# The Environment and Directed Technical Change

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September 22, 2009

# Basic question

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  $\longrightarrow$ costs and benefits of environmental policy or of delaying it

# Popular answers

- Three types of answers so far

1. **Nordhaus approach:** intervention should be limited and gradual; small long-run growth costs.
2. **Stern/Al Gore approach:** intervention needs to be large, immediate and maintained permanently; large long-run growth costs.
3. **Greenpeace approach:** only way to avoid disaster is zero growth.

- Our paper: yet another approach.

# Importance of technology

- All approaches essentially ignore the essence of technological responses.
  - **Popp (2002)** relates energy prices and energy saving innovation

Dependent variable:% of total domestic patent applications in each technology group

| Independent Variables | Unweighted Stock of Patents | Weighted Stock of Patents |
|---|---|---|
| Constant | -9.015 | -7.311 |
| | (-12.362) | (-46.625) |
| Energy prices | 0.028 | 0.060 |
| | (2.146) | (2.852) |
| Lagged knowledge stock | 0.719 | 0.838 |
| | (25.612) | (72.323) |
| Government R and D | 0.006 | -0.009 |
| | (0.968) | (-1.741) |
| Truncation error | 1.924 | -1.203 |
| | (2.445) | (-5.054) |
| Lambda | 0.933 | 0.829 |
| | (18.905) | (13.662) |
| Long-run energy elasticity | 0.421 | 0.354 |
| Long-run government R and D elasticity | 0.085 | -0.052 |
| Median lag | 13.81 | 4.86 |
| Mean lag | 9.92 | 3.71 |
| GMM criterion | 86.560 | 93.421 |
| Number of technology groups | 11 | 11 |

Notes: Table shows the induced innovation regression results. Lagged party of the president and lagged government R&D are used as instruments for government R&D. A time trend and lagged values of other exogenous variables are used as instruments for the knowledge stocks. t-statistics appear below estimates. Data are from 1971-1991

# This paper (1)

- Two sector growth model with "clean" and "dirty" inputs.
- Dirty inputs create environmental degradation.
- Researchers work to improve the technology depending on expected profits and "build on the shoulders of giants" in their sector.
- Policy interventions can redirect technical change towards clean technologies.

# This paper (2)

- **Two key externalities:**
  1. *Environmental externality*: production of dirty inputs creates environmental degradation.
  2. *Knowledge externality*: advances in dirty (clean) inputs make their future use more profitable.

# Model (1): production

- Infinite horizon in discrete time (suppress time dependence for now)
- Final good $Y$ produced competitively with a clean intermediary input $Y_c$, and a dirty input $Y_d$

$$Y = \left( Y_c^{\frac{\varepsilon-1}{\varepsilon}} + Y_d^{\frac{\varepsilon-1}{\varepsilon}} \right)^{\frac{\varepsilon}{\varepsilon-1}}$$

- For $j \in \{c, d\}$, input $Y_j$ produced with labor $L_j$ and a continuum of machines $x_{ji}$:

$$Y_j = L_j^{1-\alpha} \int_0^1 A_{ji}^{1-\alpha} x_{ji}^{\alpha} di$$

- Machines produced **monopolistically** using the final good

# Model (2): consumption

- Constant mass 1 of infinitely lived representative consumers with intertemporal utility:

$$\sum_{t=0}^{\infty} \frac{1}{(1+\rho)^t} u(C_t, S_t)$$

where $u$ increasing and concave, with

$$\lim_{S \to 0} u(C, S) = -\infty; \frac{\partial u}{\partial S}(C, \bar{S}) = 0$$

# Model (3): environment

- Production of dirty input depletes environmental stock $S$:

$$S_{t+1} = -\xi Y_{dt} + (1+\delta) S_t \text{ if } \in (0, \bar{S}) . \quad (1)$$

- $S = 0$ is absorbing
- $\delta > 0$: rate of "environmental regeneration" (measures amount of pollution that can be absorbed without extreme adverse consequences)
- $\bar{S} < \infty$: baseline (unpolluted) level of environmental quality.

# Model (4): innovation

- At the beginning of every period scientists (of mass 1) work either to innovate in the clean or the dirty sector, then randomly allocated to one machine in their target sector.
- If successful, proportional improvement in quality by $\gamma > 0$ and the scientist gets monopoly right for one period

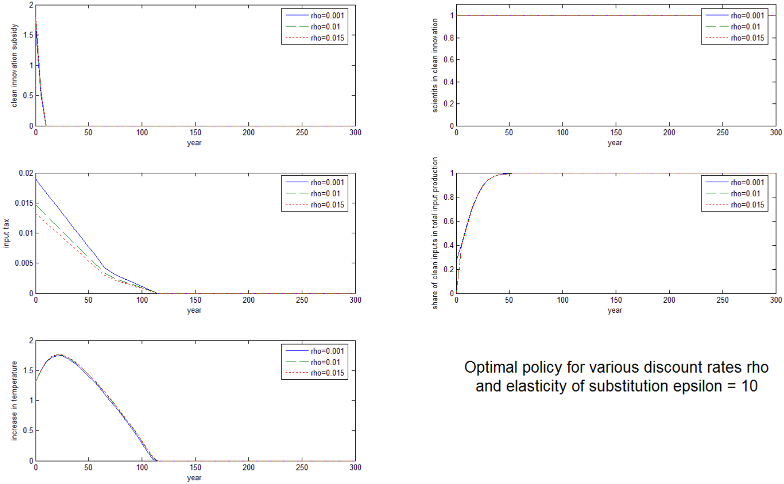
# Our answer

- Once directed technical change is factored in, a very different answer.
  1. Immediate and decisive intervention is necessary (in contrast to Nordhaus)
     → without intervention, innovation is directed towards dirty sectors; thus gap between clean and dirty technology widens; thus cost of intervention (reduced growth when clean technologies catch up with dirty ones) increases
  2. Temporary intervention may be sufficient (in contrast to Stern/Al Gore)
     → once government intervention has induced a technological lead in clean technologies, firms will spontaneously innovate in clean technologies (if clean and dirty inputs are sufficiently substitutes).
  3. Two instruments: optimal policy involves both a carbon tax and a subsidy to clean research to redirect innovation to green technologies
     → Carbon tax alone would reduce consumption too much in the short run.

# Calibration

- Relate $S$ with the atmospheric concentration of carbon
- Parametrize utility function to match welfare cost of environmental degradation with Nordhaus' DICE 2007 model over the range of temperature increases up to $3.5^{\circ}$C.
- Choose the elasticity of substitution between clean and dirty input as $\varepsilon = 3, 5, 10$ (low, moderate, high).
- Choose $\rho$, time discount rate (/year here) as $\rho = 0.001$ (Stern; discount factor$\simeq 0.999$), $\rho = 0.01$ (moderate; discount factor$\simeq 0.99$), and $\rho = 0.015$ (Nordhaus; discount factor$\simeq 0.985$).

# Optimal policy for different discount factors




Optimal policy for various discount rates rho
and elasticity of substitution epsilon = 10

# Act now

**Welfare costs of delayed intervention in function of discount rate**

(Percentage reductions in consumption relative to immediate intervention)

| | | | |
|---|---|---|---|
| Elasticity of substitution | 10 | | |
| discount rate | 0.001 | 0.01 | 0.015 |
| 10 years | 9.00 | 5.99 | 2.31 |
| 20 years | 14.62 | 8.31 | 2.36 |
| 30 years | 18.55 | 8.88 | 2.43 |

# Cost of using only carbon tax

**Welfare costs of relying solely on the carbon tax in function of discount rate**

(Percentage reductions in consumption relative to optimal policy)

| | | | |
|---|---|---|---|
| Elasticity of substitution | 10 | | |
| discount rate | 0.001 | 0.01 | 0.015 |
| Cost | 0.92 | 1.33 | 1.55 |

# Global Interactions

- Consider a world with North and South:
  1. *environmental externality*: dirty input productions by both contribute to global environmental degradation;
  2. *knowledge externality*: South imitates North' technologies
- Do we need global coordination to avoid disasters?
- The answer is no again because of **directed technical change** (advances in the North will induce the South to also switch to clean technologies).
- But free trade may undermine this result by creating **pollution havens.**

# Policy implications on global negotiation

1. North should take the lead in moving towards clean production and innovation
2. North should facilitate diffusion of new clean technologies to the South...
3. ...but at the same time, North should use the threat of carbon tariffs to prevent or mitigate pollution haven effect

# Summary: Factoring in endogenous directed technical change calls for...

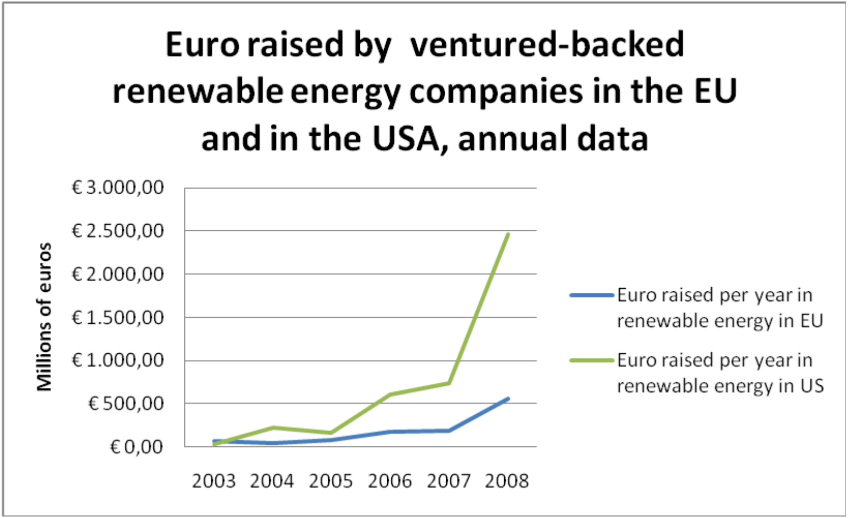
- **Acting now**, even with Nordhaus' discount rate for reasonable degree of substitutability between clean and dirty inputs
- **Using two instruments, not one**: carbon tax and subsidy to clean innovation, not just the former
- **Developed countries acting as technological leaders and diffusers worldwide** and diffuser on clean technologies to the South.
- **Use threat of Carbon Tariffs to prevent Pollution Haven Effect**

# Evidence on green patents

| | Share in world environmental patents | RTA in environmental patents |
|---|---|---|
| JAPAN | 45% | 1.14 |
| US | 15% | 0.68 |
| GER | 9% | 1.04 |
| KOREA | 7% | 1.07 |
| CHINA | 5% | 1.34 |
| FRANCE | 3% | 1.03 |
| UK | 2% | 0.95 |
| CANADA | 1% | 1.18 |

Source: WIPO 2008, PCT applications in environmental technologies (2001-2005 average)
Note: RTA= share of the country in world environmental patents relative to the share of the country in total world patents; RTA > 1 measures specialization in environmental patents;

# Venture Capital Financing of Green Innovations




Source on basis of Dow Jones Venture Source