Oslo Centre of Research on Environmentally friendly Energy

Innovation prizes for environmental R&D

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Emissions Reductions

- Paris agreement: Substantial fossil fuel reserves cannot be extracted
- Radical implications for technology
  - Electricity generation, transport, manufacturing, CCS (?), agriculture
- Innovation in clean technologies will be essential
- Innovation may also be critical for local air pollution, fresh water use,,,

The appropriability problem
Arrow (1962)

- Profits from an innovation less than social surplus of the innovation
  - Too low R&D investment
  - Rationalization for government intervention
- The regulator can use env. policy to expropriate the value of a patented innovation; amplifying the appropriability problem
  - Laffont and Tirole (1996), Montgomery and Smith (2007)

- Is the appropriability problem greater for env. R&D than for a market good R&D?
  - If yes, increase env. R&D support

Policy to support R&D in addition to patents

- Standard measures: R&D subsidies, tax brakes
- Alternative: Innovation prize
  - The innovator receives an amount of money if he innovates
  - EU Horizon 2020 (max 3 million euro)
- What are the efficiency properties of an innovation prize?
  - Compare prize for env. R&D to prize for market good R&D
  - Compare innovation prize to R&D subsidy

Contributions

- Can first-best outcome be reached?
  - Requate (2005): Government should pre-commit to an emission tax to be implemented if innovation occurs (improves welfare)
  - We: Innovation prize to spur R&D and a diffusion subsidy (when there is a monopoly innovator) to reach the first-best outcome
  - The problem with a monopoly innovator (protected by a patent)
- Where does R&D take place?
  - Old literature: No R&D sector – just one firm
  - Recent literature and we: R&D sector. Laffont and Tirole (1996), Denicolo (1999), Requate (2005), Montero (2011)

Contributions, cont.

- Benefits from innovation
  - Identical across firms: Laffont and Tirole (1996), Montero (2011)
  - Heterogeneous across firms: Requate (2005)
  - We: Both cases

- Additional R&D policy measures (to patent, subsidy, tax brake)
  - Patent buyout (Wrigth 1983; Weyl and Tirole 2012)
  - Market commitment (Kremer 2000)
  - Innovation prize (Lerner and Nicholas 2011)
  - We: analytical treatment of an innovation prize

The appropriability problem
Market good R&D

- Actors: Monopoly innovator, firms producing a standard market good, actors demanding the market good
- Monopoly innovator: Max profits. Will charge a license fee *l*
- Firms: Can either use old, inefficient technology or new, efficient technology (must pay license fee)
- Each firm can produce one unit
- Continuum of firms
- Firms are ranked: Firm *i* has cost γi (old technology), or $l+\alpha\gamma i$ (new technology), $0 < \alpha < 1$

Market good R&D – sequence of moves

- The government announces an innovation prize
- The innovator invests in R&D
- If innovation materializes, the monopoly innovator sets a license fee
- Each downstream producer either produces with old technolgy or with the new, efficient, technology (and pays the license fee)

Market good R&D

- OMC – old MC
- NSMC – new social MC
- NPMC – new private MC
- AF: license fee
- p: output price
- B: initial eq.
- D: first-best post-innovation eq.
- V* =OBD max social value of innovation
- C: eq. after innovation
- V^M =FABCE increase in social value caused by the monopoly innovator
- Dead weight losses: OAF & ECD
- v^M =FACE income of innovator
- $V^M > v^M$ ABC There is an appropriability problem

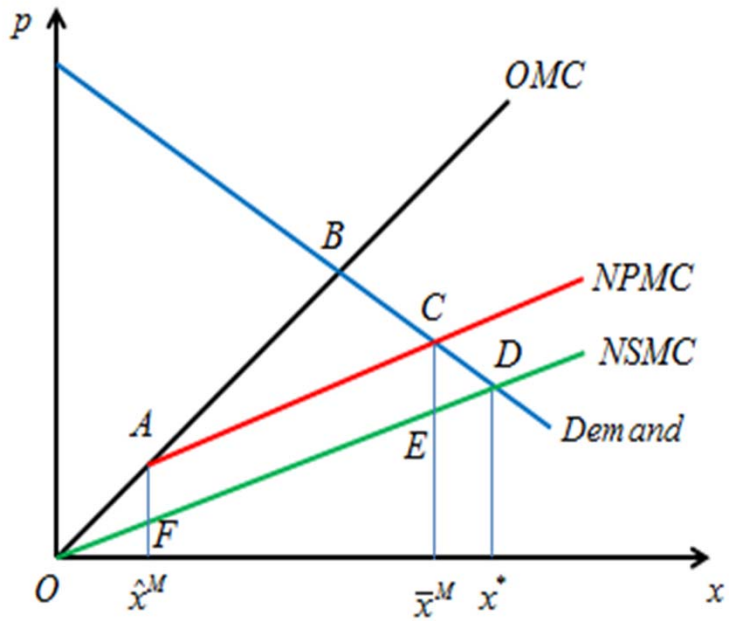


Figure 1

The appropriability problem
Environmental R&D

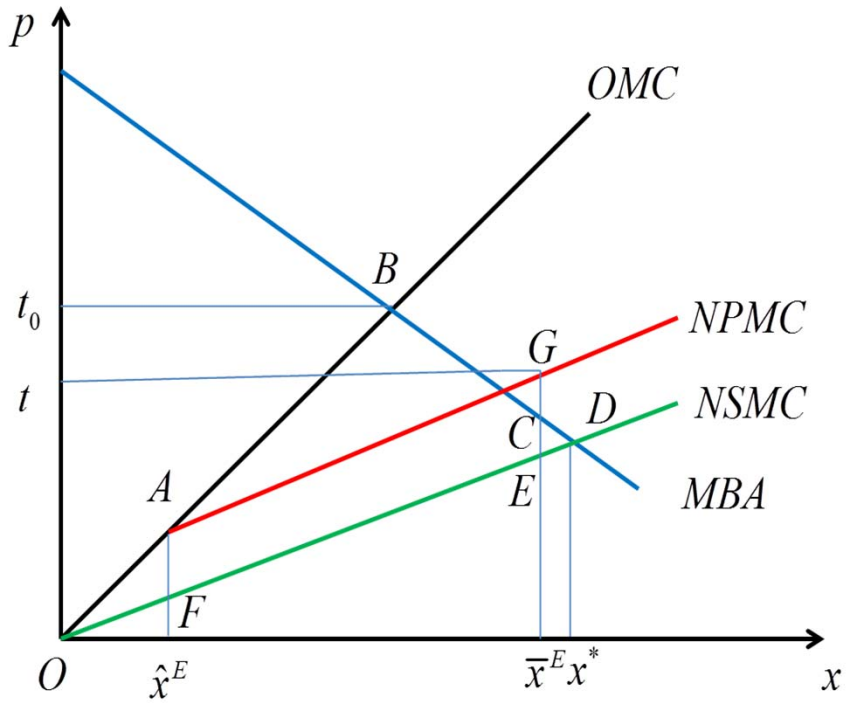
- Actors: Monopoly innovator, polluting firms, government
- Monopoly innovator: Max profits. Will charge a licence fee *l*
- Government: Imposes an environmental tax
- Prior to abatement, each firm has one unit of emission
- Polluting firms: Can either
  - Abate using the old, inefficient technology
  - Abate using the new, efficient technology (pay the license fee)
  - Pay the environmental tax (not abate)
- Continuum of firms
- Firms are ranked: Firm *i* has cost of abatement γi (old technology) or $l+\alpha\gamma i$ (new technology)
- Cost and benefit functions are identical to the market good case
  - Marg Benefit of Abatement identical to demand under market good R&D

Environmental R&D – sequence of moves

- The government announces an innovation prize
- The innovator invests in R&D
- If innovation materializes, the government sets a new environmental tax
- If innovation materializes, the monopoly innovator sets a license fee
- Polluting firms decide whether to abate, and which technology to use

Environmental R&D

- OMC – old MC
- NSMC – new social MC
- NPMC – new private MC
- AF: license fee
- p: MBA
- B: initial eq.
- D: first-best post-innovation eq.
- V* =OBD max social value of innovation
- C: eq. after innovation
- V^E =FABCE increase in social value caused by the monopoly innovator
- Dead weight losses: OAF & ECD
- v^E =FAGE income of innovator
- v^E vs. V^E appropriability problem?



Environmental R&D vs. market good R&D

- Government uses an environmental tax to maximize welfare
  - No similar instrument under market good R&D
- Is there an appropriability problem under environmental R&D?
  - Could the appropriability problem be «negative» under env. R&D?
- Strategic difference
  - Market good R&D: the innovator exploits that a higher license fee will increase the price of the output that is produced by the downstream firms
  - Environmental R&D: Emission tax is given when the innovator sets the license fee.

Innovation prize

- Government specifices technical requirements of a new technology. It will reduce cost by a factor *1-*α. If *1-*α is realized, the prize (amount of money) is received by the innovator
- The new technology is patent protected; monopoly innovator

- $\check{z}(k;\alpha) = z(k)$ is the probability to successfully innovate and thereby reduce cost by a factor *1-*α, where k is R&D investment.
- This function is increasing and concave in *k*

R&D effort

- Without public support, innovator solves: $\max_k \{z(k)v - k\}$
- Foc: $z'(k)v = 1$

- Social optimal R&D: $\max_k \{z(k)V - k\}$
- Foc: $z'(k)V = 1$

- Appropriability problem if $v < V$

- Optimal innovation prize: $P = V - v$
  - Innovator receives v + P = V

Innovation prize with a market good

- Competitive eq. prior to innovation (linear demand): $\gamma x^0 = 1 - \beta x^0$

- Indifferent downstream firm: $\gamma \hat{x}^M = \alpha\gamma \hat{x}^M + \ell^M$
- Equilibrium after innovation: $\alpha\gamma \bar{x}^M + \ell = 1 - \beta \bar{x}^M$
- Innovator: $v^M = \max_{\ell^M} \left\{ \ell^M \left[\bar{x}^M - \hat{x}^M \right] \right\}$

- Social value of innovation

$$V^M = \int_{\hat{x}^M}^{x^0} (\gamma x - \alpha\gamma x) dx + \int_{x^0}^{\bar{x}^M} (1 - \beta x) dx - \int_{x^0}^{\bar{x}^M} \alpha\gamma x dx$$

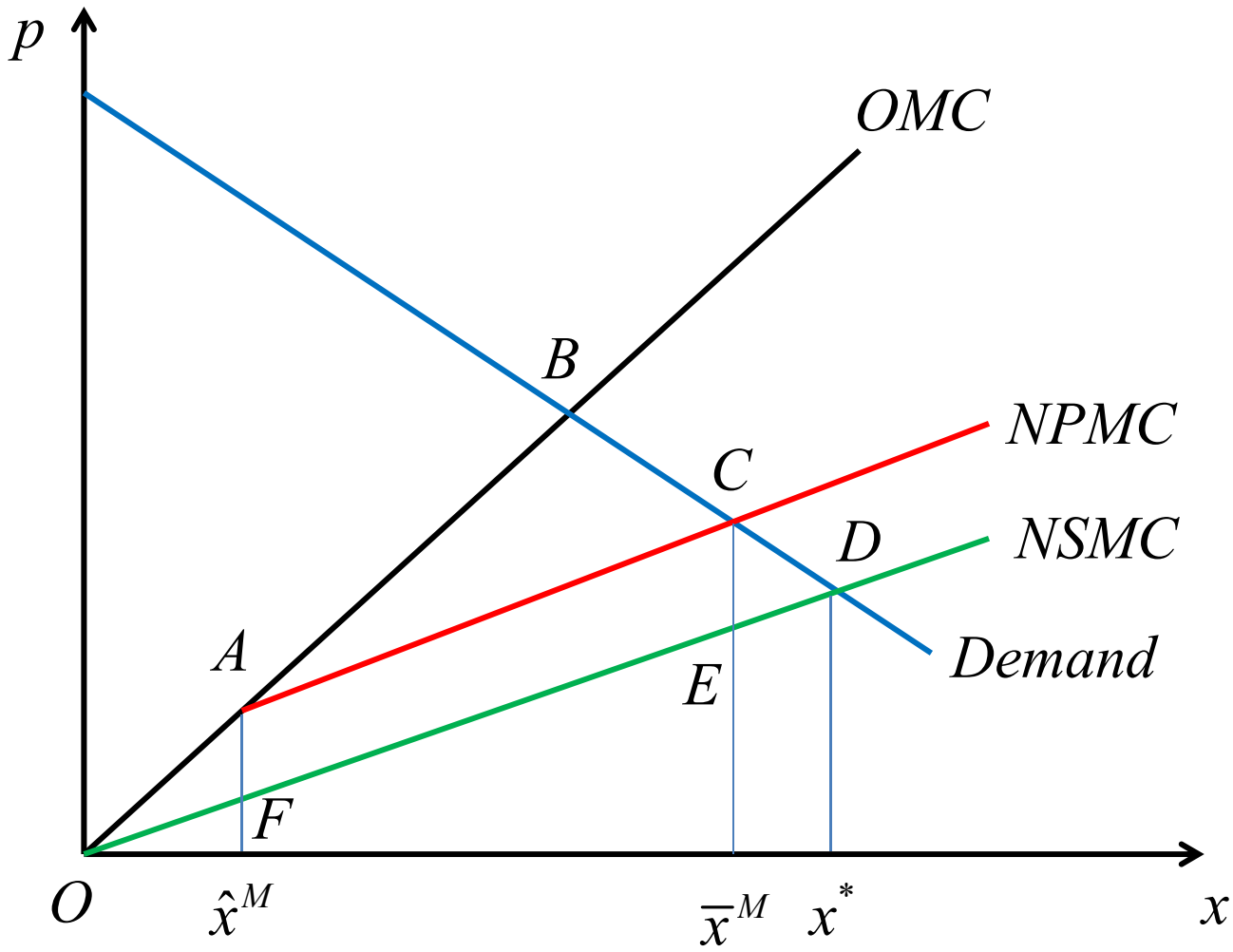


Figure 1

Innovation prize with a market good, cont.

- $P^M = V^M - v^M = \frac{(1-\alpha)}{8\gamma(\alpha+\frac{\beta}{\gamma})(1+\frac{\beta}{\gamma})}$ > 0

- Know this already from discussion based on a figure

Environmental R&D

- Abatement: $\alpha\gamma\bar{x}^E + \ell = t.$
- Innovator: $v^E = \max_{\ell^E} \left\{ \ell^E \left[\bar{x}^E - \hat{x}^E \right] \right\}$

$$\ell^E(t) = \frac{(1-\alpha)t}{2} \qquad \hat{x}^E(t) = \frac{t}{2\gamma} \qquad \bar{x}^E(t) = \frac{t(1+\alpha)}{2\alpha\gamma}.$$

- Government: $\max_t \left\{ B(\bar{x}^E(t)) - C(\bar{x}^E(t), \ell^E(t) \right\}$

- Social optimal innovation prize:
-

$$P^E = V^E - v^E = \frac{(1-\alpha)\left(4\alpha^3 + \alpha^2 - \alpha + \alpha^2\frac{\beta}{\gamma} + 2\alpha\frac{\beta}{\gamma} + \frac{\beta}{\gamma}\right)}{2\gamma\left(1+\frac{\beta}{\gamma}\right)\left(3\alpha^2 + \alpha + \alpha^2\frac{\beta}{\gamma} + 2\alpha\frac{\beta}{\gamma} + \frac{\beta}{\gamma}\right)^2}$$

- Positive for several parameter values, e.g. $\alpha \geq 0.4$

Comparison
Market good R&D vs. environmental R&D

$$V^E - V^M = \frac{(\alpha-1)^2(3\alpha\frac{\beta}{\gamma}+\alpha+\frac{\beta}{\gamma})}{8\gamma^2(1+\frac{\beta}{\gamma})(\alpha+\frac{\beta}{\gamma})(3\alpha^2+\alpha+\alpha^2\frac{\beta}{\gamma}+2\alpha\frac{\beta}{\gamma}+\frac{\beta}{\gamma})} > 0.$$

- Prop 2: Highest increase in social value from the innovation under env. R&D
  - Reflects that the government chooses the env. tax to maximize welfare

- Solve $P^M = P^E$ wrt. α

$$\frac{\beta}{\gamma} = \alpha\frac{-3\alpha^2+2\sqrt{4\alpha^4+10\alpha^3+17\alpha^2+14\alpha+4}+1}{\alpha^3+5\alpha^2+7\alpha+3} = f(\alpha)$$

$$f(1) = 0.75 \qquad f'(\alpha) > 0$$

Comparison of innovation prizes

- Highest prize under env. R&D:

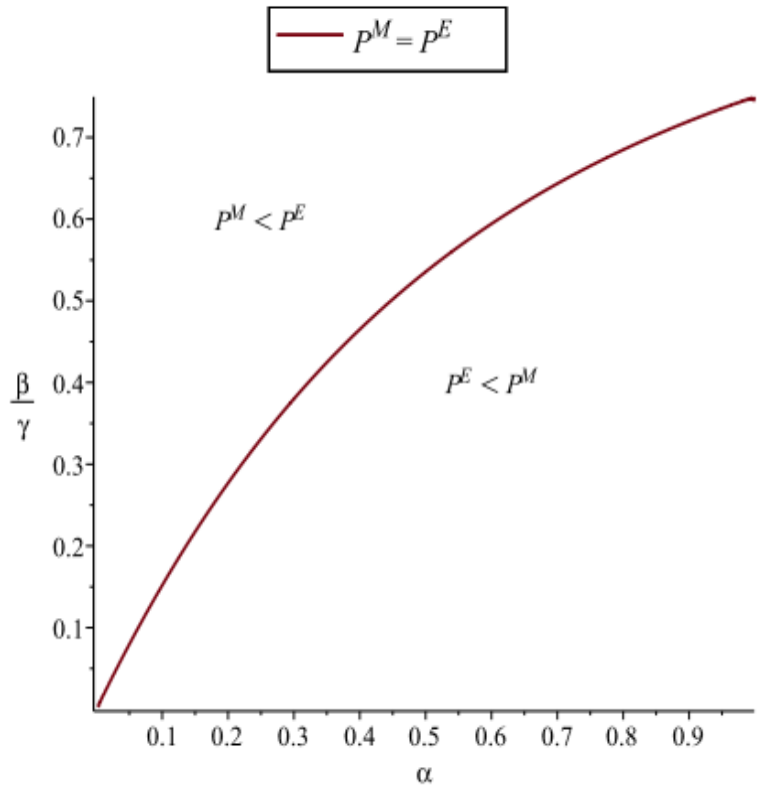
  $\beta/\gamma \geq 0.75$

- $0 < \beta/\gamma < 0.75$ if α is suff. low

- Lowest prize under env. R&D:

  $\beta = 0$

  - World market price is given
  - MBA/social cost of carbon is given



Diffusion subsidy

- Optimal innovation prize ensures social optimal R&D effort, but not the social optimal diffusion of new technology
  - Two market failures; need two instruments
- The government offers a diffusion subsidy τ to all firms adopting the new technology (in addition to innovation prize)
- Sequence of moves:
  - The government announces an innovation prize
  - The innovator invests in R&D
  - If innovation materializes, the government offers the diffusion subsidy (and imposes an environmental tax in the environmental R&D case)
  - The innovator sets the license fee

Diffusion subsidy – results
Subgame perfect equilibrium

- Optimal diffusion subsidy τ should be equal to eq. license fee
  - All firms will adopt the new technology

$$\tau^E < \tau^M$$

- Optimal innovation prize:

$$P_\tau^M = -\frac{1-\alpha}{\gamma}\frac{1}{2\left(1+\beta/\gamma\right)\left(\alpha+\beta/\gamma\right)} < 0$$

$$P_\tau^E = \frac{1-\alpha}{\gamma}\frac{(1-2\alpha)(\beta/\gamma)-\alpha}{2\left(1+\beta/\gamma\right)\left(\alpha+\beta/\gamma\right)^2}, \quad \text{positive if } \alpha < \frac{\beta/\gamma}{1+2\beta/\gamma}$$

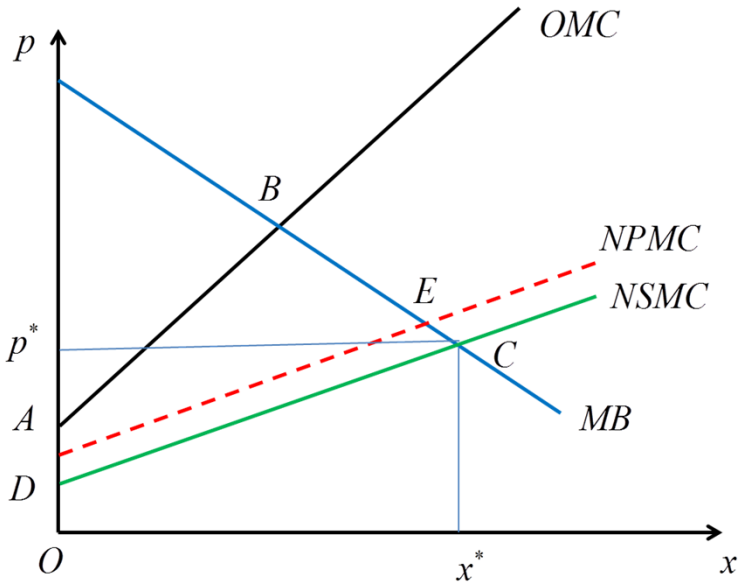
$$V_\tau^M = V_\tau^E = V^*$$

$$P_\tau^E > P_\tau^M$$

$$\ell_\tau^M > \ell_\tau^E \text{ and } v_\tau^M > v_\tau^E$$

Generalization

- Shift in costs of production/abatement caused by innovation: Shift in slope **and** intercept of the cost function



- Instruments: Innovation prize and diffusion subsidy

Generalization - results

- First-best is achieved with innovation prize and diffusion subsidy
- Set diffusion subsidy equal to eq. license fee

  $\tau^E < \tau^M$
- Optimal innovation prizes: $P_\tau^E > P_\tau^M$
  - To sign prizes, additional specifications are required wrt. functions

Extension I - R&D subsidy

- The government pays a share *s* of cost of R&D (*k*)
- Innovator solves: $\max_z \{z(k)v(\alpha) - (1-s)k\}$
- Foc for innovator: $z'(k)v(\alpha) = 1 - s$
- The government wants: $z'(k)V(\alpha) = 1$
- Optimal subsidy rate: $s = \frac{V(\alpha) - v(\alpha)}{V(\alpha)} = \frac{P(\alpha)}{V(\alpha)}$

R&D subsidy - results

- Can achieve optimal R&D effort also with R&D subsidy

- First-best subsidy rate under market good R&D: $s_\tau^M = -1$
- Second-best subsidy rate under market good R&D: $s^M = \frac{1}{3}$

- Ranking of first-best subsidies: $s_\tau^E > s_\tau^M$
  - Reflects $P_\tau^E > P_\tau^M$

Extension II – Asymmetric information

- Have assumed innovator and government know the success function *z(k)* and all parameters of the model
- But: The innovator may know more than the government

- Assume the government does not know *z(k)*
  - Government can still use innovation prize or R&D subsidy to achieve efficiency

Asymmetric information, cont.
Innovation prize vs. R&D subsidy

- Assume the government does not know α ex ante
- Assume the government can commit credibly to a contingent innovation prize P(α)
  - Government can still use innovation prize to achieve efficiency

- Government can ensure optimal market good R&D with an R&D subsidy
  - These subsidy rates are constant $s_\tau^M = -1 \quad s^M = \frac{1}{3}$

- Difficult to ensure optimal env. R&D with an R&D subsidy:
  - Has to offer a subsidy based on expected α
  - If true cost reduction is lower than expected, then too much R&D effort was triggered (subsidy was unnecessary high)
  - If true cost reduction is higher than expected, then the offered subsidy may have been to low to trigger innovation (too little R&D)

Extension III – sequence of moves
No diffusion subsidy

- Have assumed government moves first under env. R&D
  - Standard assumption (feasible to compare results to other papers)
  - Most realistic case (?) because it may be easier for government to commit than for the private innovator (passing a law, officially announcing a policy,..)
- Simultaneous moves (environmental tax, license fee)
  - Similar results as when government moves first
  - Ranking of prizes depends on slopes of demand and cost functions
- Innovator moves first
  - Highest innovation prize under market good R&D

Main results

- Can achieve social optimal R&D effort with an innovation prize
- Can achieve social optimal R&D effort and social optimal diffusion with an innovation prize and a diffusion subsidy
- If optimal diffusion subsidy is offered: Highest innovation prize under environmental R&D
  - Appropriability problem greatest under environmental R&D