Linking Climate and Innovation Policy – Timing of R&D and Abatement Policies

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1. Motivation I

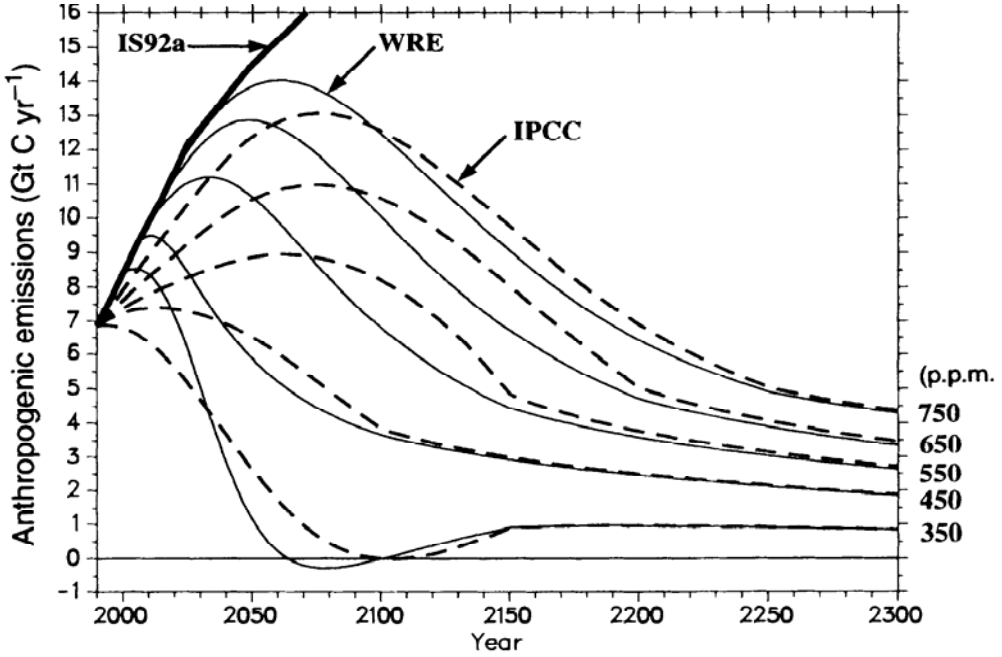
There seems to be widespread understanding that effort should be taken to reduce climate change, but there is a debate on the timing of abatement effort.

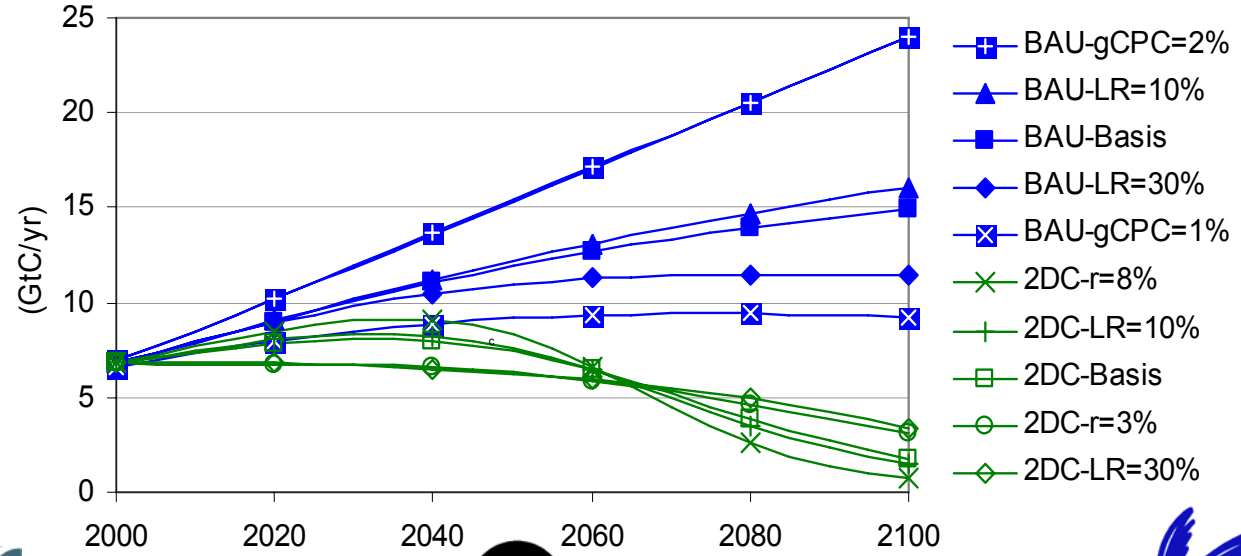
- Reasons to delay effort (Wigley *et al*. 1996):
  - Discounting of future costs
  - Natural depreciation of GHG concentrations
  - Technological change.

- Reasons to accelerate effort (Ha-Duong et al., 1997; Grübler and Messner, 1998; van der Zwaan et al., 2002; Kverndokk and Rosendahl, 2006):
  - Experience curves
  - A too rapid switch of capital stock is unrealistic

- The standard models (Goulder and Mathai, 2000):
  - LbD: Costs fall by experience → argument for early abatement
  - R&D: Costs are low when the technology should be used→ argument for delaying abatement

2. Advance or Delay?





3. Motivation II

- Should environmental problems affect innovation policy?
- Common perception: when environmental policies set the prices right (e.g. pricing emissions), then environmental prices will trigger R&D and innovations automatically; i.e. there is no need for a separate environmental innovation policy.

But this logic assumes perfectly working innovation markets

- There is a huge patent literature on optimal patent lengths, which asks what the optimal patent length is given imperfect innovation markets (Nordhaus 1969; Roemer, 1987, 1990).
  - Patented knowledge is undersupplied by monopolists (the patent holder) … thus we want to reduce patent length, in order to increase the supply of valuable new products.
  - Private agents will only develop new knowledge through innovations when these are privately valuable through long patents.
    … as knowledge is a public good (to be used by other innovators), we want to stimulate more of its production through longer patents.

- What happens with these arguments in the typical dynamic setting of environmental problems (Biglaiser and Horowitz 1995; Parry 1995)?
- Shorter/longer patents, or variable subsidy, for abatement goods?

4. Our contribution

Develop a simple model on abatement with endogenous technology:

- Patents have a finite lifetime; this has often been neglected in the environmental economics literature.
  - Innovators problem: Why invest in research if the profit will be in the far future?
  - This problem is very similar to LbD model, thus we expect results from R&D model to become more similar to LbD model

Conjectures to be tested: In R&D model with finite patent life-time, we have

- Higher upfront subsidies for green R&D (optimal subsidy rate falls over time), or
- Longer upfront optimal patent time, or
- Higher upfront emission tax (ratio tax/Pigouvian tax falls over time)

We do NOT compare scenarios with and without endogenous technological change

- We think in these comparisons it is too hard to disentangle effect of different speed of technological change from effect of endogeneity of technological change.

5. RESULTS

- Abatement equipment with running patents is undersupplied, i.e. patent holders exercise monopoly power and levy mark up. Sales of abatement equipment with running patents are below optimal. To correct for this, you may need higher carbon tax, compared to Pigouvian level.
- When abatement technology is new, a relatively high share of knowledge still has running patents.

- You should have relatively high carbon taxes (compared to Pigouvian level) in early phase of abatement technology development.
  - Social value of patent is proportional to Net Present Value of future use of patented knowledge, including its use when patent has expired.
  - Private value of patent is proportional to Net Present Value of future use of patented knowledge, only as long as patent is running.
  - If use of patented knowledge in equipment is steeply increasing (faster than real interest rate), than ratio Social Value / Private Value becomes VERY large.
- Given constant patent lifetime, you should have relatively high subsidy on abatement R&D in the early phase of abatement technology development.

- Is this obvious?

6. Abatement Production

- Define emissions as benchmark Y_t minus abatement: $E_t = \bar{E}_t - A_t$
- Benchmark emissions increase at constant growth rate: $\bar{E}_t = e^{gt}\bar{E}_0$
- Abatement uses equipment $x_{t,i}$ of $i \leq H_t$ varieties: $A_t = \int_0^{Ht} x_{t,i}^{\beta} \mathrm{d}i$
  - There are M_t varieties with expired patents
  - and N_t varieties with running patents
  - Total number of varieties: $H_t = M_t + N_t$
  - Expired patents: equipment per variety: y_t, total equipment $Y_t = M_t y_t$
  - Running patents: equipment per variety: z_t, total equipment $Z_t = N_t z_t$
- Abatement production: $A_t = M_t y_t^{\beta} + N_t z_t^{\beta} = M_t^{1-\beta} Y_t^{\beta} + N_t^{1-\beta} Z_t^{\beta}$

7. Dynamics and Objective

- Innovations for individual (crowding out): $new\ varieties = rR_t^{\psi-1}$
- Aggregated innovations: $\dot{H}_t = R_t^{\psi}$
  - patents are valid for T periods: $\dot{N}_t = R_t^{\psi} - R_{t-T}^{\psi}$
  - after which knowledge becomes public good: $\dot{M}_t = R_{t-T}^{\psi}$
- Stock accumulation (atmospheric CO_2):
  - $\dot{S}_t = -\varepsilon S_t + E_t$.
- The social planner minimises the present value of expenditures on abatement subject to environmental constraint (ceiling):
  - $\text{Min} \int_0^{\infty} e^{-\rho t}[M_t y_t + N_t z_t + R_t]\mathrm{d}t$
  - $S_t \leq \overline{S}$

8. Social Optimum

- Min $\int_0^{\infty} e^{-\rho t}[M_t y_t + N_t z_t + R_t]\mathrm{d}t$ subject to
  - $\dot{S}_t = -\varepsilon S_t + \bar{E}_t - (M_t y_t^{\beta} + N_t z_t^{\beta})$
  - $\dot{N}_t = R_t^{\psi} - R_{t-T}^{\psi}$
  - $\dot{M}_t = R_{t-T}^{\psi}$
  - $S_t \leq \bar{S}$
- Let θ_t, η_t, ζ_t, λ_t be the shadow price of the atmospheric stock, new patent knowledge, new patent-free knowledge, and the cap. Working with Hamiltonians is a bit difficult as there is a lag in the public knowledge creation.
  - $\theta_t = \int_0^{\infty} e^{-\rho t}\,\lambda_{t+s}\,ds$
  - $\eta_t = \int_0^{T} e^{-\rho t}\,\theta_{t+s} z_{t+s}^{\beta}\,ds + \zeta_{t+T}$
  - $\zeta_t = \int_0^{\infty} e^{-\rho t}\,\theta_{t+s} y_{t+s}^{\beta}\,ds$
- First order condition for equipment:
  - $y_t = z_t = (\beta\theta_t)^{1/(1-\beta)}$

9. Social Optimum, ctd

- Min $\int_0^\infty e^{-\rho t}[M_t y_t + N_t z_t + R_t]\mathrm{d}t$ subject to
  - $\dot{S}_t = -\varepsilon S_t + \bar{E}_t - (M_t y_t^\beta + N_t z_t^\beta)$
  - $\dot{N}_t = R_t^\psi - R_{t-T}^\psi$; $\dot{M}_t = R_{t-T}^\psi$; $S_t \leq \bar{S}$
- There are 3 control variables: y_t , z_t , R_t
- Carbon tax sets the level of patent-free equipment at its optimal level.
  - Carbon tax is a 'natural' policy variable. You need it.
- Subsidy on patented equipment can set the use of patented equipment at its SO level.
  - Most literature on patent policy assumes you cannot subsidize patented equipment only (how to make the distinction?).
- Subsidy on R&D or endogenous patent time can set R&D at its SO level.
  - Patent literature calculates optimal patent time, but can it be time and sector-dependent? Varying R&D subsidy seems more realistic.
- Proposition 1: Three instruments can implement the SO.
- But, more interestingly, we will look at second-best (market equilibrium) with endogenous tax, but no subsidy on patented equipment.

10. Markets for Equipment

- The public agent implements a tax τ_t on emissions = price of abatement goods.
- Equipment has unit production costs.
  - Those equipment with expired patents are competitively supplied, i.e. sold at unit costs
  - Those with running patents are sold at mark-up price that maximizes the value of the patent to the owner: $p_t = 1/\beta$
- Abatement good is produced competively : $Y_t = \beta \tau_t A_t \Longrightarrow M_t y_t = \beta \tau_t M_t y_t^{\beta} \Longrightarrow$
  - $y_t = (\beta \tau_t)^{1/(1-\beta)}$
  - $z_t = (\beta^2 \tau_t)^{1/(1-\beta)}$

- For patent-free equipment, Pigouvian tax would do fine. For patented equipment, Pigouvian tax would be too low (that is, equipment use would be too low).

11. Markets for Innovation: Value of Knowledge

- The patent rent is equal to the mark up value
  - $\pi_t = (p_t - 1) z_t = (\beta^{-1} - 1)(\beta^2 \tau_t)^{1/(1-\beta)}$
- Private value of a patent at time of innovation is the net present value of the future patent rents (=mark up) over the patent life-time $[t, t+T]$:
  - $V_t = \int_0^T e^{-\rho s} \pi_{t+s} ds$
- Patents are produced competitively, so that costs of research (minus subsidy σ_t) is value of patents
  - $(1-\sigma_t) R_t = V_t R_t^{\psi}$
- Social Optimum: Marginal value of research should be equal to social costs
  - $\psi \eta_t R_t^{\psi - 1} = 1$
- Optimal subsidy on R&D
  - $\sigma_t = 1 - V_t / \psi \eta_t$
  - $\eta_t = \int_0^T e^{-\rho s} \theta_{t+s} z_{t+s}^{\beta} ds + \zeta_{t+T}$
  - $\zeta_t = \int_0^{\infty} e^{-\rho s} \theta_{t+s} y_{t+s}^{\beta} ds$
- What does this say about optimal policy?

12. Optimal Policy in Second Best

- Min $\int_0^\infty e^{-\rho t}[(M_t + \beta^{1/(1-\beta)}N_t)\, y_t + R_t]\mathrm{d}t$ subject to
  - $\dot{S}_t = -\varepsilon S_t + \bar{E}_t - (M_t + \beta^{\beta/(1-\beta)}N_t)\, y_t^{\beta}$
  - $\dot{N}_t = R_t^{\psi} - R_{t-T}^{\psi}$
  - $\dot{M}_t = R_{t-T}^{\psi}$
  - $S_t \leq \bar{S}$
- There are 2 control variables: y_t , R_t
  - Carbon tax sets the level of y_t (and $z_t = \beta^{1/(1-\beta)}y_t$)
  - R&D subsidy sets the level of R_t
- Let t^* be the time at which the ceiling becomes binding. The period $[0,\ t^*]$ is the 'pre-ceiling' period during which the shadow price for atmospheric carbon increases at rate $\rho+\varepsilon$.
- Lemma: Given all other model parameters unchanged, for $\bar{E}_0/\bar{S} \to 0$ we have $t^* \to \infty$.
- Intuition: We can start the model arbitrarily long back in time, when the economy was too small to cause a problem.

13. Optimal Carbon Tax Policy in Second Best

- Min $\int_0^\infty e^{-\rho t}[(M_t + \beta^{1/(1-\beta)}N_t)\, y_t + R_t]\mathrm{d}t$ subject to
  - $\dot{S}_t = -\varepsilon S_t + \bar{E}_t - (M_t + \beta^{\beta/(1-\beta)}N_t)\, y_t^{\beta}$
  - $\dot{N}_t = R_t^{\psi} - R_{t-T}^{\psi}$
  - $\dot{M}_t = R_{t-T}^{\psi}$
  - $S_t \leq \bar{S}$

- Compare Social Optimum (SO) with Market Equilibrium (ME) for y_t
  - SO (FOC) $(M_t + \beta^{1/(1-\beta)}N_t) = \beta\theta_t(M_t + \beta^{\beta/(1-\beta)}N_t)\, y_t^{\beta-1}$
  - ME: $1 = \beta\tau_t\, y_t^{\beta-1}$
  - ME/SO: $1 < \tau_t/\theta_t = (M_t + \beta^{\beta/(1-\beta)}N_t)/(M_t + \beta^{1/(1-\beta)}N_t) < \beta^{-1}$

- Proposition 2. The optimal carbon tax exceeds the Pigouvian tax. The ratio is bounded from below by 1 and from above by β^{-1}. When the abatement sector moves from a young technology with a large share of patented equipment, to a mature technology with a smaller share of patented equipment, than the optimal carbon tax comes closer to the Pigouvian tax level.

14. Optimal Research Policy in Second Best

- Compare Social Optimum (SO) with Market Equilibrium (ME) for R_t
  - SO: $R_t^{1-\psi} = \psi[\beta^{\beta/(1-\beta)}\int_0^T e^{-\rho s}\,\theta_{t+s}\,\tau_{t+s}^{\beta/(1-\beta)}\,ds + \int_T^\infty e^{-\rho s}\,\theta_{t+s}\tau_{t+s}^{\beta/(1-\beta)}\,ds]$
  - ME: $(1-\sigma_t)\,R_t^{1-\psi} = (\beta^{-1}-1)\beta^{2/(1-\beta)}\int_0^T e^{-\rho s}\,\tau_{t+s}^{1/(1-\beta)}\,ds$
  - ME/SO: R&D subsidy σ_t must be high because value of knowledge in SO covers infinite horizon, while ME covers only patent time.
  - R&D subsidy σ_t must be low because SO acknowledges crowding out ψ, while ME does not.

- Proposition 3. The optimal R&D subsidy in the first period, σ_0, increases to 100% for $\bar{E}_0/\bar{S} \to 0$.
- Intuition. (i) When $t^* \to \infty$, all terms within the integral in the SO and ME differ only up to a constant ratio. (ii) In the pre-ceiling period, the term $\tau_{t+s}^{1/(1-\beta)}$ increases faster then the interest rate. Thus, the social value which is the integral over the infinite period becomes infinitely larger than the private value, which is the integral over the patent time only.
- Corollary: With given fixed patent time, R&D subsidies should be very high long before the problem becomes binding, and decrease over time.

15. Conclusions

- In the early phase of technology development, one has to extra stimulate the development of clean technologies for future use through high R&D subsidies.
  - The reason is that innovations are based on short-term and medium-term benefits, while social benefits may lay in the long-term.
- Furthermore, in the early phase with a high share of patented knowledge, the ratio of carbon taxes over Pigouvian taxes should be relatively high.
  - The reason is that patented equipment tends to be undersupplied.
- In the literature on technology development and climate change, the proponents of delayed and early action have often been divided along the lines of users of R&D models versus users of LbD models. Our analysis suggests that an R&D model with finite patent time may produce similar results as a LbD model on optimal carbon taxes and abatement policy: A need for higher upfront environmental taxes (compared with Pigouvian path) and R&D subsidy.