Regulations and the incentive for environmental innovations on emissions

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Introduction – context

- Biofuels reduce GHG emission in comparison to fossil fuels
- However, the production costs of biofuels are higher.

$\Rightarrow$ Lack of private incentives to use biofuels

$\Rightarrow$ Implementation of regulations to (1) mandate the use of biofuels and (2) favor innovation to make biofuels more attractive

- Examples of regulations: Renewable Energy Directive in 2009 (Europe), Renewable Fuel Standard in 2007 (USA).
  Different types of instruments: mandates (minimum quantities or minimum share), differentiated taxes depending on fuel type, emission standard.

Introduction – objectives

- Compare the impact of different regulations on the incentives to innovate to reduce biofuel-related emissions
- Example: improving canola nitrogen efficiency
  - $\Rightarrow$ Improves cost efficiency. Decrease the nitrogen use for a given yield or increase the yield with a given nitrogen use.
  - $\Rightarrow$ Decreases emission related to biodiesel because nitrogen production induce high emissions.
- Theoretical analysis based on IO modeling

Literature

- Clancy and Moschini (2018): incentives to innovate for decreasing biofuel production cost, in a context with perfect competition for fuel supply.
  $\Rightarrow$ Very similar model, but with a different type if innovation, and perfect competition/monopoly for fuel supply

- Holland et *al.* (2009): analysis of the effect of Low Carbon Fuel Standard (and variations around) on fuel product, with or without market power.
  $\Rightarrow$ Analysis of the incentives to adopt an innovation

Main results

- Quantity based regulation (quotas or biofuel incorporation rate) generate no incentive to adopt an innovation that enables to reduce emission.
- Such incentives exists with emission standard or a tax that is related to emission level.
- These two regulations have different properties:
  - With an emission standard, emission based innovation reduces the share of biofuel and increases total quantities.
    The incentive to innovate depends on the level of innovation, and the market power in the fuel supply.
  - With a tax, emission based innovation increases the share of biofuel without reducing total quantities. The incentives to innovate are less dependent on market structure.

The model

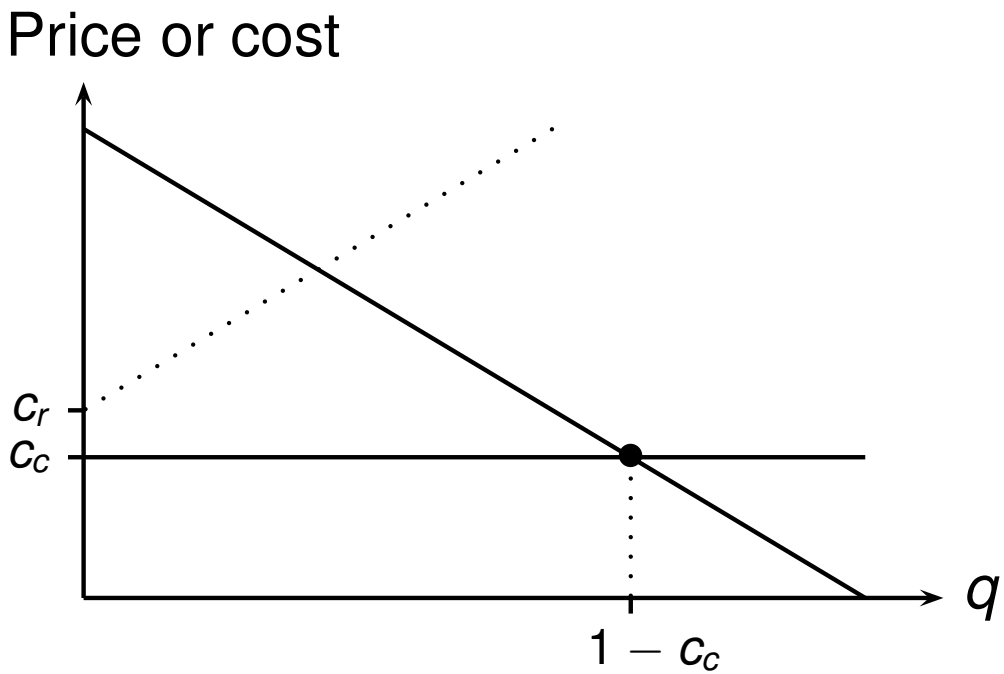
- Fuel supplied by an industry in perfect competition (PC) or monopoly (M). Production is based on two sources:
  - Fossil fuel (quantity q_c)
    - Constant marginal cost: c_c
    - Per unit emission level standardized to 1.
  - Biofuel – renewable resource (quantity q_r)
    - Increasing marginal cost: $c_r + q_r$ (with $c_r > c_c$)
    - Per unit emission level: $\phi_r < 1$
- The fuel demand is supposed to be linear: $P = 1 - q$ with $q = q_r + q_c$ et $c_c < c_r < 1$.
- An upstream monopoly can license an innovation on biofuel:
  - Enables to reduce emission level $\phi_r \to \phi_r - \Psi$ with $\Psi \in [0, \phi_r]$
  - Royalty based license: r per unit of biofuel

Outline or the rest of this presentation

- Two benchmarks:
  - Equilibrium with no regulations
  - Quantity based regulation
- Presentation of the two regulations (tax and emission standard)
- Comparison in a context with free innovation:
  - Equilibrium with each regulation
  - Incentives to adopt a free innovation
- Comparison in a context with endogenous level of royalty

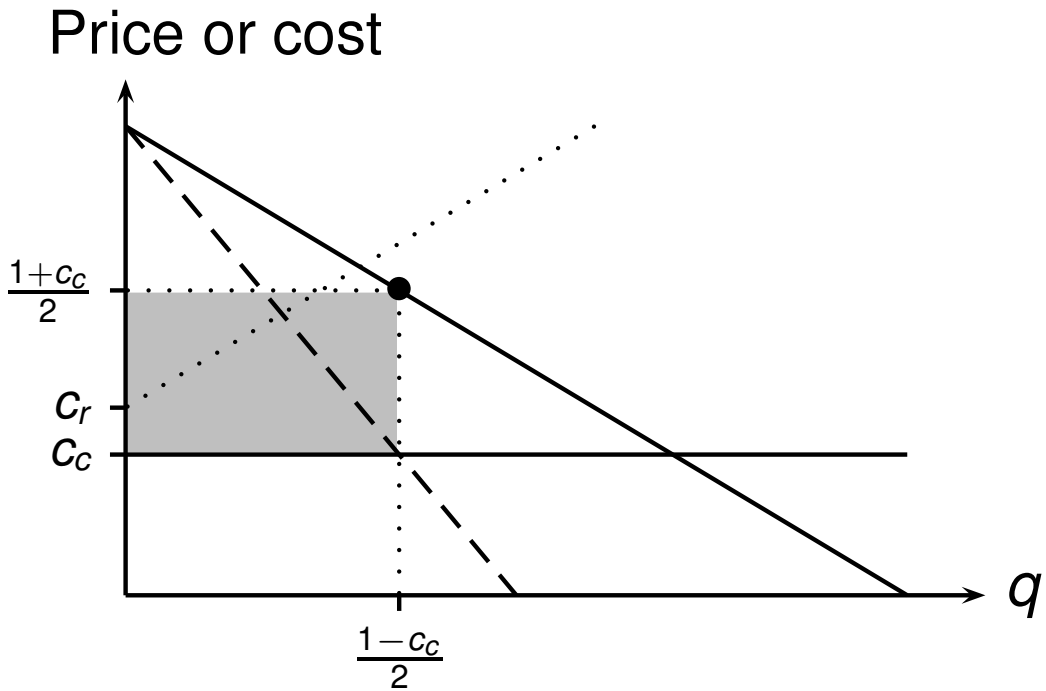
Equilibrium with no regulation - Perfect competition

- Without regulation, the industry adopt fossil fuel the is less costly.
- Equilibrium with perfect competition
  - $P = 1 - q = c_c \quad \Leftrightarrow \quad q = 1 - c_c$.
  - the industry makes no profit.



Equilibrium with no regulation - Monopoly

- No interest to use biofuel. The equilibrium is:
  - $P'q - P = c_c \quad \Leftrightarrow \quad q = \dfrac{1 - c_c}{2}$.
  - The industry makes a positive profit: $\pi^M = \dfrac{(1 - c_c)^2}{4}$.



Quantity related regulation

- Example of a minimum incorporation rate (γ): $q_r \geq \gamma q$
- Equilibrium with perfect competition :

$$P = 1 - q = (1 - \gamma)c_c + \gamma(c_r + \gamma q)$$

$$\Leftrightarrow \quad q = \frac{1 - c_c - \gamma(c_r - c_c)}{1 + \gamma^2} < 1 - c_c$$

- The regulation leads the industry to produce less. The price equilibrium is above the fossil fuel marginal cost and the industry makes a positive profit.
- **An innovation that the reduces biofuel emission is not adopted** because it has no effect in the constraint $q_r \geq \gamma q$ and thus the quantity and profit at the equilibrium.
- Same property with a regulation that defines a minimum quantity of biofuel ($q_r \geq q_r^{min}$).

Two regulations that integrates emission levels

- **A per unit tax** proportional to the emission level: $t = \tau \cdot \frac{q_c + q_r \phi_r}{q_c + q_r}$.
- The innovation enables to decrease the tax level:

$$\tau \cdot \frac{q_c + q_r(\phi_r - \Psi)}{q_c + q_r} < \tau \cdot \frac{q_c + q_r \phi_r}{q_c + q_r}$$

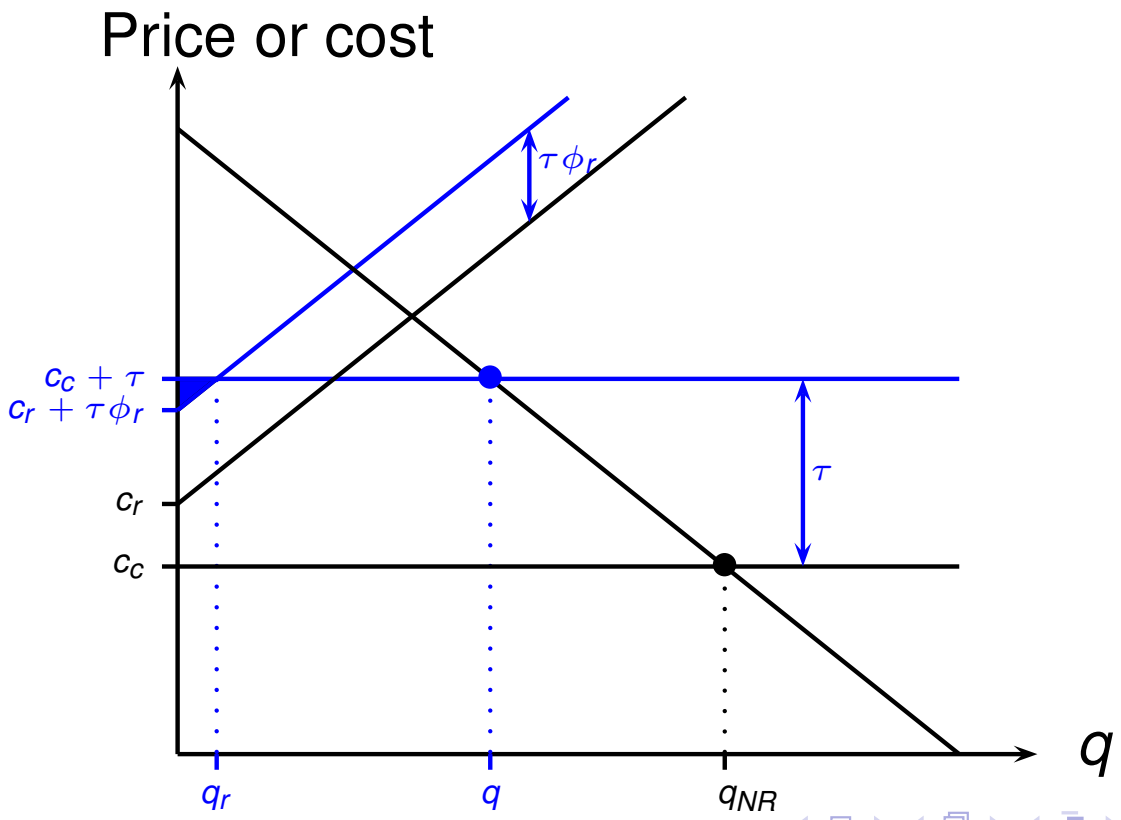
- **Emission standard ($\sigma \in [\phi_r, 1]$):** maximum emission level of the final fuel
- Equivalent to a minimum incorporation rates:

$$\frac{q_c + q_r \phi_r}{q_c + q_r} \leq \sigma \quad \Leftrightarrow \quad \frac{q_r}{q_c + q_r} \geq R_\sigma \quad \text{avec : } R_\sigma = \frac{1 - \sigma}{1 - \phi_r}$$

- Emission based innovation enables to reduce the share of biofuel that is more costly (R_σ decreases with ϕ_r)

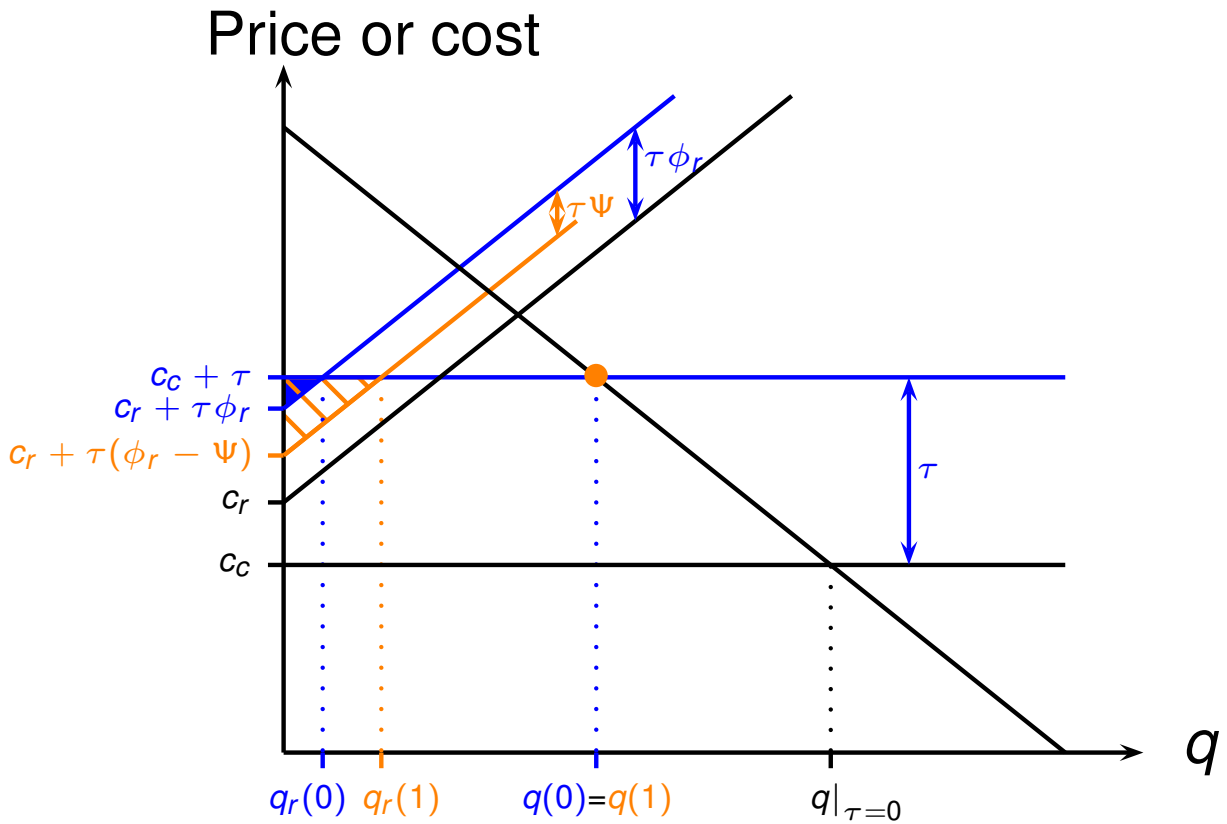
Equilibrium with a tax - Perfect competition

- A tax is equivalent to an increase of product cost by τ for fossil fuel and $\tau\phi_r$ for biofuel.
- A high enough tax ($\tau > \frac{c_r - c_c}{1-\phi_r}$) leads to integration of biofuel.



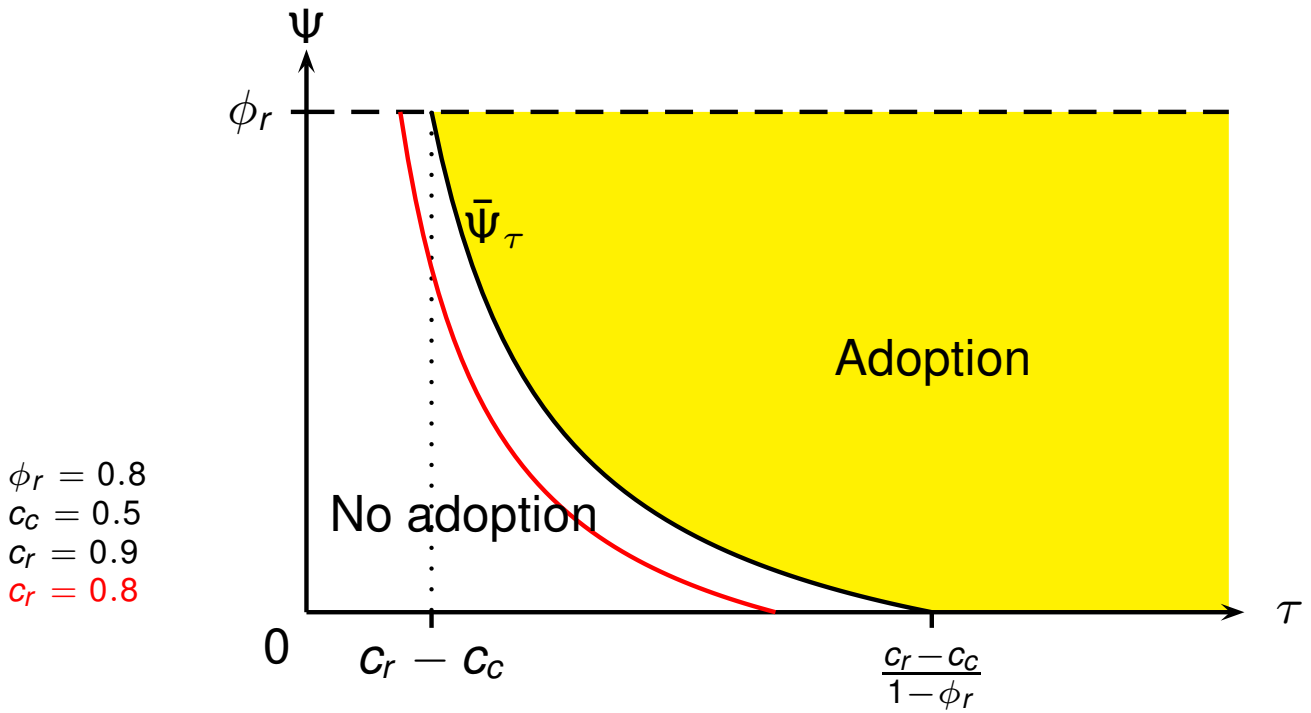
Impact of a free innovation

- With a linear tax, an emission based innovation is equivalent to a cost based innovation of $\tau\Psi$.
- Biofuel quantity and industry profit increases.



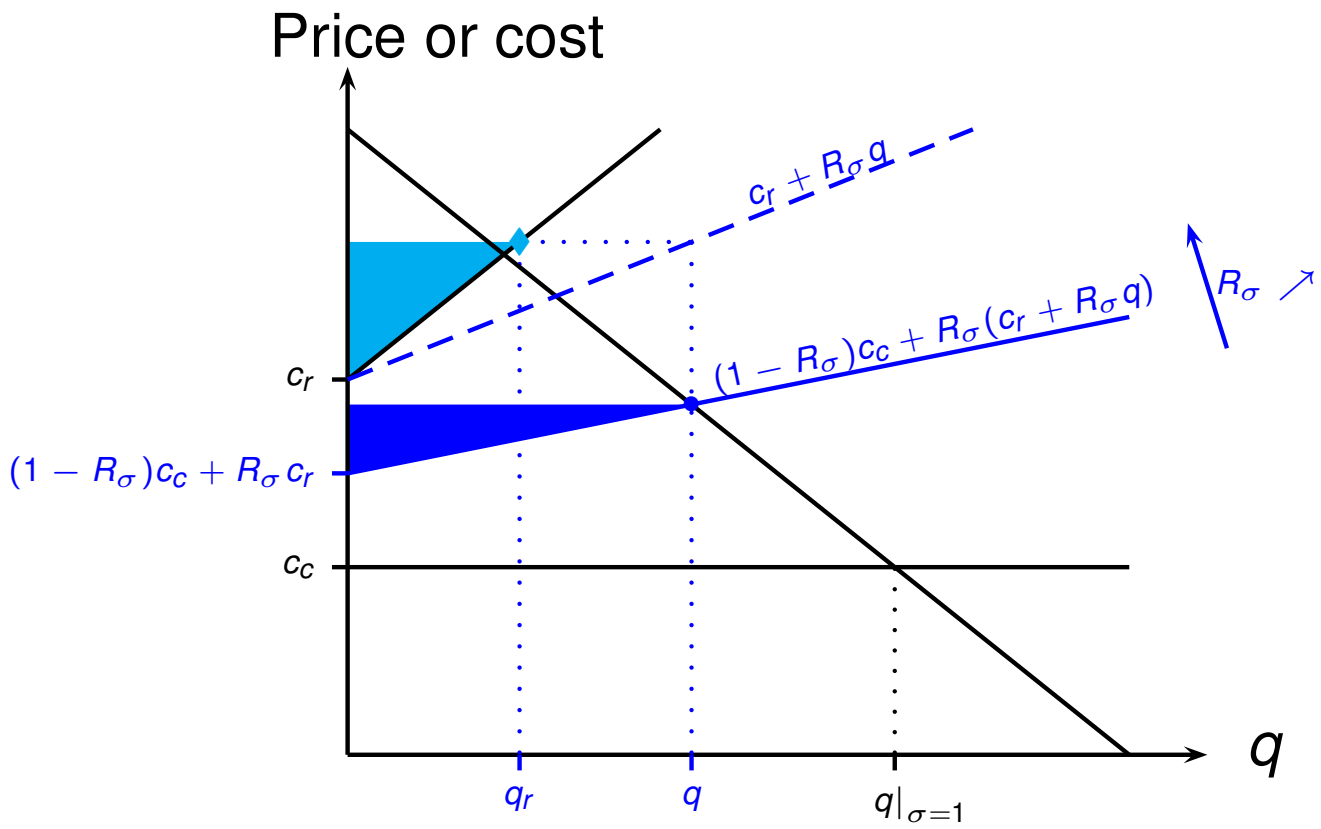
Condition for adopting a free innovation (PC or M)

$$q_r(1) > 0 \quad \Leftrightarrow \quad \Psi > \bar{\Psi}_\tau \quad \text{with:} \quad \bar{\Psi}_\tau = \frac{c_r - c_c}{\tau} - (1 - \phi_r)$$



Equilibrium with an emission standard - Perfect comp.

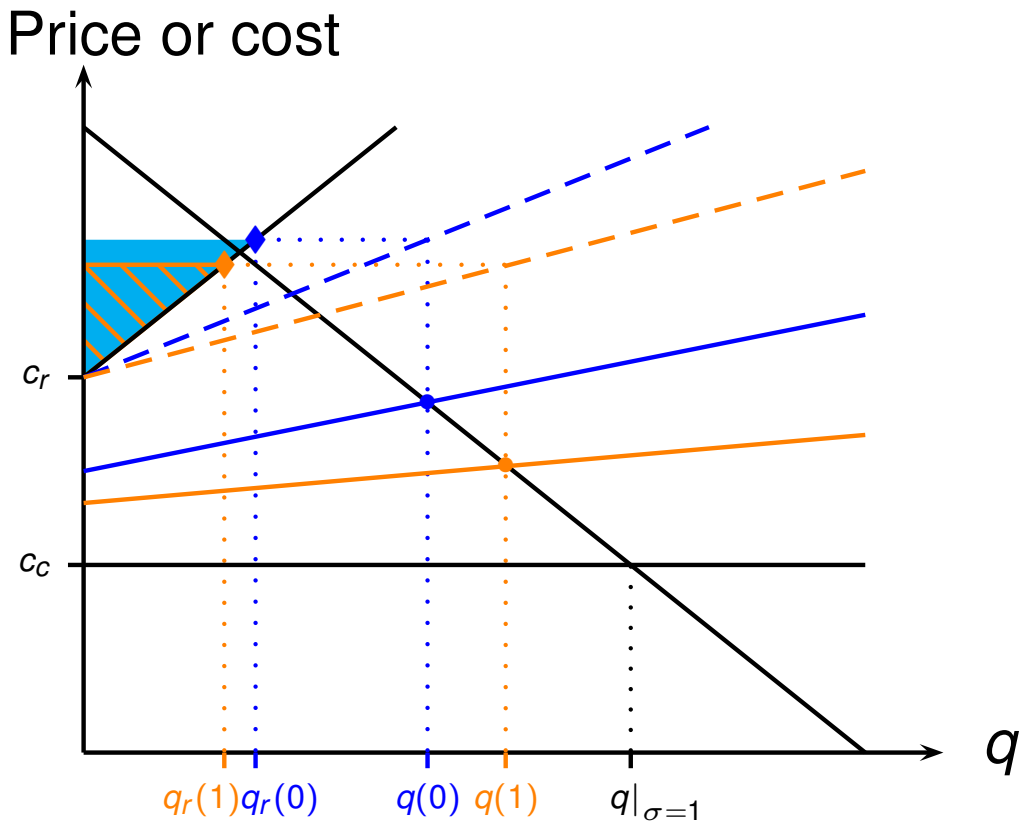
- The lower is σ the higher is the incorporation rate R_σ
- Total quantity is reduced and the industry makes positive profit.



Equilibrium with a free innovation (1/2)

- Lower proportion of the renewable input R_σ (negative effect)
- Total quantity increases (positive effect)
- No benefit from innovation if ratio effect dominates quantity effect

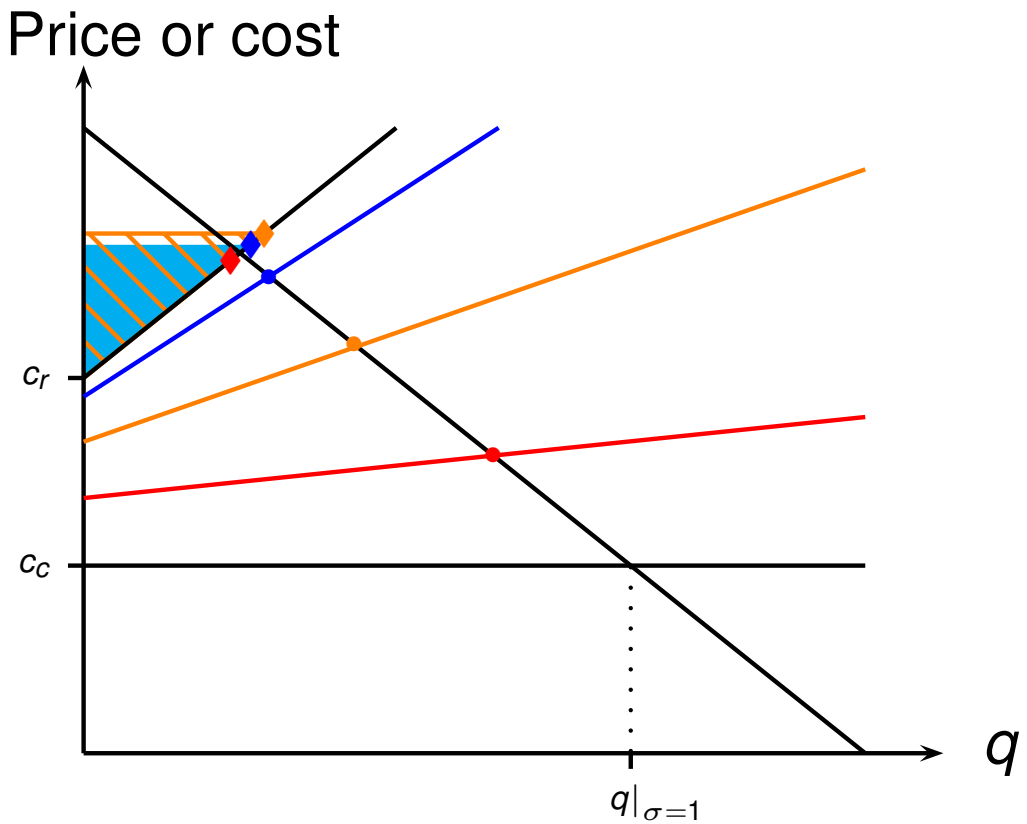
$c_c = 0.3$
$c_r = 0.6$
$\phi_r = 0.8$
$\sigma = 0.9$
$R_\sigma(0) = 0.5$
$\Psi = 0.1$
$R_\sigma(1) = 0.33$



Equilibrium with a free innovation (2/2)

- The innovation can be beneficial is the quantity effect dominates ratio effect
- Innovation becomes non profitable if its magnitude increases

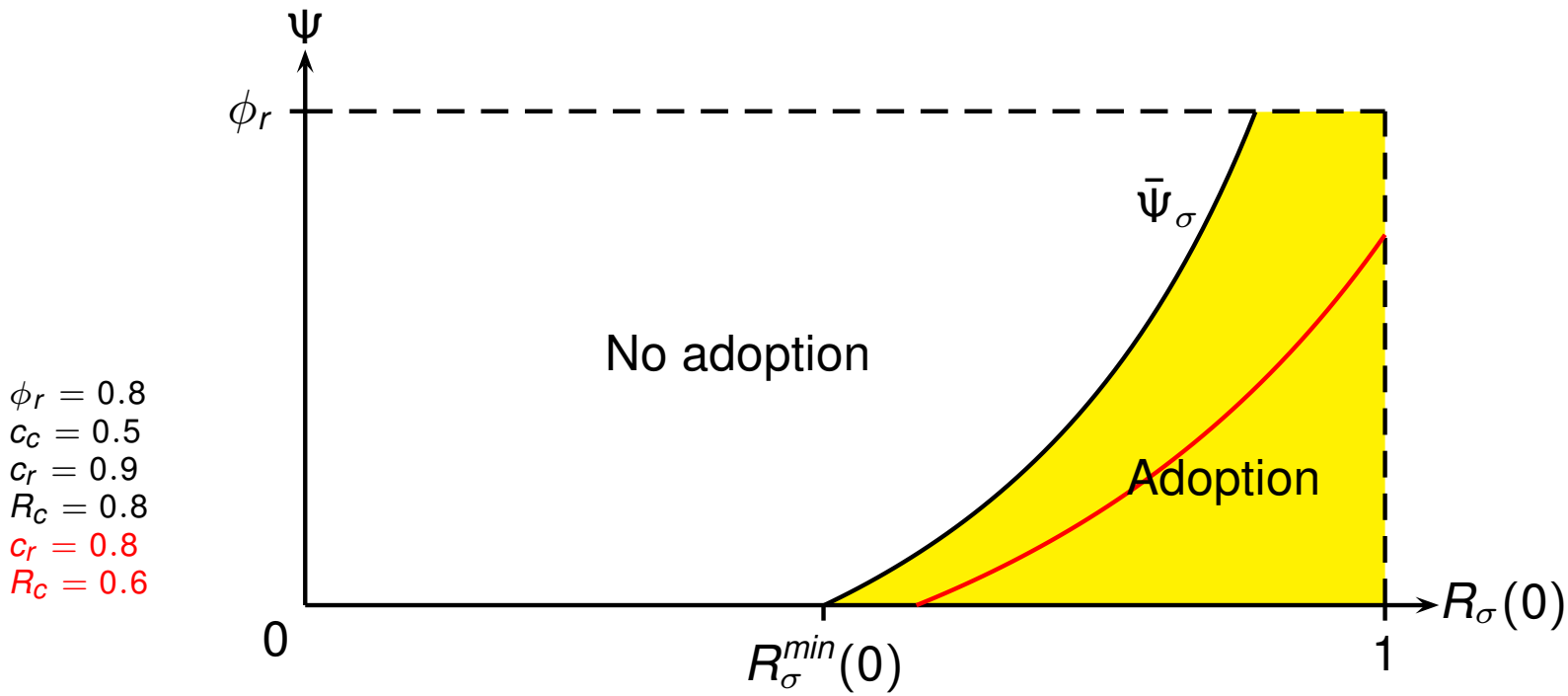
$c_c = 0.3$
$c_r = 0.6$
$\phi_r = 0.8$
$\sigma = 0.82$
$R_\sigma(0) = 0.9$
$\Psi = 0.07$
$R_\sigma(1) = 0.66$
$\Psi = 0.3$
$R_\sigma(1) = 0.36$



Condition for adopting a free innovation

$$\pi(1) > \pi(0) \quad \Leftrightarrow \quad q_r(1) > q_r(0) \quad \Leftrightarrow \quad \Psi < \bar{\Psi}_\sigma$$

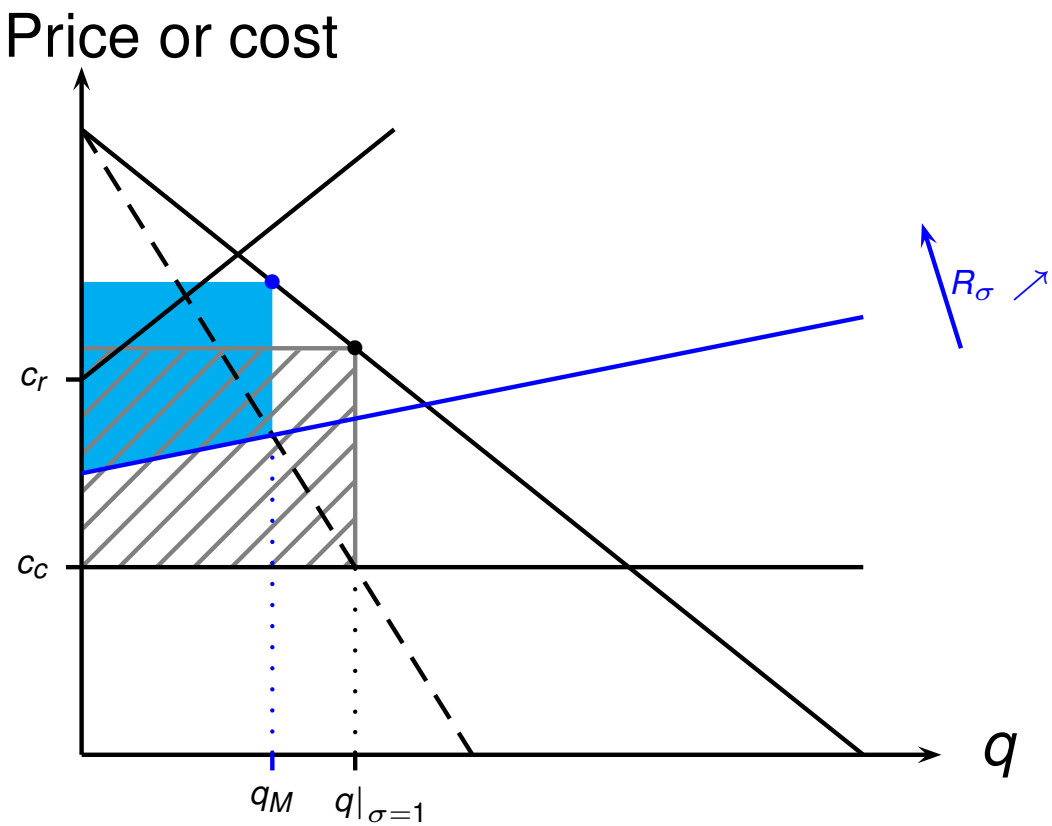
$$\text{with:} \quad \bar{\Psi}_\sigma = (1-\phi_r) \cdot \frac{2R_cR_\sigma(0) + R_\sigma(0)^2 - 1}{1 - R_cR_\sigma(0)} \quad \text{and } R_c = \frac{c_r - c_c}{1 - c_c}$$



Equilibrium with an emission standard - Monopoly

- Regulation leads to a reduction of total quantities
- Monopoly profit decreases with R_σ

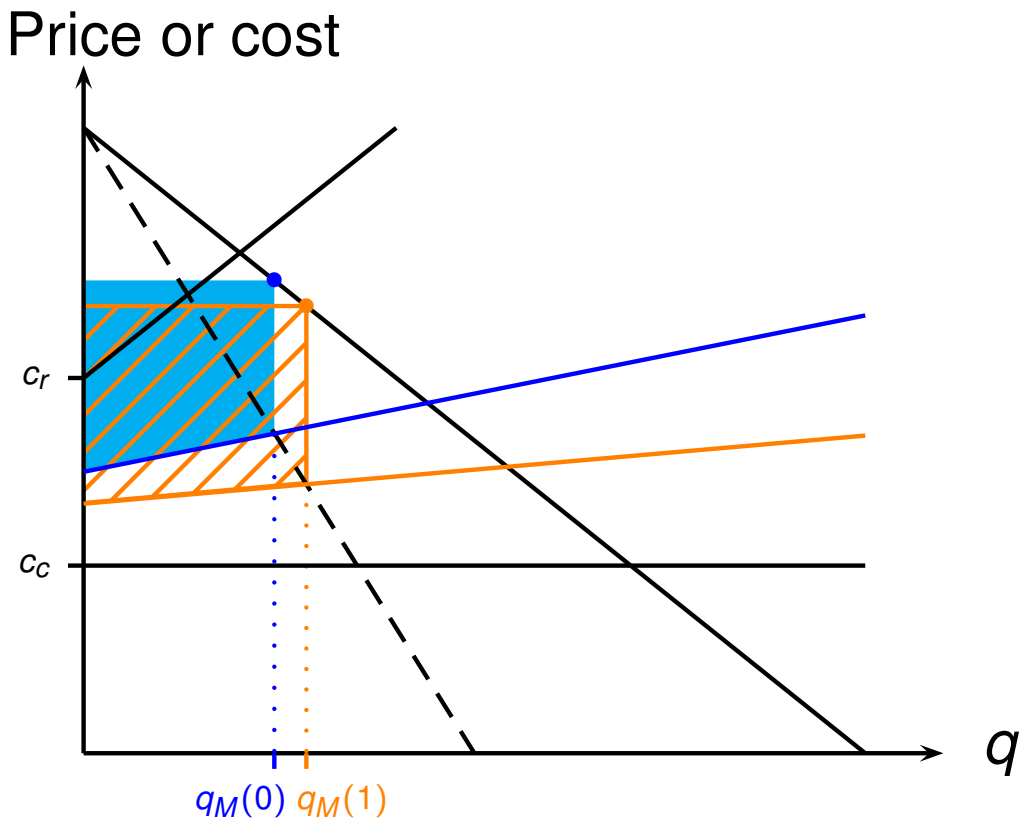
$c_c = 0.3$
$c_r = 0.6$
$\phi_r = 0.8$
$\sigma = 0.9$
$R_\sigma(0) = 0.5$



Equilibrium with a free innovation

- Innovation leads to a reduction of R_σ, an increase of equilibrium quantities and higher profit
- A free innovation is adopted whatever its magnitude.

$c_c = 0.3$
$c_r = 0.6$
$\phi_r = 0.8$
$\sigma = 0.9$
$R_\sigma(0) = 0.5$
$\Psi = 0.1$
$R_\sigma(1) = 0.33$



Regulation impact on the adoption of a free innovation

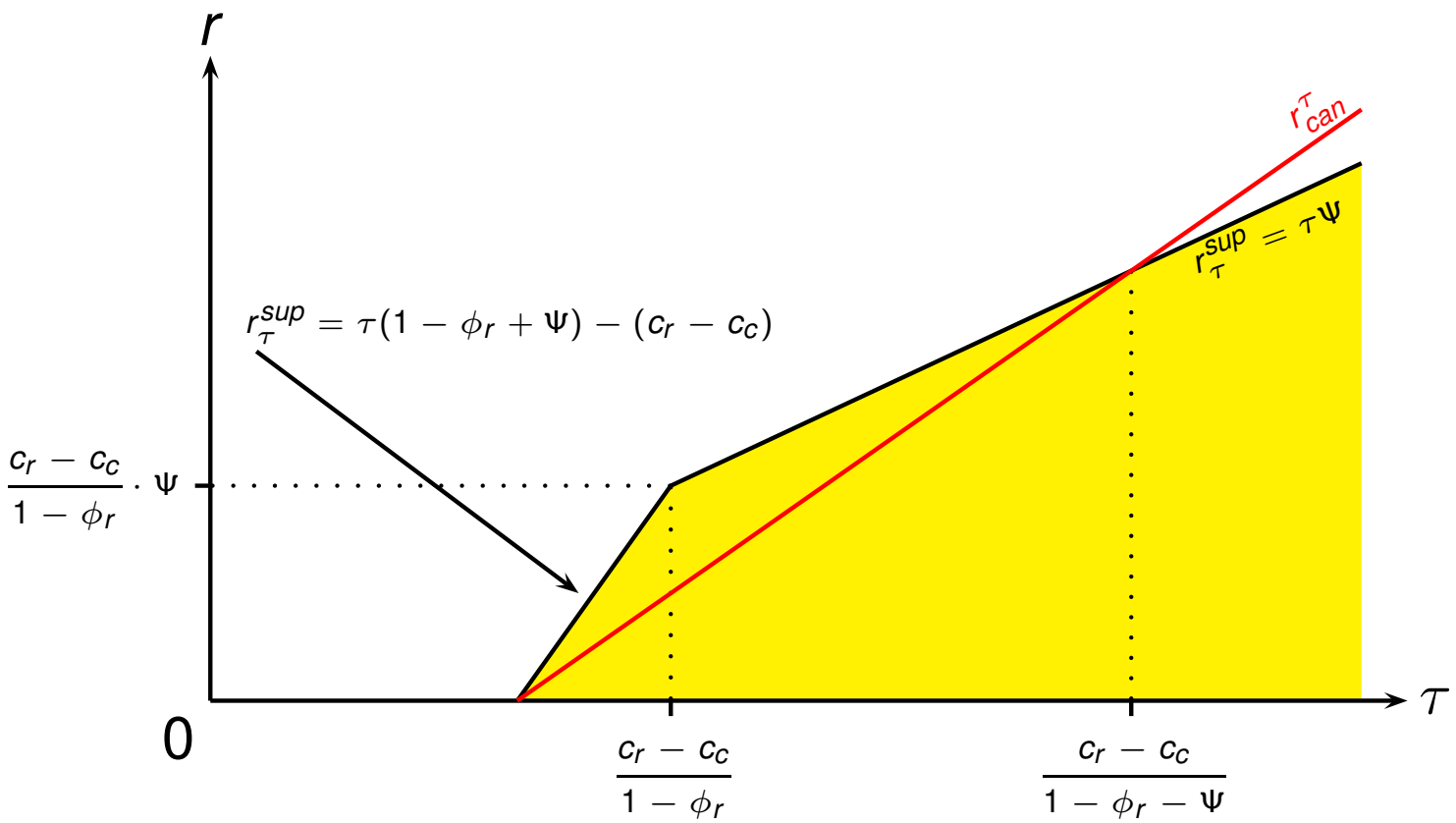
- Tax linear with the emission level (perfect competition or monopoly):
  - Emission based innovation of $\Psi \Leftrightarrow$ cost based innovation of $\tau\Psi$.
  - Adoption if tax leads to the integration of biofuel with innovation.
  - Adoption favored by high enough innovation level ($\Psi > \bar{\Psi}_\tau$)
  - $\bar{\Psi}_\tau$ decreases if c_r decreases (complement)
- Emission standard and perfect competition:
  - Adoption if emission standard is stringent enough.
  - Adoption favored by low enough innovation level ($\Psi < \bar{\Psi}_\sigma$).
  - $\bar{\Psi}_\sigma$ increases if c_r decreases (substitute)
- A monopoly always adopts and emission standard.

Generalities about compiling equilibrium royalty

- The upstream innovator maximize $r \cdot q_r(1)$ under the constraint that the fuel industry benefits from adoption ($\pi(1) \geq \pi(0)$)
- We have: $\text{argmax}_r [q_r(1) \cdot r] = r^{can}$
  and: $\pi(1) \geq \pi(0) \Leftrightarrow r \leq r^{sup}$
- Equilibrium royalty is $\min[r^{can}, r^{sup}]$ and more precisely:
  - r^{can} (interior solution) if $r^{can} < r^{sup}$.
    $\Rightarrow$ Adoption leads to an increase of the industry profit ($\pi(1) > \pi(0)$)
  - r^{sup} (corner solution) if $r^{can} > r^{sup}$.
    $\Rightarrow$ Adoption leads to the same industry profit ($\pi(1) = \pi(0)$)
- Analysis limited to the case with perfect competition

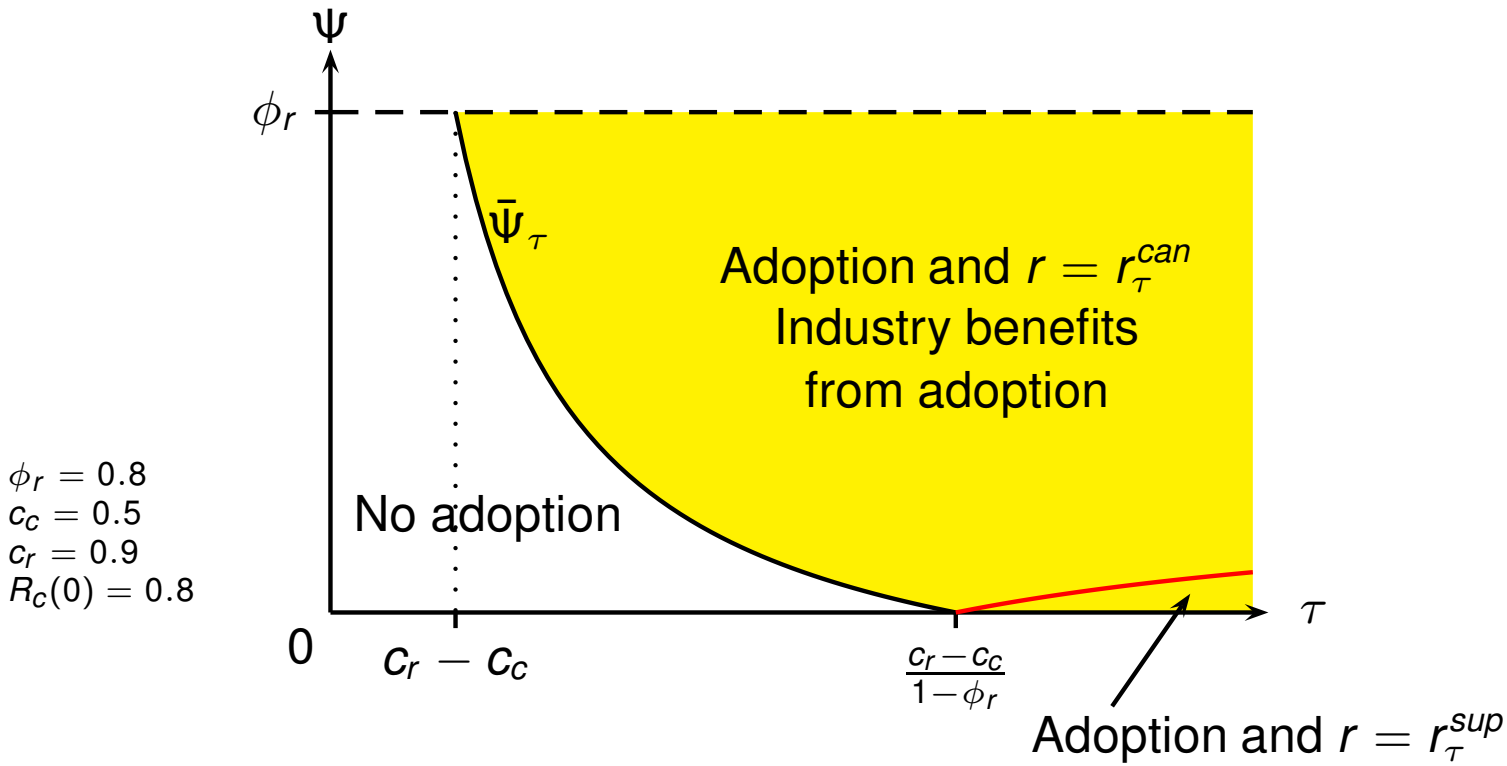
Royalty equilibrium with a tax (1/2)

$$r_{\tau}^{can} = \frac{\tau(1 - \phi_r + \Psi) - (c_r - c_c)}{2}$$



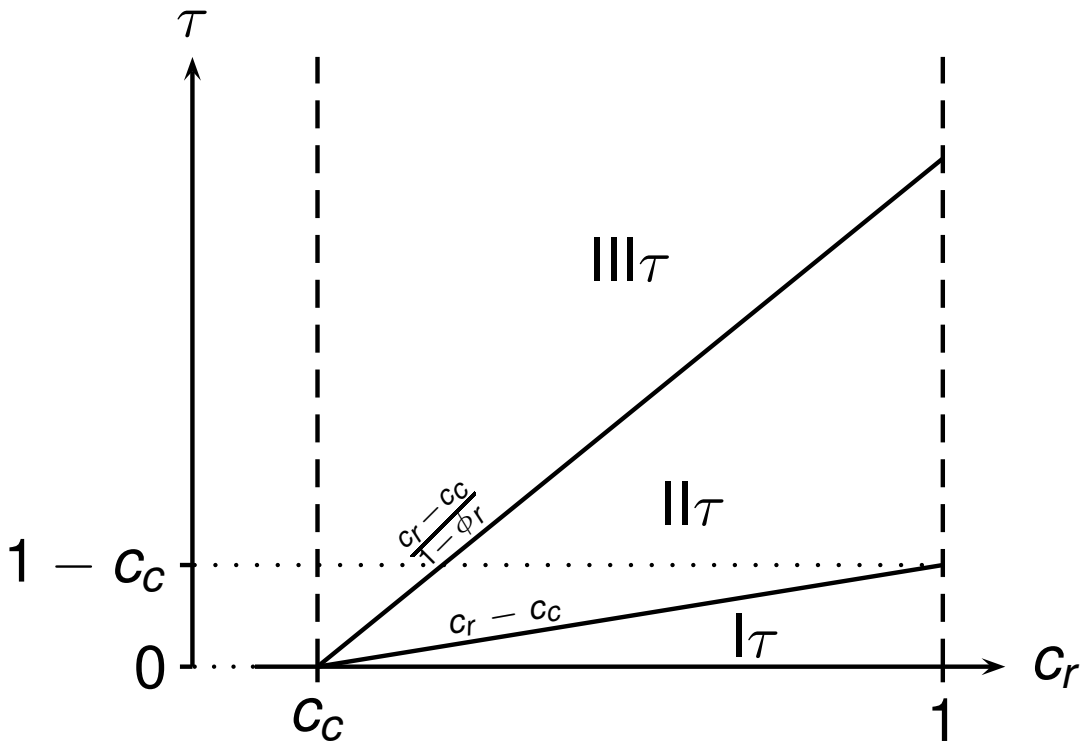
Royalty equilibrium with a tax (2/2)

- With intermediary τ, $q_r = 0$ without innovation. Always interior solution with adoption.
- With high τ, $q_r > 0$ without innovation. Corner solution if innovation level is low.



Synthesis

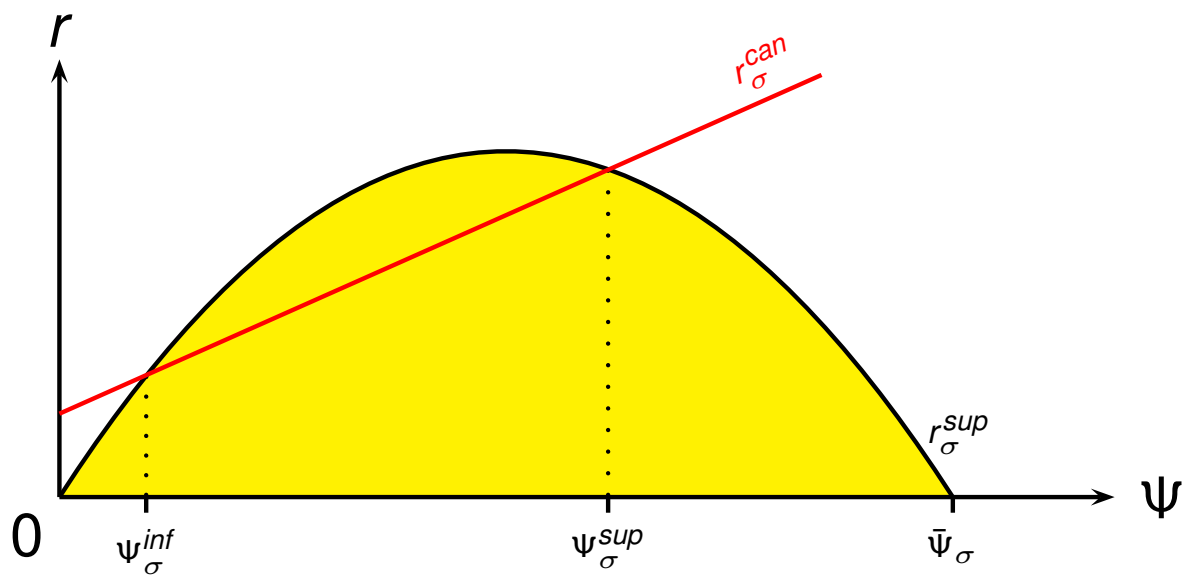
- $\mathrm{I}\tau$ No biofuel integration and free innovation not adopted.
- $\mathrm{II}\tau$ Biofuel integration if innovation level if high enough (and r_τ^{can}).
- $\mathrm{III}\tau$ Innovation adopted. r_τ^{sup} with low innovation, r_τ^{can} otherwise.



Royalty equilibrium with a emission standard (1/2)

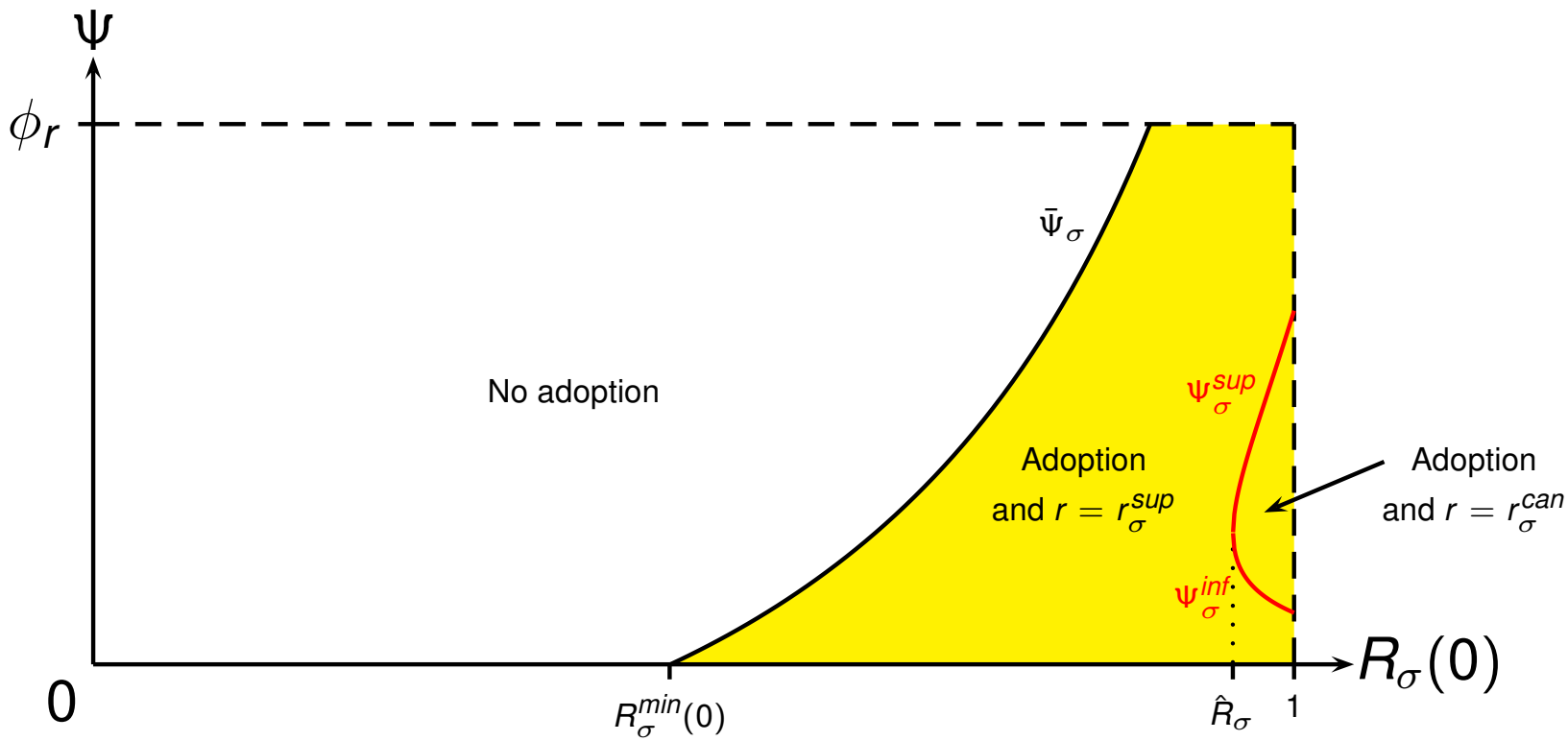
$$r_\sigma^{can} = \frac{1 - c_c}{2} \cdot \left(\frac{1}{R_\sigma(1)} - R_c(0) \right)$$

$$r_\sigma^{sup} = (1 - c_c) \cdot \frac{\Psi}{1 - \phi_r} \cdot \frac{\bar{\Psi} - \Psi}{1 - \phi_r} \cdot \frac{1 - R_c(0)R_\sigma(0)}{R_\sigma(0)(1 + R_\sigma(0)^2)}$$



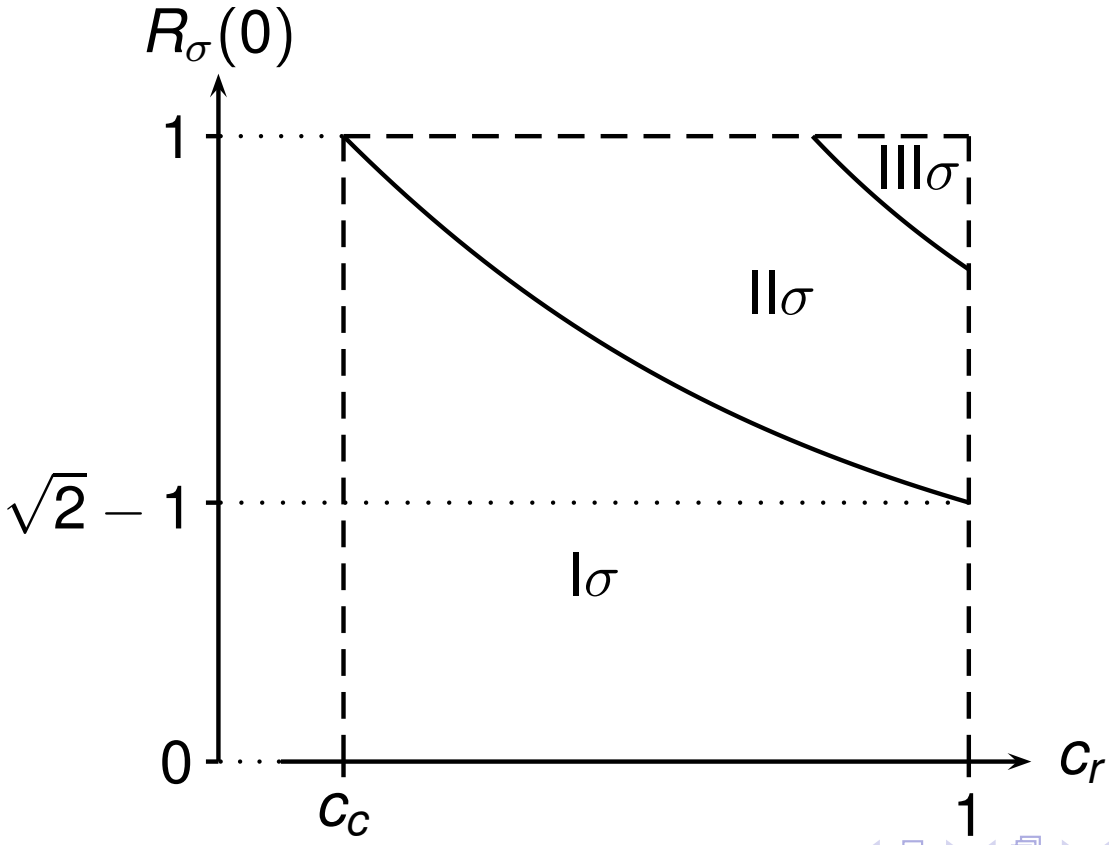
Royalty equilibrium with a emission standard (2/2)

- $R_\sigma(0)$ intermediary $\Rightarrow$ adoption with low enough innovation. Corner solution for royalty.
- $R_\sigma(0)$ high $\Rightarrow$ always adoption. Interior solution if innovation intermediary $\Psi \in [\Psi_\sigma^{inf}, \Psi_\sigma^{sup}]$)



Synthesis

- $\mathrm{I}\sigma$ No biofuel integration, even with a free innovation.
- $\mathrm{II}\sigma$ Biofuel integration if innovation level if low enough (and r_σ^{sup}).
- $\mathrm{III}\sigma$ Innovation adopted. r_τ^{can} with intermediary innovation, r_τ^{sup} otherwise.



Conclusion

- The incentive to a adopt an emission based innovation requires regulation that takes emission into account!
  Comparison of a tax and emission standard.
- The two instruments have different effects on biofuel and total quantities.
- The properties of the tax are rather standard: innovation adoption if high enough, royalty level is first constrained and then interior..
- The properties of emission standard are rather counter-intuitive with perfect competition. These properties depends on the industry structure.
- A cost based innovation on biofuel favors the adoption of an emission based innovation with a tax, but unfavors the adoption of an emission based innovation with an emission standard.

Perspectives

- Analysis of intermediary situation between perfect competition and monopoly (ex: Bertrand duopoly)
- Welfare analysis and optimal policy
- Endogenous level of innovation (integrating R&D investment decision by upstream innovator)
- Possible subsidies on R&D investment from tax revenues
- Combining a cost based and an emission based innovation