Strategic Recycling of Critical Raw Materials

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Motivation: Context

- Critical raw materials' (CRM) prospective role for digital, military and energy transition industries
- Policymakers' focus on dependence from foreign suppliers
- Politically determined shocks in commodity markets at the center stage in economics: Oil shocks vs CRM shocks
  - $\simeq$ widely traded commodities in global market; upstream large firms and upfront investments; long-term contracts with sovereign governments; fiscal revenues
  - $\neq$ oil & gas mainly energy inputs with pervasive impacts; minerals affect specific sectors and products;
  - $\neq$ minerals embedded in traded manufactured products $\Rightarrow$ minerals recoverable from end-of-life products

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- European Union's "open strategic autonomy" objective:
  - 2024 CRM Act targets: 25% from recycling by 2030;
- **Question 1**: Could governments subsidize recycling not for environmental concern but for strategic trade purposes, with the sole aim of ensuring a trade advantage to their national firms?
- **Question 2**: Could importing material-intensive goods, despite their negative perception, actually be beneficial by creating a large reservoir for recycling?
- **Question 3**: If so, how much subsidy should governments target for recycling?

Related Literature

- Strategic trade policy:
  - Competing in third country: Brander and Spencer (1985), Dixit and Grossman (1986), Eaton and Grossman (1986), etc
  - Competing in reciprocal markets: Brander (1981), Brander and Spencer (1984), Dixit (1984, 1988), Collie (1991), etc
- Trade and recycling:
  - Sugeta and Shinkuma (2012), Sugiyama and Koonsed (2019), Egger and Keuschnigg (2024), etc
- Strategic green technology investment with spillover under emission taxation:
  - Ulph(1996), Poyago-Theotoky (2007), etc

Our Approach

1. Extend the strategic trade model à la Dixit (1984) to include material inputs sector with specific technology on recycling:
   - Focus on a $2 \times 2 \times 2$ setting with two countries, two markets (output and input) and two inputs (virgin and recycled)
   - Economies of scale in recycling on local consumption
2. Model a two-stage policy game:
   - Stage 1: The government moves first by choosing the **recycling subsidy** to maximize the country's welfare
   - Stage 2: Firms take the announced policy as given and make their production decisions to maximize their profits
3. Characterize the equilibrium under different scenarios:
   - Laissez-faire, first-best allocations
   - Cooperative and non-cooperative policies

The Output Market

- A homogeneous **traded** final good, produced by two firms, one located in Home and the other in Foreign$(*)$
- Firms compete à la Cournot and do not incur any transport costs in supplying either market
- Total domestic output: domestic sales + exports to foreign

$$H: \quad z = q + x$$
$$F: \quad z^* = q^* + x^*$$

- Domestic demand for final good is linear:

$$H: \quad P(q, x^*) = A - (q + x^*)$$
$$F: \quad P^*(q^*, x) = A^* - (q^* + x)$$

Final Good Technology

- Final production z requires inputs from virgin materials v, and recycled materials r, according to a linear technology:

$$H: \quad z = q + x = v + r$$
$$F: \quad z^* = q^* + x^* = v^* + r^*$$

  - Transform one unit of material input into one unit of output
  - Virgin and recycled materials are perfect substitutes
  - Only domestic material inputs can be employed
  - No scarcity of virgin resources
  - No market for end-of-life products and waste

- Same value as inputs

$$p_v = p_r \equiv p_m, \quad p_v^* = p_r^* \equiv p_m^*$$

Material Inputs Technology

- Perfectly competitive virgin and recycling industries
- Cost of supplying virgin materials:

$$H: \quad C_v(v) = \frac{\lambda}{2} v^2$$

$$F: \quad C_v^*(v^*) = \frac{\lambda^*}{2} (v^*)^2$$

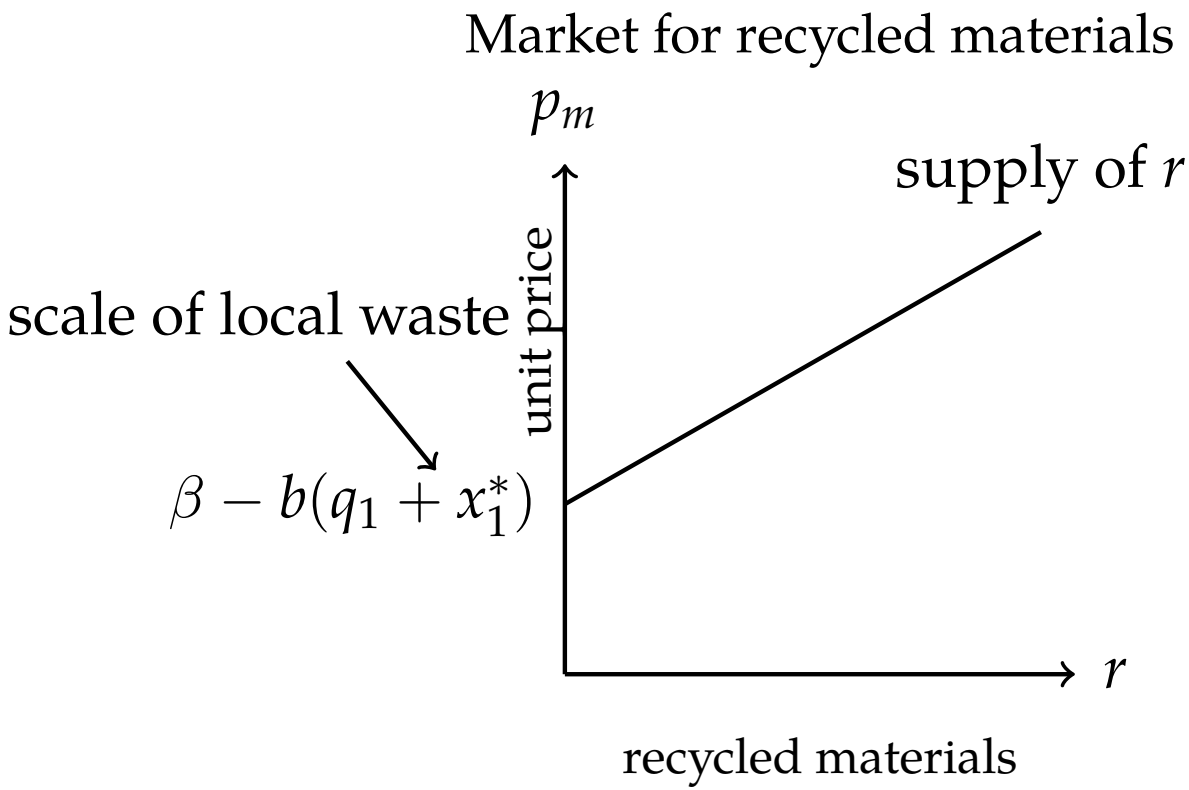
- Cost of supplying recycled materials:

$$H: \quad C_r(r) = \frac{\gamma}{2} r^2 + [\beta - b(q + x^*)]r$$

$$F: \quad C_r^*(r^*) = \frac{\gamma^*}{2} (r^*)^2 + [\beta^* - b^*(q^* + x)]r^*$$

where b measures economies of scale in recycling depending on local consumption (size of disposed end-of-life products).

Material Inputs Markets



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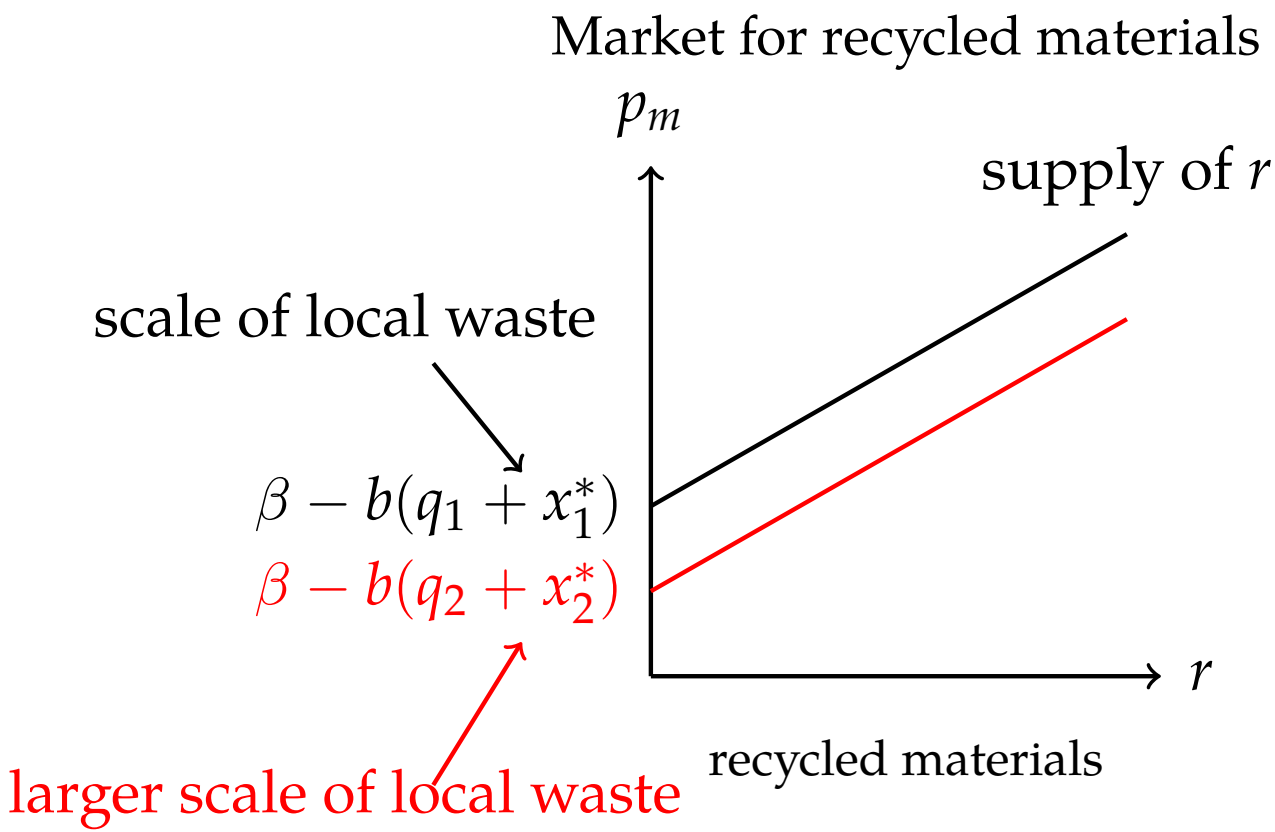

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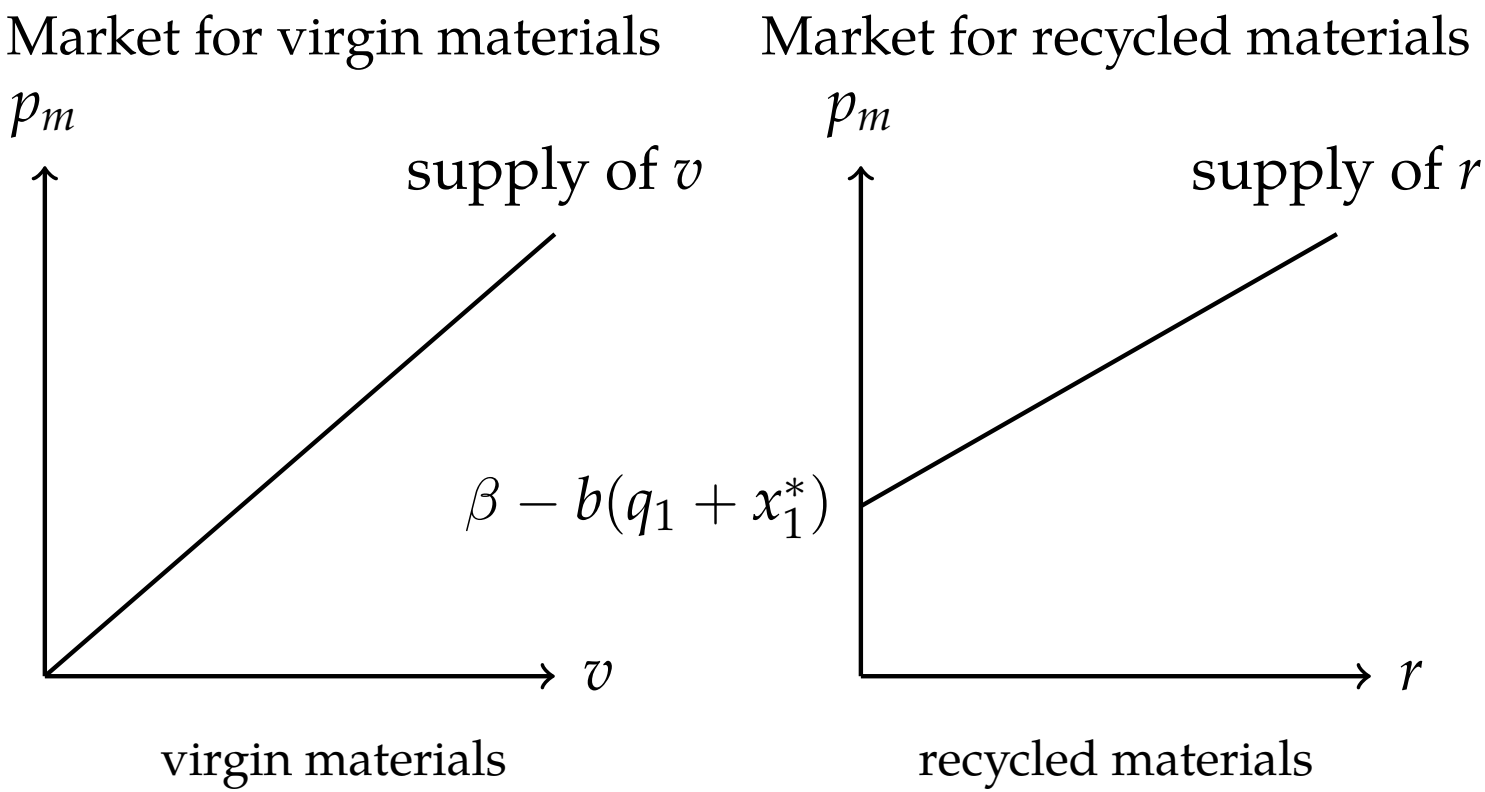
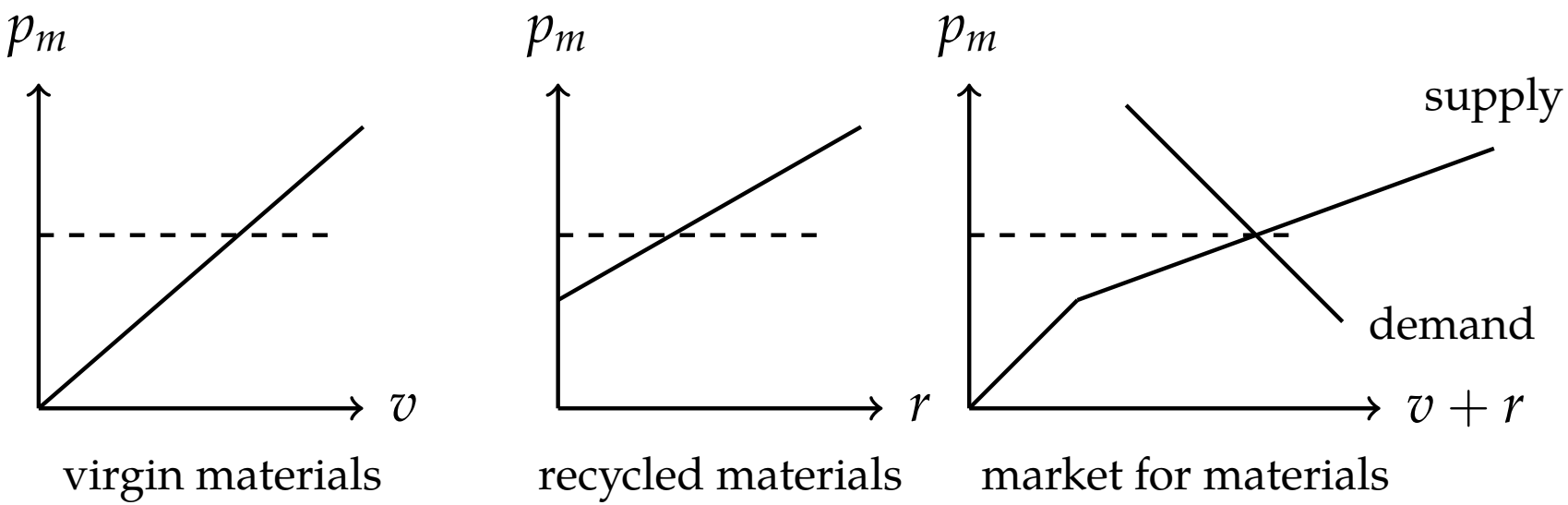


Multiplier Effect of Recycling Subsidies

Laissez faire equilibrium.

Subsidy to recycling



Multiplier Effect of Recycling Subsidies

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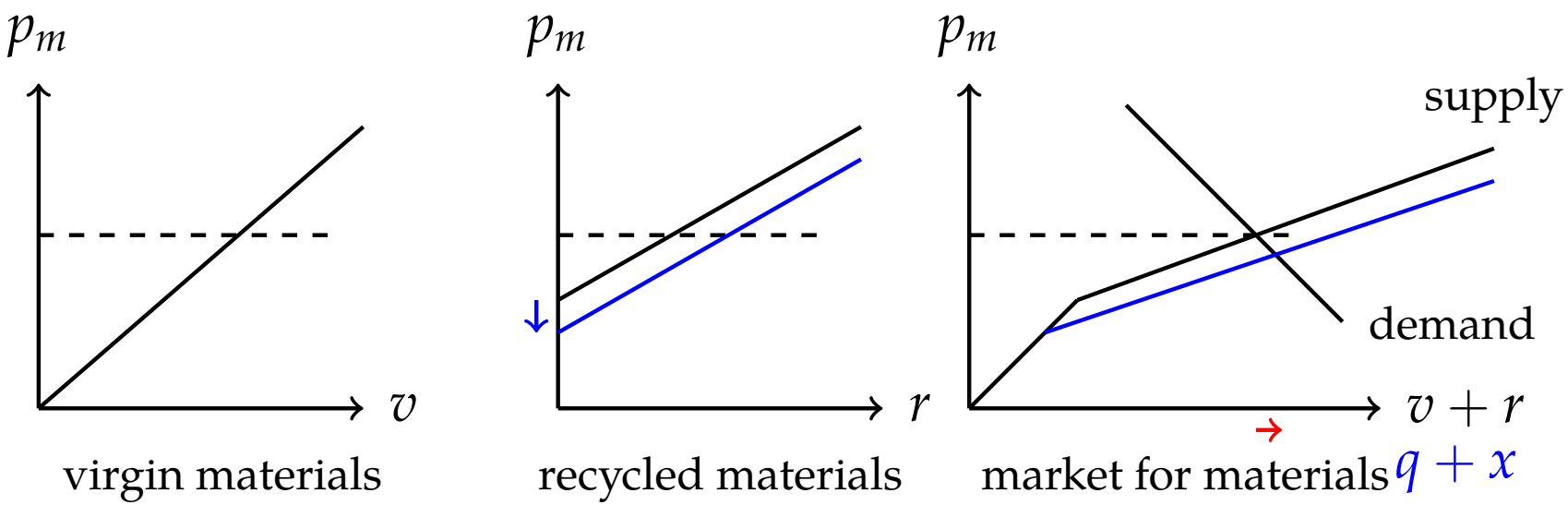
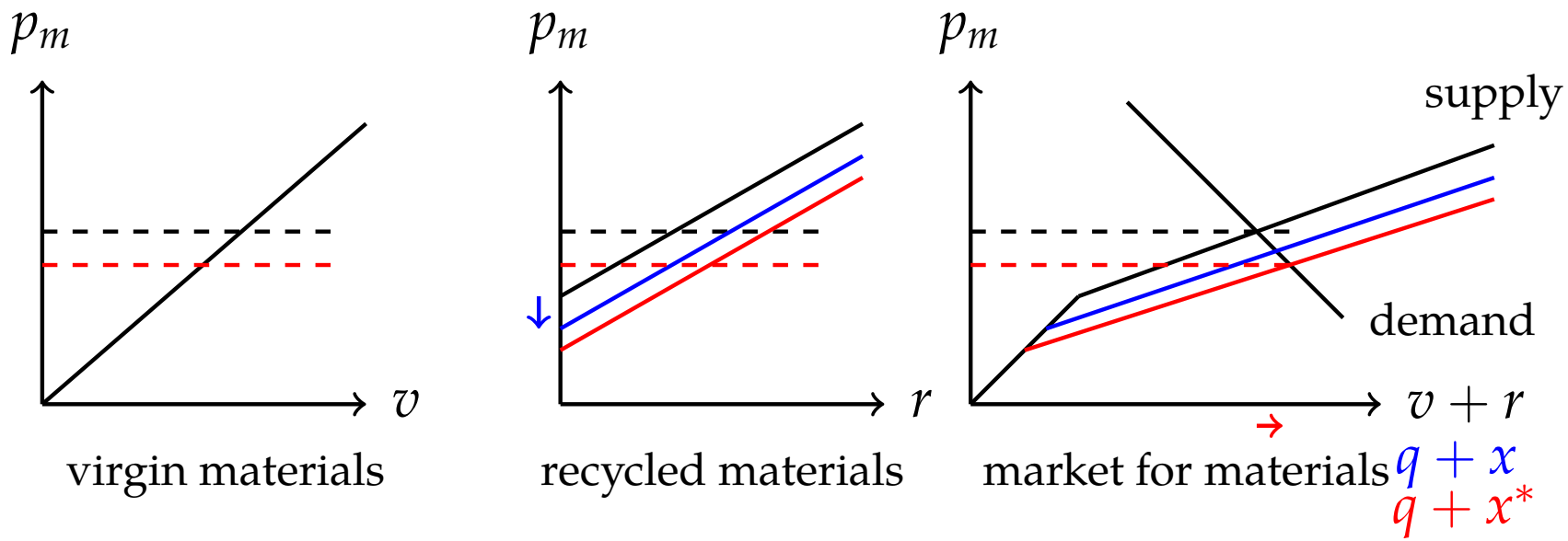
Subsidy to recycling$\Rightarrow \uparrow$ supply of $r \Rightarrow \uparrow$ supply of materials
$\Rightarrow \uparrow$ material inputs used $\Rightarrow \uparrow$ final output



Multiplier Effect of Recycling Subsidies

Laissez faire equilibrium.

Subsidy to recycling$\Rightarrow \uparrow$ supply of $r \Rightarrow \uparrow$ supply of materials
$\Rightarrow \uparrow$ material inputs used $\Rightarrow \uparrow$ final output
$\Rightarrow \uparrow$ end-of-life products waste $\Rightarrow \downarrow$ recycling cost $\Rightarrow \uparrow$ supply of materials ...



Market and Policy Failures

- Two market failures
  - (1) market power
  - (2) positive production externalities (economies of scale)
- A potential policy failure
  - (3) governments play a non-cooperative policy game in the aim of "stealing rents"

- Failures (1)+ (3) are considered in strategic trade literature

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Second best

Relying exclusively on recycling subsidy does not allow to restore the first-best allocation.

- If the optimal total output is attained, the input ratio is suboptimal.
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A Two-stage Game

- For given recycling policies (σ, σ^*), solve the market equilibrium in each sector

(C) **Cooperative** equilibrium: the world council of gov'ts sets a uniform σ

  - **Foresighted** gov'ts: aim at correcting both market failures
  - **Myopic** gov'ts (take the cost function of recycling as given): aimed at correcting only market power

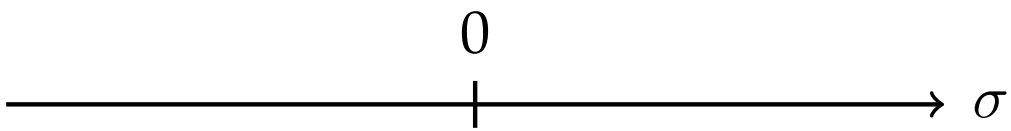
(NC) **Non-cooperative** policy equilibrium: each gov't chooses its σ taking as given the other country policy

  - **Foresighted** gov'ts: aim at correcting both market failures + stealing rents
  - **Myopic** gov'ts: correcting market power + stealing rents

- Restrict analysis to configurations of parameters with interior solution and positive intercept of MC_r.

Results I

Compare the non-cooperative to the cooperative equilibrium in the case **without positive production externality** ($b = 0$)



Absent any environmental or resource concern,

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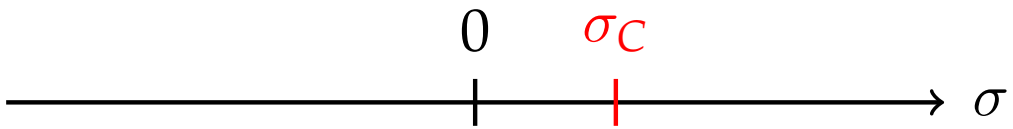

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- Recycling subsidies allow to (partially) tackle market power

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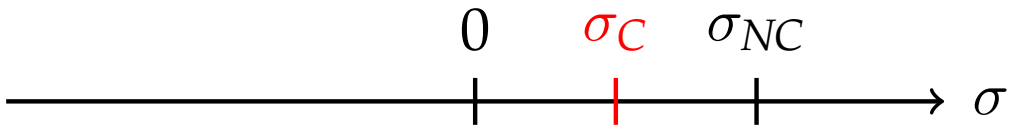


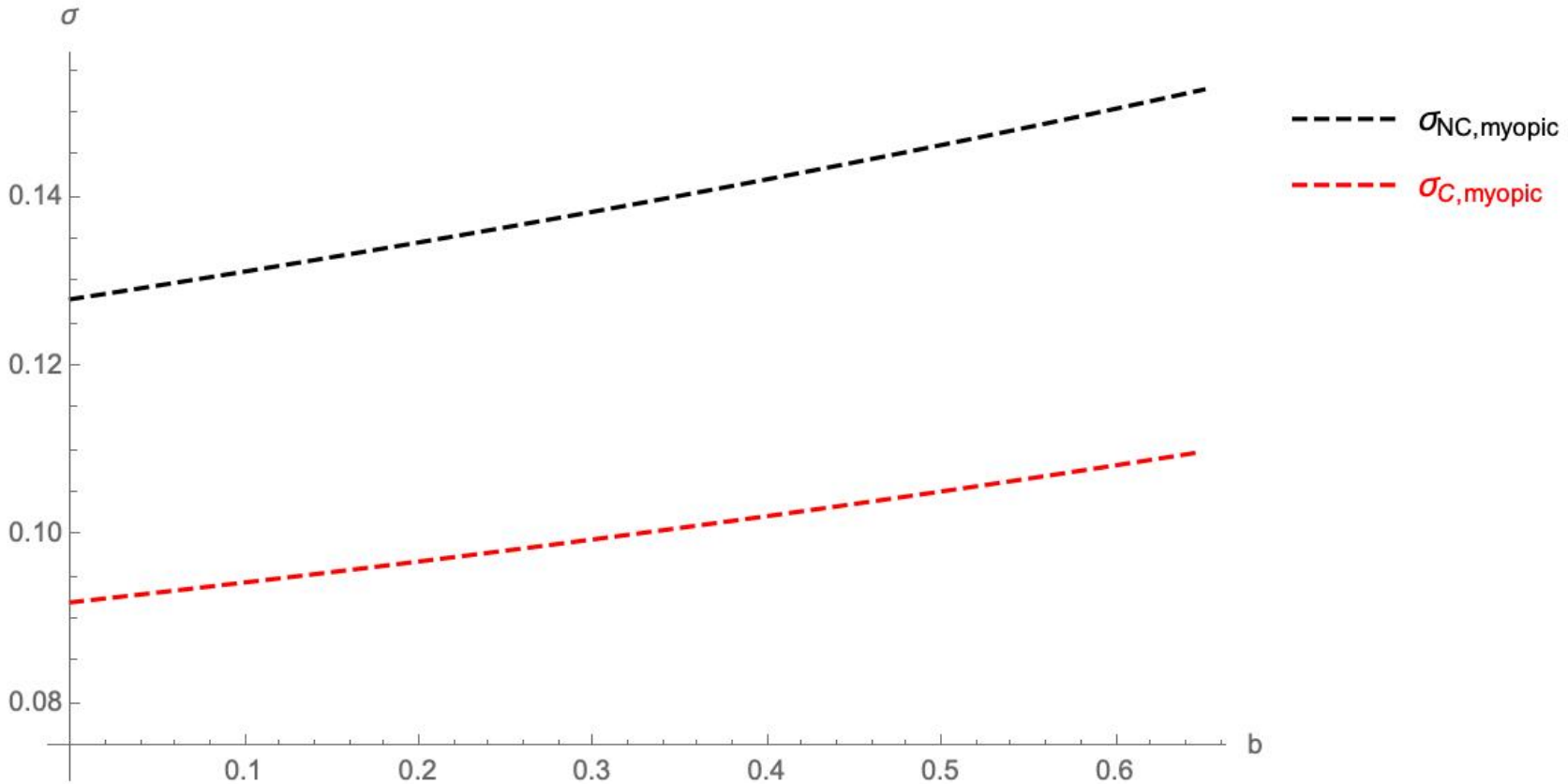
Strategic subsidies to recycling

Absent any environmental or resource concern, governments excessively subsidize recycling to boost the competitiveness of their national firm.

- Recycling subsidies allow to (partially) tackle market power
- Rent stealing motive makes recycling subsidies strategic complements

Results II

Compare the **myopic non-cooperative** equilibrium to the **myopic cooperative** equilibrium (evaluated at laissez-faire)



Results II

Compare the **myopic non-cooperative** equilibrium to the **myopic cooperative** equilibrium (evaluated at laissez-faire)

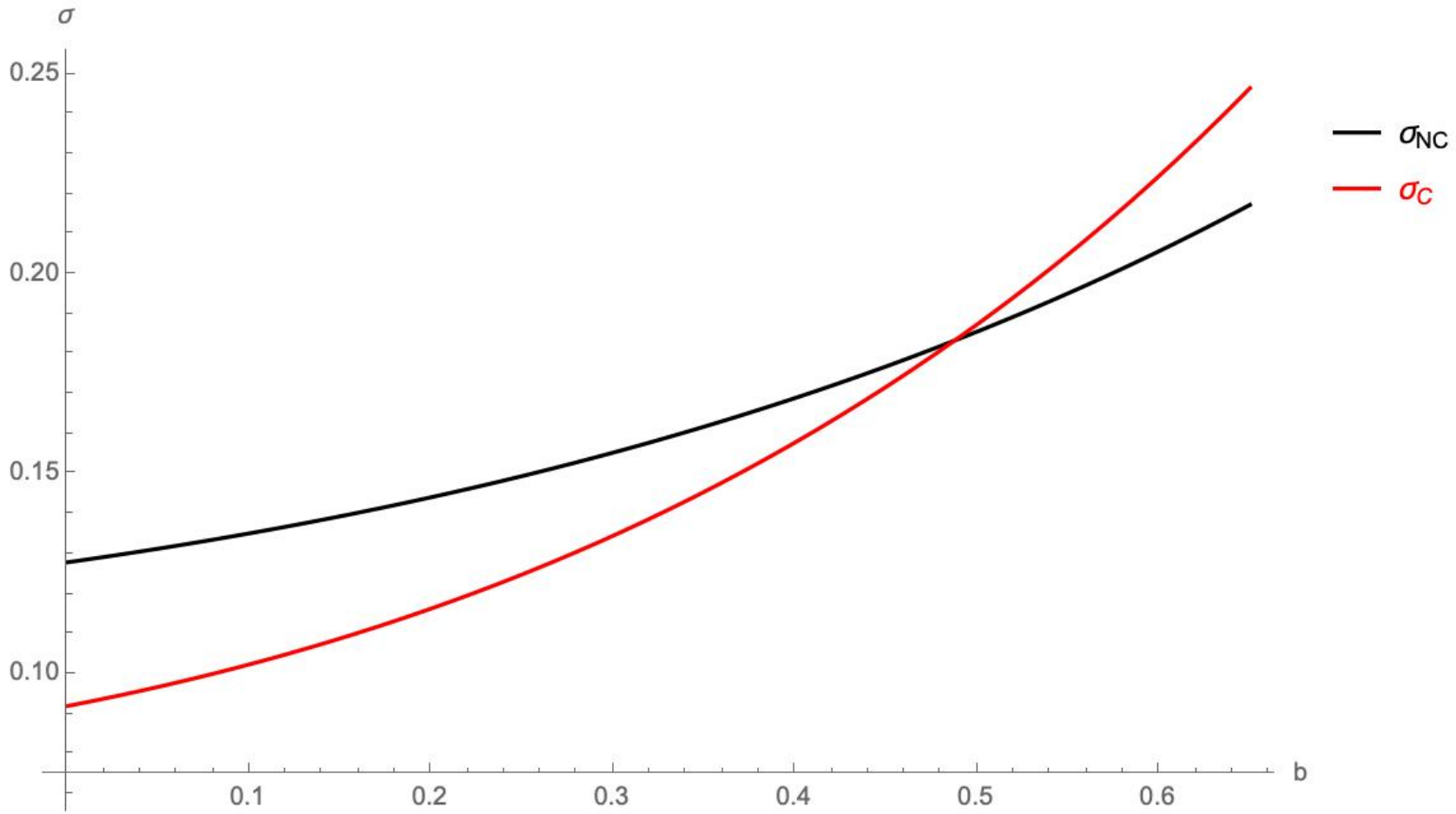
Economies of scale in recycling and loss from market power

- Even if governments **do not** take into account the feedback effect from increased output on the cost of recycling,
  - the stronger the externality,
  - the lower the production cost, the greater the marginal gain from correcting the market power distortion;
- The cooperative and noncooperative subsidies to recycling set by myopic governments are an increasing function of b.

Results I and II are based on market and policy failures: (1) and (3), similar to results in seminal papers on strategic trade theory.

Results III

Compare the **foresighted non-cooperative** equilibrium to the **foresighted cooperative** equilibrium



Results III

Compare the **foresighted non-cooperative** equilibrium to the **foresighted cooperative** equilibrium:

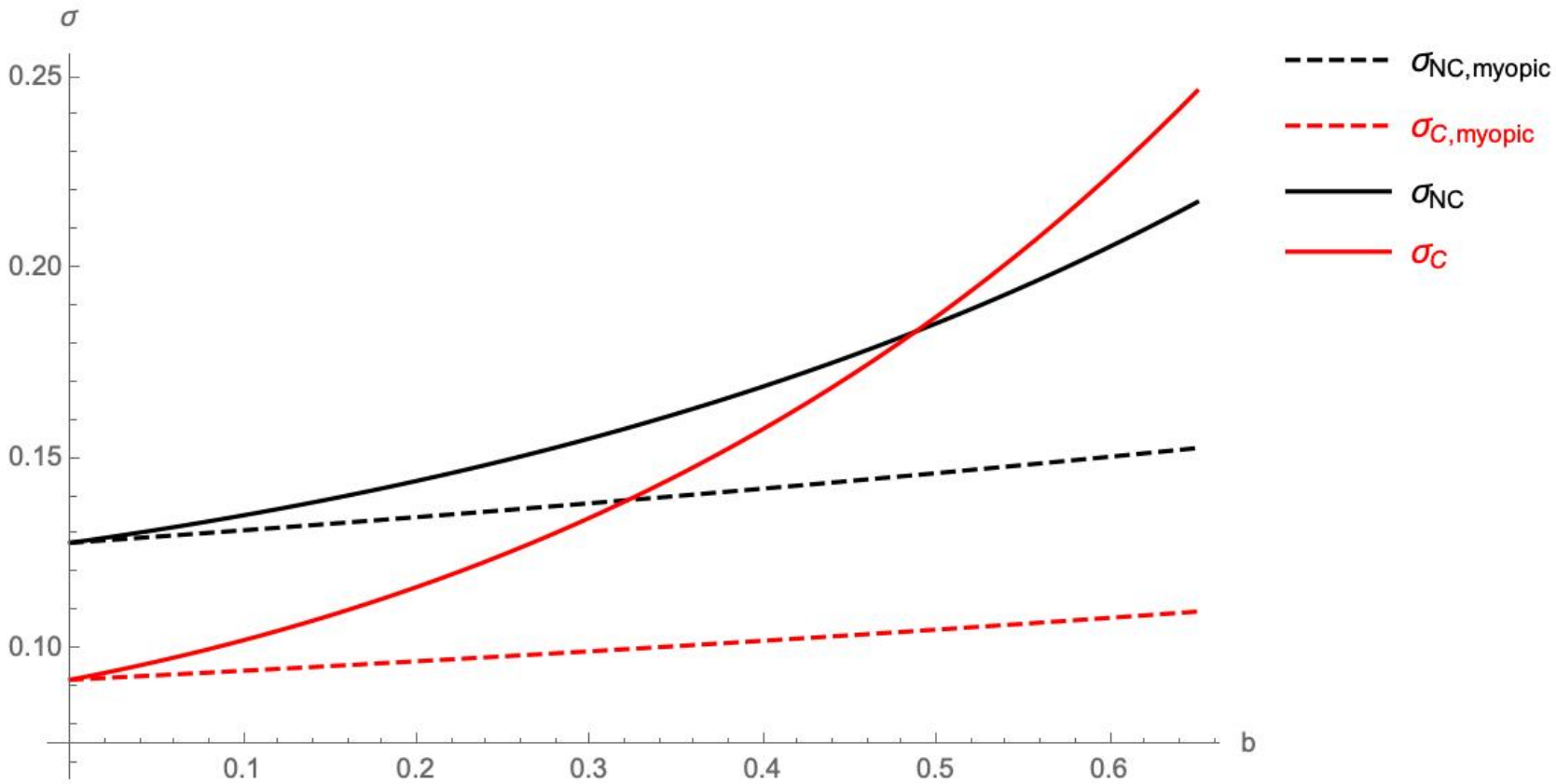
Subsidies to recycling can be insufficient or excessive

depending on the strength of the positive production externality

- Two countervailing forces: one due to rent stealing (excessive subsidies), the other due to the externality (insufficient subsidies).
- The subsidies to recycling set by foresighted noncooperative and cooperative governments are increasing functions of b.

Results IV

Compare the **myopic** versus the **foresighted** equilibrium



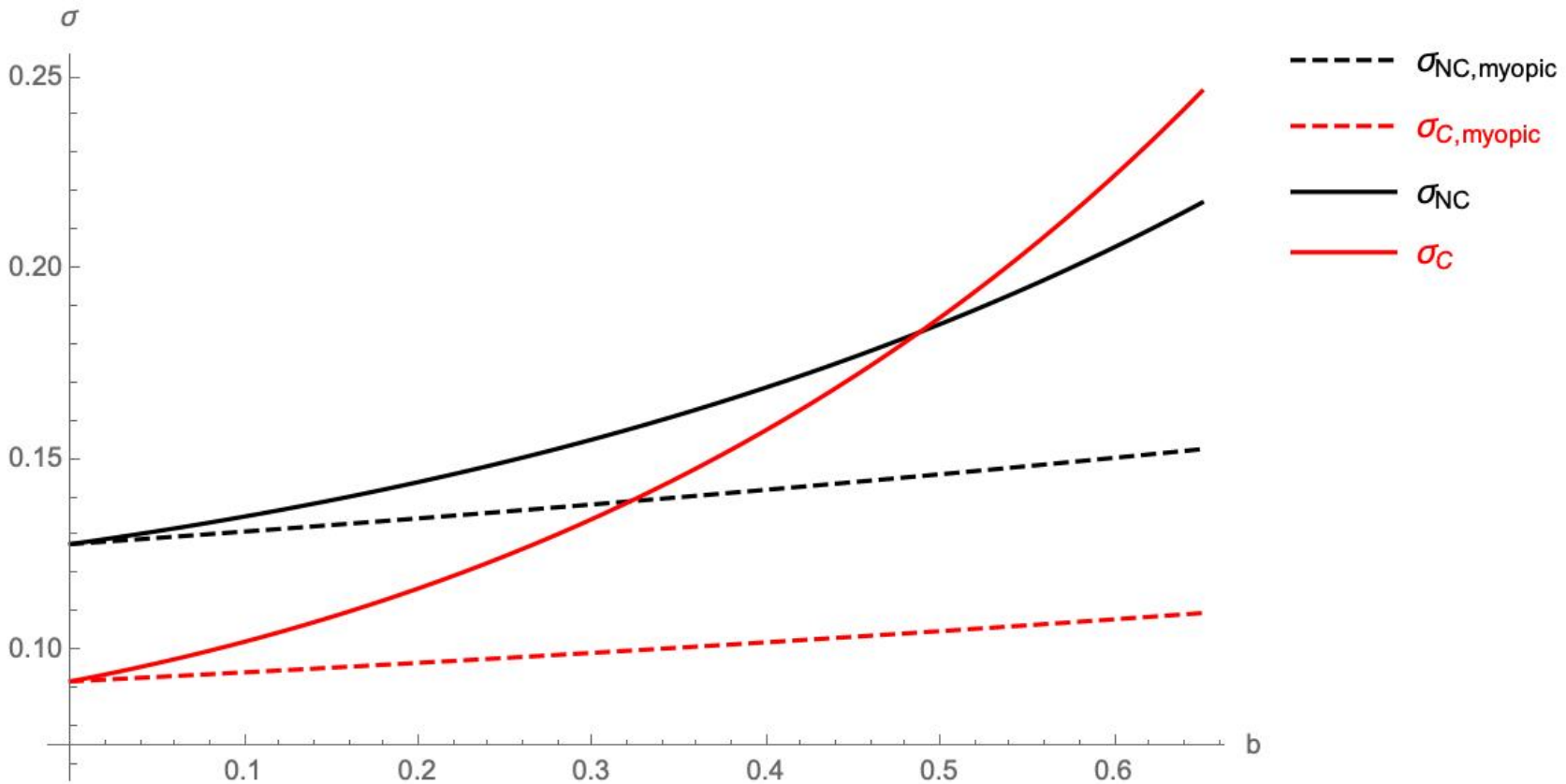
Results IV

Compare the **myopic** versus the **foresighted** equilibrium

Economies of scale in recycling

- When governments take into account the feedback effect from increased output on the cost of recycling,
  - the stronger the externality,
  - the greater the marginal return on recycling subsidy in terms of reduced production cost.

Results V



$\Rightarrow$ Absent international cooperation, it may be preferable to have myopic policy making!

Conclusion

- The positive production externality in recycling motivates targeted subsidies;
- Subsidies can be inefficiently large as long as their rationale lies in favouring the national firm;
- It may be socially preferable that governments ignore the externality affecting the recycling technology.

Road Ahead

- Asymmetric and corner equilibrium
- Asymmetry in the cost of virgin resources
- Combination of policy instruments
- Exhaustible virgin resources $\rightarrow$ Dynamic game
- Trade in primary and secondary inputs

THANK YOU!