates share  $0 \leq \sigma \leq 1$  of the gains from subcontracting

# back-up cost parameter $\beta$

Firm  $j$

		$w$	$\bar{w}$
Firm $i$	$w$	0	$TC(q_j)$
	$\bar{w}$	$TC(q_i)$	$TC(q_i) + TC(q_j)$ $-2TC(0.5(q_i + q_j))$

determines total cost function

- *direct* effect: generation costs if  $(\bar{w}, \bar{w})$
- *indirect* effect: subcontracting costs!

# $i$ 's profit function

- if  $i$  sets the *lowest* price
  - customer revenues - costs without subcontracting

$$(1 - p_i) p_i - (1 - \alpha) TC(Q(p_i))$$

+

- appropriated gains from subcontracting

$$(1 - \sigma) \left( \underbrace{\frac{1 - \rho}{2} TC(Q(p_i))}_{(\bar{w}, w)} + \underbrace{\frac{1 - 2\alpha + \rho}{2} 0.5 TC(Q(p_i))}_{(\bar{w}, \bar{w})} \right)$$

# $i$ 's profit function

- If rival  $j$  sets the *lowest* price
  - customer revenues - costs without subcontracting

0

+

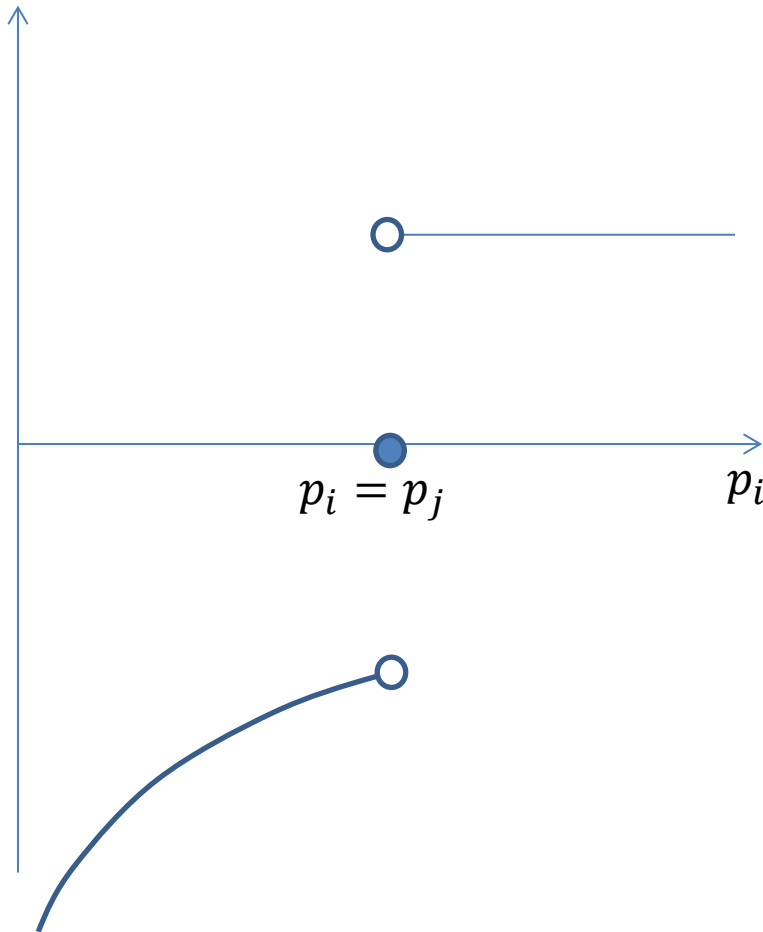
- appropriated gains from subcontracting

$$\sigma \left( \underbrace{\frac{1-\rho}{2} TC(Q(p_j))}_{(w, \bar{w})} + \underbrace{\frac{1-2\alpha+\rho}{2} 0.5TC(Q(p_j))}_{(\bar{w}, \bar{w})} \right)$$



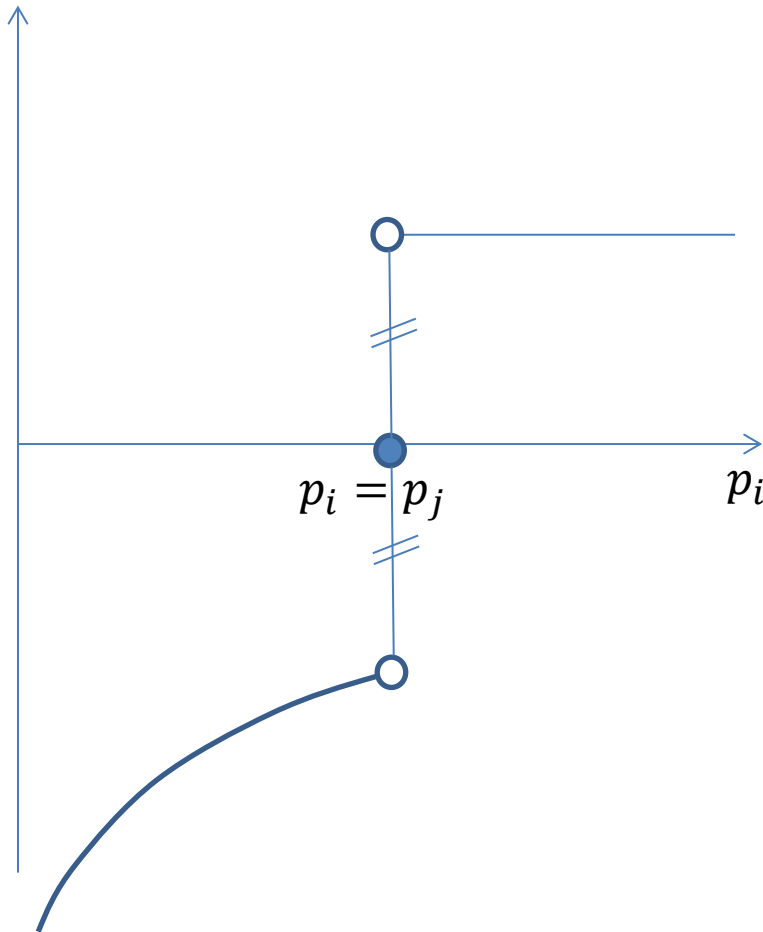
# subcontracting revenues

subcontracting  
revenues



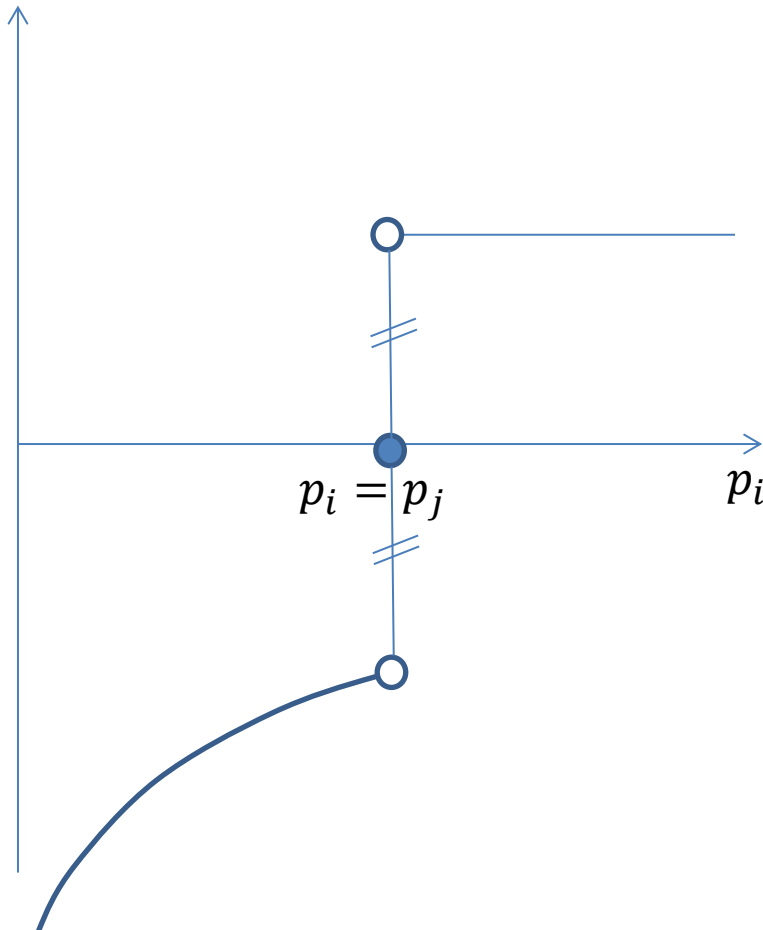
# subcontracting revenues

subcontracting  
revenues



# subcontracting revenues

subcontracting  
revenues



- High equilibrium price
- A “bill and keep” system is not equivalent

# profit-maximizing subcontracting terms

- are set in a binding “ex ante option contract”, after which firms compete
- are a device to increase profits

# profit-maximizing subcontracting terms

## firms

- non-cooperatively set identical  $\sigma = \sigma_a$
- maximize profits s.t.  $\sigma_a \leq 1$   
(option contract must outperform in-house production)
- set  $\sigma_a^* = 1$  if back-up is cheap
- charge  $\sigma_a^* < 1$  if back-up is expensive:  
can non-cooperatively implement monopoly profits

# numerical example

- let  $\rho = 0$  and  $\alpha = 0.5$ , so that either  $(\bar{w}, w)$  or  $(w, \bar{w})$
- industry generation costs are always zero
- if  $\beta = 1$  (cheap), then  $p^* = \frac{1}{1 + 2/\sigma_a}$
- ideally  $p^m = 1/2$  requiring an infeasible  $\sigma_a = 2$
- if  $\beta = 4$  (expensive), then  $p^* = \frac{1}{1 + 1/(2\sigma_a)}$
- firms obtain monopoly profits by  $\sigma_a^* = 0.5$

# investment in idle dispatchable units: *a prisoner's dilemma*

- from each firm's perspective:
  - willingness to incur a fixed investment cost to install dispatchable units
  - By doing so, they reduce the subcontracting payments made to the rival
  - Overcapacity in power markets is here explained by firms protecting themselves against hold-up by the rival.
- from an industry perspective:
  - when all firms mothball their underused dispatchable units, firms can charge subcontracting payments to one another so that profits increase.

# colluding subcontracting terms

colluding firms set  $0 \leq \sigma_a^c \leq 1$  to minimize deviation profits:

- $\sigma_a^{c*} = 1$  if back-up is cheap  
intuition: increase subcontracting payments
- $\sigma_a^{c*} < 1$  if back-up is expensive  
intuition: deviation/competing *coincides* with colluding



# colluding subcontracting firms

## **Proposition:**

The ex ante subcontracting terms if firms behave competitively also maximize the sustainability of collusion.

*policy implication*—It is impossible for a third party, i.e. a regulator or antitrust authority, to distinguish collusive from competitive behavior on the basis of the ex ante subcontracting terms.

# colluding subcontracting firms

## **Proposition:**

Only if subcontracting payments are substantial, firms deviate from the collusive price by charging a *higher* price.

## Intuition:

- the “revenue effect” from selling at a lower price does not outweigh the additional expected subcontracting cost.
- the “subcontracting effect” from selling at a lower price dominates the “revenue effect”.

# welfare

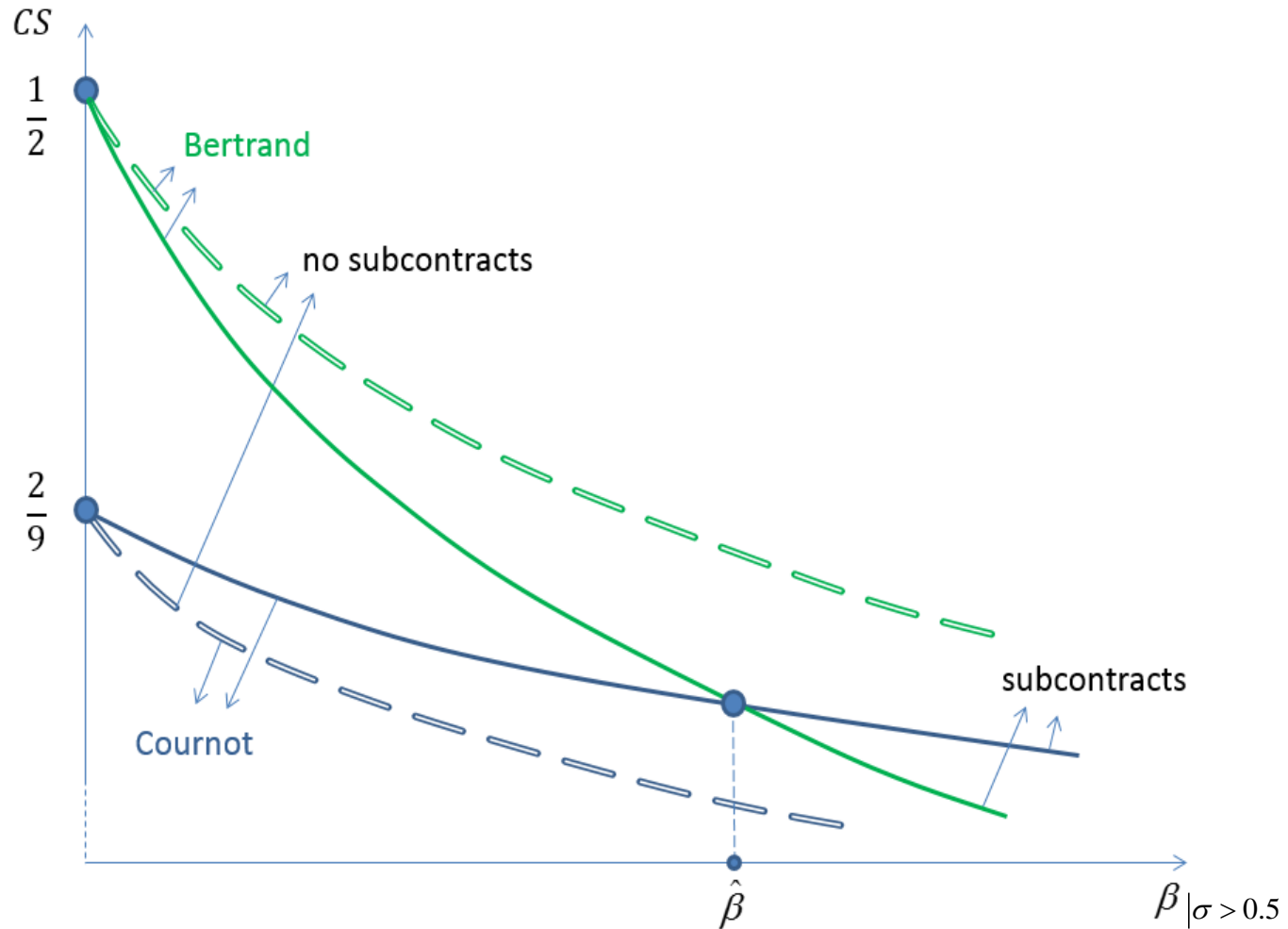
## **Proposition:**

If the subcontractor appropriates a larger share of the subcontracting rents, industry output decreases so that consumers are worse off.

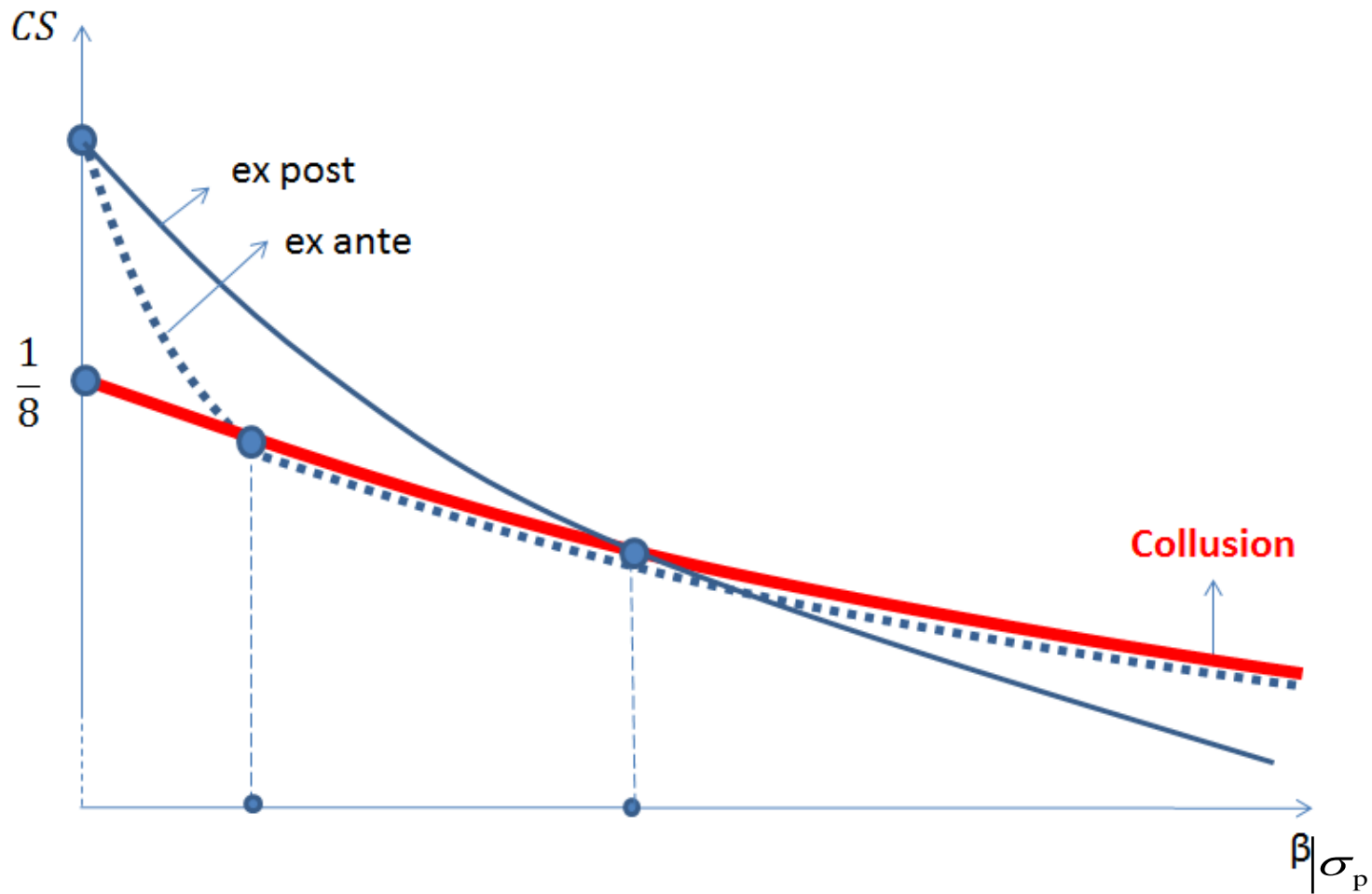
## **Proposition:**

Subcontracts always increase industry profits.

# subcontracting and consumer surplus



# profit-maximizing subcontracts need not deteriorate consumer surplus



# discussion and robustness

- supply function competition
- limited wind
- oligopoly
- linear tariffs
- subsidies and taxes

# insights

- conventional plants *need* not be used to increase profits
- prisoner's dilemma
  - industry incentive to divest
  - firm incentive to invest
- subcontracting terms
  - maximize each firm's profits non-cooperatively
  - need not deteriorate consumer surplus

**THANK YOU!**