Prices vs quantities for the development of clean technologies: The role of commitment

*** work very much in progress ***

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Motivation

- ongoing debate among economists and policy makers on the best way to curb carbon emissions; whether to use prices (uniform carbon taxes) or quantities (carbon permits)

  > "...Economists prefer carbon prices, especially those set by taxes rather than cap-and-trade systems...." (The Economist, Dec 5, 2009)

- one of the most important characteristics of an effective climate policy is to provide firms with credible incentives to make long-run investments in R&D towards cleaner technologies (Aldy and Stavins, 2007)
- what if governments cannot commit to future policies? what if they ex-post "expropriate" innovation rents because it's socially optimal to do so?
- the "expropriation" is not inflicted by potential imitators but by the government through a change in the regulation (e.g., issuing more permits).

Literature

- what does the (vast) literature on innovation and environmental policy say (e.g., Requate, EE 2005; Popp et al., NBER 2009)
- in the absence of aggregate uncertainty, it makes no difference whether to use prices or quantities if innovations are private (i.e., done by polluting sources for internal use) and polluting sources are non-strategic (Laffont and Tirole, JPubE 1996a). Commitment is not an issue here either.
- things change if innovations are "public", i.e., developed by a third party to be sold to polluting sources (focus of **this paper**)
- paper closer to mine is Laffont and Tirole (JPubE, 1996b). See also Denicolo (1999), Scotchmer (2010).
- As Laffont and Tirole and related papers, I rule out that the government could write a ex-ante contract with the single innovator (if it can identify him) where it promises to purchase the innovation at some previously agreed price and then license the technology for free to firms

A single-sector/innovator model

- there are two periods, $t = 1, 2$, and a continuum of polluting firms each emitting one unit of pollution in the absence of regulation
- the social damage of each unit of pollution is h
- firms are indexed by $\theta \in [0, 1]$, where θ is the value (e.g., profit) firm θ obtains from emitting one unit of pollution
- valuation θ is distributed according to the cumulative distribution $F(\theta)$, with density $f(\theta)$. Valuation θ is private information but the functions F and f are not.
- three standard assumptions: (i) $(1 - F)/f$ is nonincreasing, (ii) $(1 - F(h))/f(h) > h$, and (iii) the demand for pollution is not too convex, i.e., $f(p) + pf'(p) > 0$.

The model, cont.

- A single innovator can at $t = 1$ develop a new technology that can remove a fraction $x \in [0, 1]$ of a firm's emissions
- consider a deterministic R&D process where the innovator at cost $I(x)$ develops technology x where $I(0) = 0$, $I'(x) > 0$ and $I''(x) > 0$.
- the technology becomes available at the beginning of period 2
- polluting firms incur in an arbitrarily small but positive cost ε to install the new technology and pay a license fee r (net of adoption costs) to the innovator for the new technology (for most part we cant set $\varepsilon = 0$)

The model, cont.

- the government regulates pollution either by setting a tax p (prices) or by allocating a total of q permits (quantities)
- (later I consider a hybrid policy: the government introduces a subsidy s to adopting firms together with p or q)
- the time at which the government announces either p or q depends on whether the government can (or want to) commit or not
- the government's commitment problem arises because at the beginning of $t = 2$ and after technology x has become available, the government may want to revise the policy it announced at $t = 1$
- if the government revises its policy at $t = 2$, it does it before the innovator sets the license fee (more on timing later)
- note that a polluting source that adopts the new technology must also cover its remaining emissions, $1 - x$, either buying permits or paying taxes (or shutdown production altogether at cost θ).

First-best

- the first-best levels of technology x and pollution level q (or pollution price p) maximize the social welfare function

$$W = -hq + \int_p^1 \theta f(\theta) d\theta - I(x)$$

- since adoption is costless, it is socially optimal to have each active firm installing x, so there is an immediate connection between p and q

$$q = \int_p^1 (1-x) f(\theta) d\theta = (1-x)[1 - F(p)]$$

- then, first-best levels p^* and x^* solve

$$h(1-x)-p=0$$

and

$$h[1-F(p)]-I'(x)=0$$

Policies in the absence of commitment

- Suppose a pollution-free technology has been developed, i.e., $x = 1$
- what is the regulator's optimal policy response at $t = 2$?
- If she is using taxes: $p \to 0$
  - the innovator undercuts and licenses its technology at price $r = 0$
  - no rents for the innovator
  - pollution is completely phased out
  - all this is ex-post socially optimal
- If she is using permits: $q \geq 1$??
  - this would drop the equilibrium price of permits to zero forcing the innovator to set $r = 0$
  - but would the technology be widely adopted (i.e., would the totality of permits remain unused in equilibrium)?
  - it is a possible equilibrium if $\varepsilon = 0$ (also that nobody adopts) but not if $\varepsilon > 0$

Prices in the absence of commitment

- given technology $x \in [0, 1]$, the government would set

$$p = p^*(x) = h(1 - x)$$

  which is ex-post efficient
- prices are too good ex-post leading to little R&D incentives ex-ante

Quantities in the absence of commitment

- ideally, the government would like to set

$$q = q^*(x) = (1 - F(h(1-x)))(1-x)$$

- however, if q is "too large", the inventor may find it optimal to ration its technology to a fraction of active firms according to

$$\max_y \pi(y) = yp(x,q,y)x$$

where y is the number of licenses sold in equilibrium, $xp(\cdot) = r$ is the license fee and $p(x,q,y)$ is the equilibrium price of permits to be found from the market clearing condition

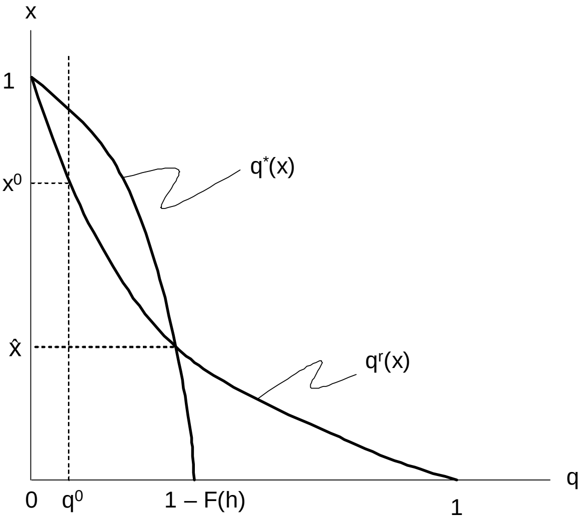
$$1 - F(p) = q + yx$$

- solving

$$y^m = p(\cdot)f(p(\cdot))/x < 1 - F(p)$$

- there will be combinations of x and q where the innovator just rations his supply, i.e., where $y^m = 1 - F(p)$; let $q^r(x)$ be such combinations

Regulator and innovator's responses under quantities



Summary of results in the absence commitment

- Prices and quantities are ex-post equivalent for "modest" innovations (i.e., $x \leq \hat{x}$). When innovations are "drastic" (i.e., $x > \hat{x}$) quantities lead to less diffusion of the clean technology, less output, less pollution and more rents to the innovator.
- In the absence of commitment quantities provide more incentives for the development of "drastic" technologies than do prices and equal for "modest" technologies.

Policies when the government can commit

- No ranking (see Denicolo, 1999)
- In a price regime with commitment, the government's optimal policy is

$$p^c = \arg\max_p \{-h[1 - F(p)][1 - x(p)] + \int_p^1 \theta f(\theta) d\theta - I(x(p))\}$$

where the function $x(p)$ is obtained from the innovator's R&D best-response

$$p(1 - F(p)) - I'(x) = 0$$

- since $x(p^*) < x^*$ the government will choose $p^c > h(1 - x_p^c) > h(1 - x^*)$ in order to bring $x_p^c \equiv x(p^c)$ closer to x^*.

- in a quantity regime with commitment, the government's optimal policy is

$$q^c = \arg\max_q \{-hq + \int_{p(q,x)}^{1} \theta f(\theta) d\theta - I(x(q))\}$$

where $p(q,x)$ is the equilibrium price of permits as a function of q and x, and $x(q)$ is the innovator's R&D response.
- the innovator will never operate in the "rationing (or perfect substitute) zone" for any allocation q, so the equilibrium price $p(q,x)$ is given by

$$1 - F(p(q,x)) = \frac{q}{1-x}$$

and $\partial p(q,x)/\partial x = -(1-F)/(1-x)f < 0$.
- then, the innovator's R&D response $x(q)$ can be obtained from the first-order condition

$$p(q,x)[1 - F(p(q,x))] + x[1 - F(\cdot) - p(q,x)f(\cdot)]\frac{\partial p(q,x)}{\partial x} - I'(x) = 0$$

- rather than computing p^c and q^c and then comparing W_p^c and W_q^c, note that the second term above is negative

Comparing policies under commitment

- if the government wants to induce with the quantity instrument the same amount of R&D brought forward by the price instrument at its optimum level, i.e., $x(q) = x_p^c$, it must set q such that $p(q, x) > p^c$ since $d[p(1 - F(p)]/dp > 0$
- but the welfare gain of doing so is negative (despite lower pollution) since $p^c > h(1 - x_p^c)$ and hence

$$\frac{\partial}{\partial p}\left(-h(1 - F(p))(1 - x) + \int_p^1 \theta f(\theta) d\theta\right) = h(1 - x)f(p) - pf(p) <$$

  for all $p \geq h(1 - x_p^c)$.
- if now the government wants now to induce with the price instrument the same amount of R&D brought forward by the quantity instrument at its optimum level, i.e., $x(p) = x_q^c$, it must set p below $p(q^c, x_q^c)$ with the corresponding welfare gain
- the price instrument can replicate the R&D outcome of the quantity instrument at a gain but not vice versa

Can we do better by combining instruments?

- unlike Roberts and Spence (1976), no gain here from combining permits and taxes (it reduces to pure taxes)
- what about a subsidy? a firm adopting technology x gets a subsidy of sx upon adoption (government can monitor who is adopting)
- it is evident that under commitment either prices or quantities combined with a subsidy implement the first best
- taxes and subsidies: if we combine taxes (p) and subsidies (s), the innovator will price its technology at

$$r = px + sx = (p + s)x$$

- so no gain for prices in the absence of commitment (prices are ex-post efficient)

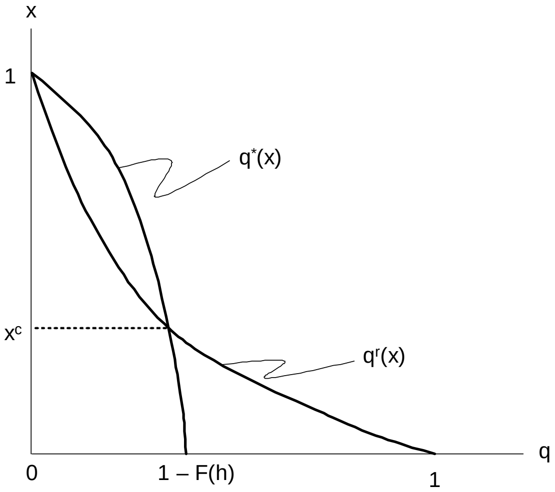
Quantities and subsidies work better in the absence of commitment

- if the government can commit, it implements the first-best by setting

$$q = \; q^* = [1 - F(p^*)](1 - x^*)$$

$$s = \frac{1 - F(p^*)}{f(p^*)} x^*$$

- although the subsidy is higher than in the price-subsidy design
- is this quantity-subsidy policy time consistent?
- the government would like to remove the subsidy for modest technologies but keep a large part of it for drastic technologies and all of it for a pollution-free technology


x
1
q*(x)
x^c
q^r(x)
q
0
1 – F(h)
1

Extending the model to multiple sectors (in progress)

- there is a continuum of sectors in the economy
- in each sector there is an continuum of polluting firms each emitting one unit of pollution in the absence of regulation
- also, in each sector there is a potential innovator who can develop a pollution free technology with some probability increasing in the amount of R&D investment
- there is a tension between ex-post efficiency and ex-ante incentives for technology development
- the government would like to "price discriminate" across sectors; levying lower taxes (or issuing more permits) in those sectors where the innovator was successful in developing the clean technology
- what if a pollution free technology has been developed in all sectors?