Endogenous Technological Change and the Cost of Environmental Policy

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Introduction

Current debates:

- Rethink policy
  emission policy and technology policy
- Rethink modelling
  endogenous technology, (international) technology spillovers

Technological change: good or bad?

- What some people (Bush, Porter?) hope:
  technology is the solution
- What facts say: Coal-driven industrial revolution, energy-intensive mass production:
  growth mainly driven by pollution-using technological change.

Both types of technological change empirically relevant.
What matters is incentive effects:

Technology policy &
Environmental policy – innovation – costs and benefits of environmental policy

ITC: (policy-)induced
technological change

Research questions in this paper

How to model technology and technological change

Which type of technological change does environmental policy induce:
pollution-saving or pollution-using?

Implications for the cost of environmental policy

Does endogenous technological change…

- reduce the cost of environmental policy?
- make optimal environmental policy more stringent?
- make postponement of environmental policy more attractive (first invest than abate)?

Answers to each of them: NO, Not Necessarily!

Theoretical literature

- partial static models: innovation reduces abatement costs.
  Goulder/Mathai 2000, Parry/Pizer/Fischer 2003
- growth models: growth driven by endogenous total factor productivity change…
  Bovenberg/Smulders 1995, Aghion/Howitt 1998, Smulders 1998, Brock/Taylor 2005

  … but if pollution (polluting inputs) is a production factor, this means that technological change increases pollution!

Calibrated models with endogenous technology

What type of technology is endogenous/induced?

- Pollution-saving technology
  Nordhaus 2002, Popp 2004,
  various papers by Gerlagh and co-authors, and by RFF authors (Fischer, Pizer, Newell)
- Total factor productivity change…pollution-using technology
  Goulder/Schneider 1999
- Total factor productivity change inseparably linked to pollution-saving technological change
  FEEM-RICE (Buonanno et al 2003)
- Separable pollution-saving and pollution-using technology
  Gerlagh 2008

How can we strike a balance?

- Allow for alternative directions (*nature, bias*) of technological change:
    - Pollution-saving
    - Pollution-using

- Allow for changes in *rate* of technological change:
    - Crowding *out* of innovation
    - Crowding *in* of innovation

Modelling strategy

Simpler and more general model to bridge the strands of literature

- Static or steady-state model
- Linearized model
- One type of research at the same time (one instead of two knowledge stocks)
- General equilibrium or feedback effects

Outline

Two steps:

- Static model, increase pollution tax $d\tau$ + market response
- Steady state model, preference shift + optimal policy

Compare

- model with given H (no-ITC)
- model with adjustable H (ITC)

Static model, marginal tax increase:
does ITC reduce the cost of environmental policy?

Static model of environmental policy

$$\max_{P,H} \quad \pi = \underbrace{y(P,H;N) - i(H;K)}_{=C} - \tau P$$

$$U = u(C,N)$$

Variables:

π profits
Y output
I investment
P pollution
H man-made capital
C consumption

Lower case letters: functions

N environmental quality
K knowledge capital

(H and K may be a vectors)

Externalities: Firms take as given

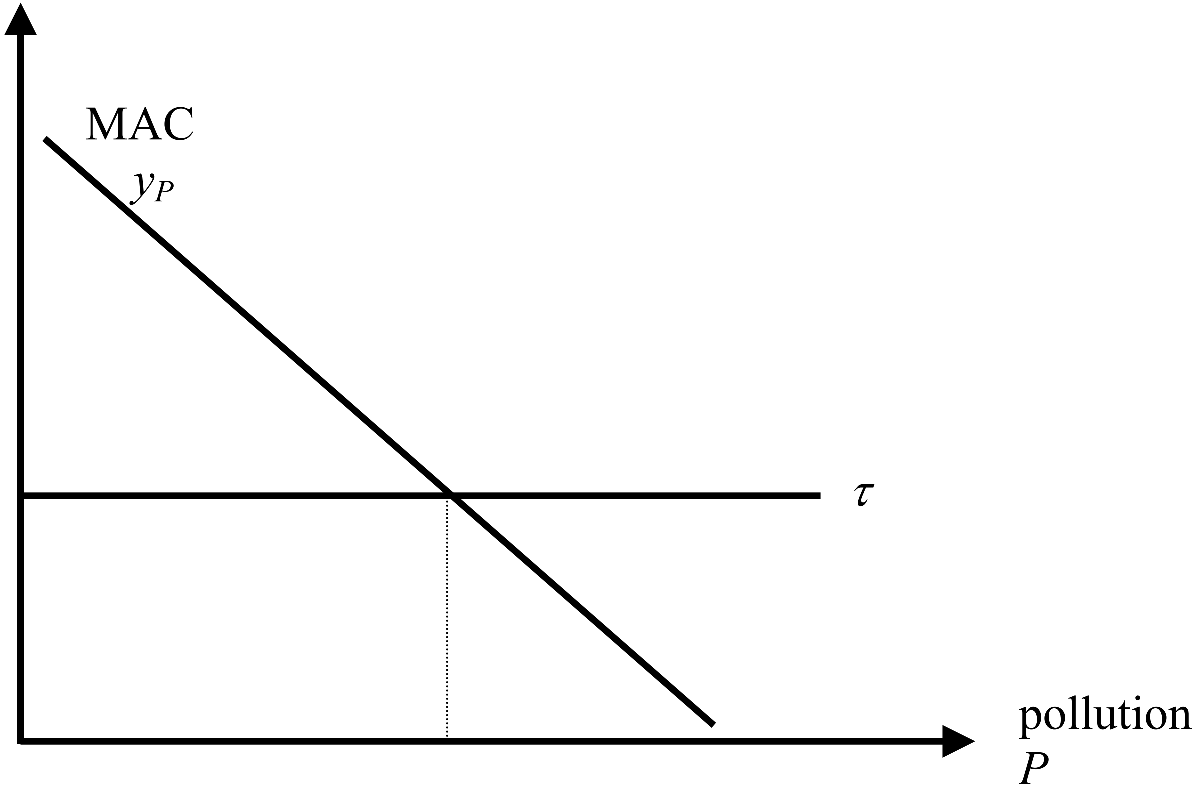
- environmental quality, but in equilibrium $N = n(P)$.
- knowledge stocks, but in equilibrium $K = H$.

Firm behaviour:

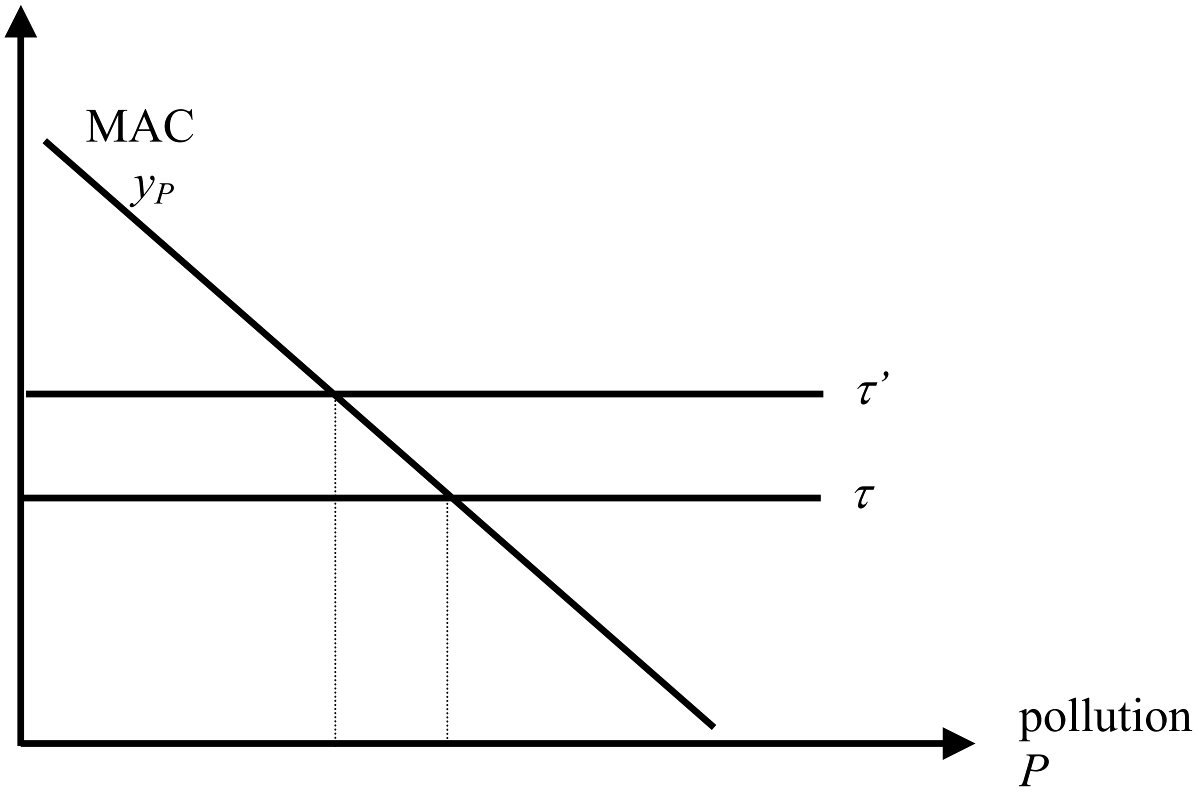
$$MAC \equiv y_P = \tau$$

$$MRR \equiv y_H = i_H$$

Illustration: textbook diagram

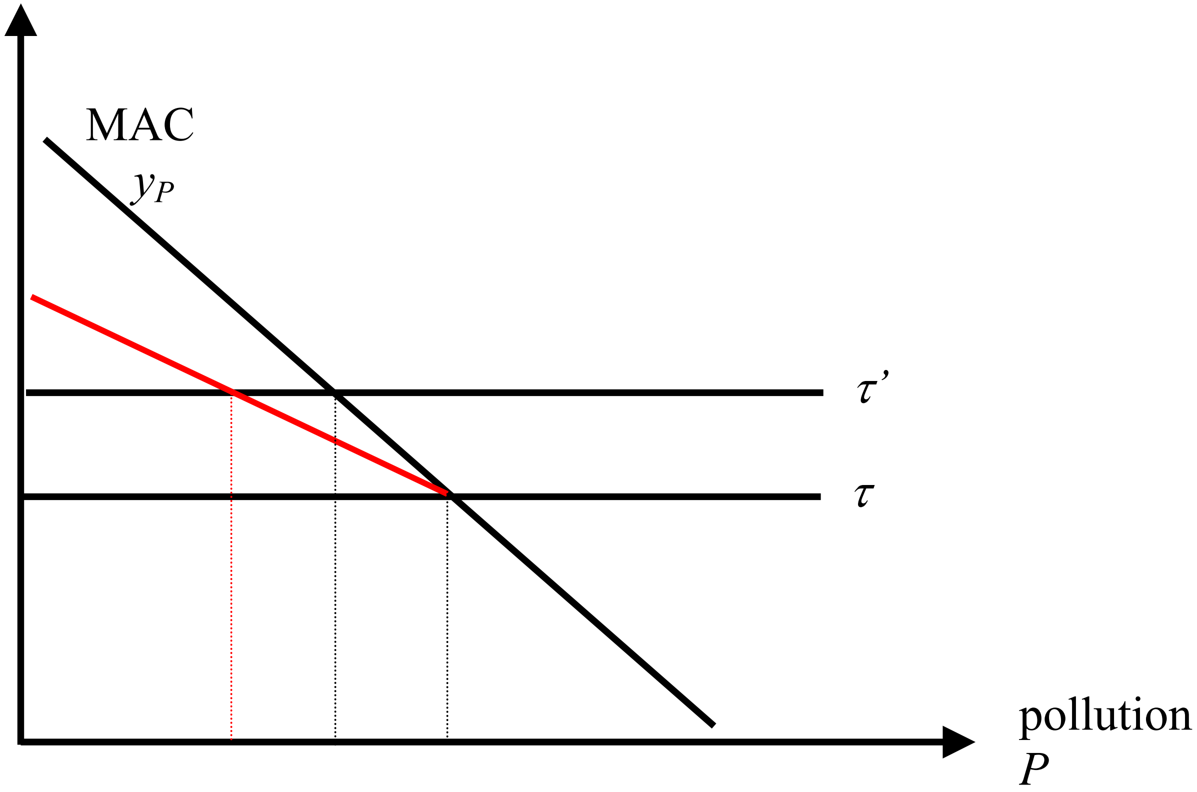


Increasing the pollution tax



Introducing endogenous technology (red lines)

Marginal abatement costs rise less steeply (larger response of P on change τ)
…Will this always be the direction?



Crowding out/in of innovation and Marginal Abatement costs

Marginal abatement cost: $\mathrm{MAC} = y_P$

Role of technology: $\mathrm{MAC}_H = y_{PH}$ if negative: pollution-saving techn.ch…

if positive: pollution-using techn.ch…

…when H increases

Return to investment: $\mathrm{MRR} = y_H$

Role environmental policy: $\mathrm{MRR}_P = y_{HP} + y_{HN} n_P = \mathrm{MAC}_H + (-)$

if negative: crowding in…

if positive: crowding out…

…of innovation when P decreases

Usually MAC_H and MRR_P have same sign: if technology reduces the cost of abatement, …

… then environmental policy increases investment,

…and vice versa.

This makes the presence of technological change (usually) **cost-reducing**, no matter whether investment increases or decreases marginal abatement costs (i.e. no matter of sign MAC_H).

Crowding out/in of innovation and Marginal Abatement costs

Marginal abatement cost: $\mathrm{MAC} = y_P$

Role of technology: $\mathrm{MAC}_H = y_{PH}$ if negative: pollution-saving techn.ch…
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Return to investment: $\mathrm{MRR} = y_H$

Role environmental policy: $\mathrm{MRR}_P = y_{HP} + y_{HN} n_P = \mathrm{MAC}_H + (-)$
if negative: crowding in…
if positive: crowding out…
…of innovation when P decreases

Usually MAC_H and MRR_P have same sign, …

but…exception when: pollution externality in production is large, and…
… technological change increases MAC (brown technology).
Then: lower P means *higher* return to investment
(mainly through the productivity effect),
…crowding *in* of investment,
….so that abatement is **more costly**.

Examples

Example 1.

End-of-pipe abatement technology improvements imply pollution-saving technological change.

$$Y = y(.) = m(N) \cdot f(P, \mathbf{H}_{-a}) - a(P)/H_a$$

$$Y_{PH_a} = a_{PP}/H_a{}^2 < 0$$

Example 2.

Multifactor productivity growth implies pollution-using technological change.

$$Y = y(.) = m(N) \cdot m(H_m) \cdot f(P, \mathbf{H}_{-m})$$

$$Y_{PH_m} = m \cdot m_{H_m} \cdot f_P > 0$$

Example 3.
With CES production function,

(i) pollution-augmenting technological change implies pollution-*saving* technological change if only if

- the elasticity of substitution between polluting inputs and other inputs, σ, is smaller than 1,
- and polluting inputs are used relatively abundantly (in effective terms).

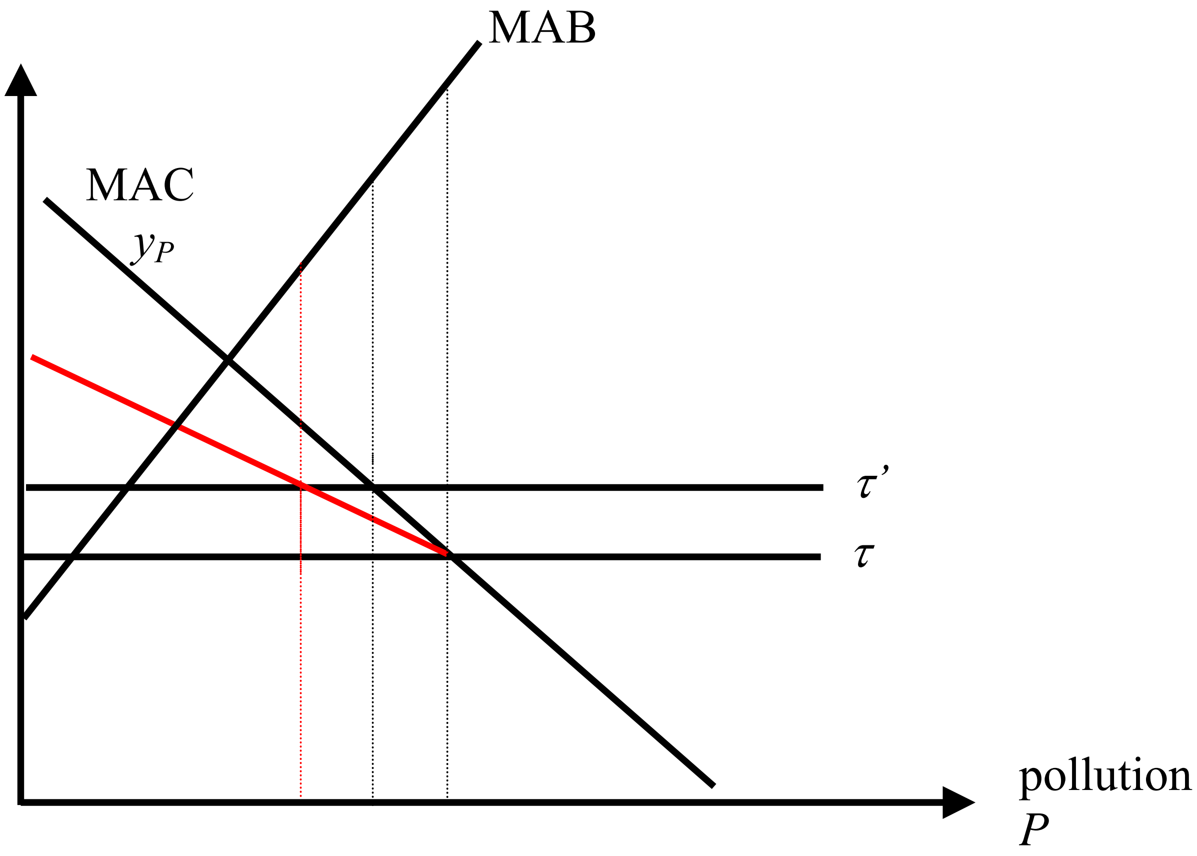
(ii) Technological change that augments other inputs than polluting inputs…
…implies pollution-*using* technological change.

$$Y = y(P, \mathbf{H}, N) = m(N) \cdot \left[\left(f(\mathbf{H}_{-p}) \right)^{\frac{\sigma-1}{\sigma}} + \left(H_p P \right)^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}}$$

$$\Rightarrow \quad Y_{PH_p} \overset{>}{<} 0 \quad \text{if} \quad \left(\frac{f(\mathbf{H}_{-p})}{H_p P} \right)^{\frac{1-\sigma}{\sigma}} \overset{>}{<} \frac{1-\sigma}{\sigma}$$

$$Y_{PH_{-p}} > 0$$

Analysing welfare gain of environmental policy: textbook diagram



But what if MAC becomes steeper, and/or MAB becomes steeper because of ITC?

Calculating the gains from environmental policy

Change in utility (measured in consumption equivalents) because of small change in environmental policy:

$$\frac{dU}{u_C} = \left[\underbrace{\frac{1}{-e_N}\left(\frac{u_N}{u_C} + y_N\right)}_{>0} + i_K \frac{dH}{dP} - \tau \right]\left(\frac{-dP}{d\tau}\right) d\tau$$

ITC affects welfare through two channels:

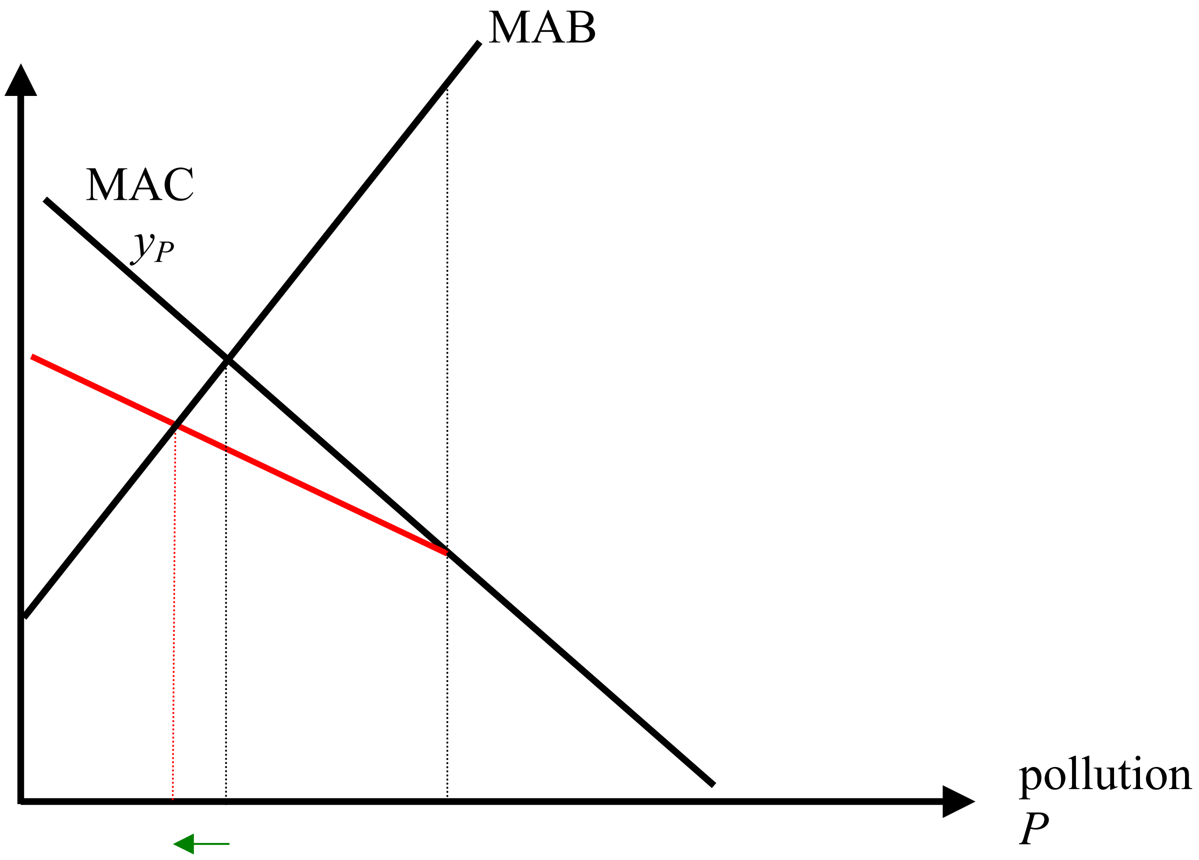
- Slope of pollution response $-dP/d\tau$
    - If ITC is pollution saving, it tends to improve welfare
    - If ITC is pollution using, it tends to reduce welfare. (Requires brown technology and large pollution externality in production)
- Externalities in investment i_K
    - Learning-by-investment: If environmental policy crowds out investment, ITC lowers welfare.
    - Fishing-out externality: If environmental policy crowds out investment, ITC lowers welfare.

Combinations are possible…

Dynamic model, optimal policy: does ITC call for more stringent environmental policy?

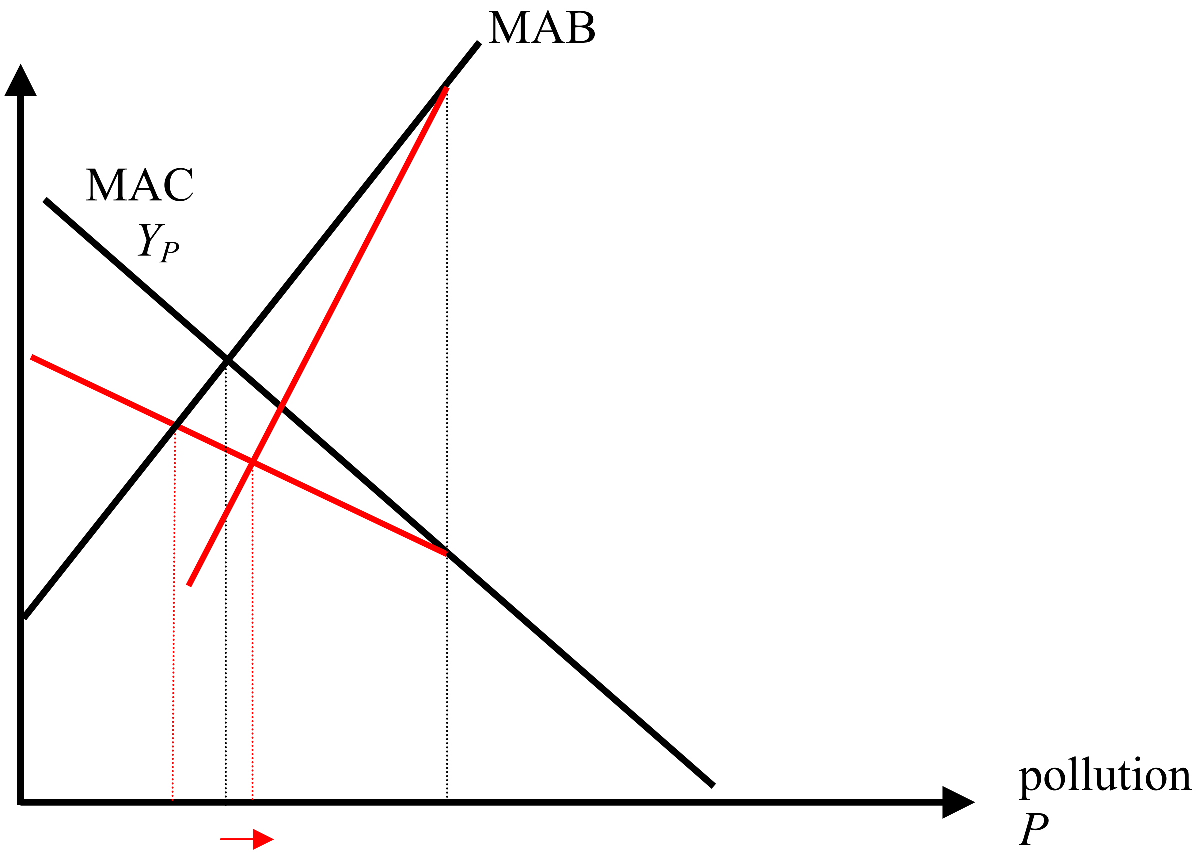
Optimal Environmental Policy: textbook diagram

Conventional case: ITC flattens MAC and *more* abatement in optimum.



Optimal Environmental Policy: textbook diagram

Conventional case: ITC flattens MAC and *more* abatement in optimum.
But… if MAC and/or MAB becomes because of ITC, *less* abatement in optimum.



Dynamic model

max $W = \int_0^\infty u(C(t), N(t)) \exp(-\rho t)\,dt$

s.t. $\dot{H} = g(I) - \delta_H H$ (Paper is more general)

$\dot{N} = \overline{e} - \delta_N N - P$ (Paper is more general)

$C = y(P, H, N) - I$

In steady state:

- Optimal investment in *N*: $y_P = \left(\frac{1}{\rho + \delta_N}\right)(u_N / u_C + y_N)$, MAC = MAB
- Optimal investment in *H*: $\frac{1}{g_I} = \left(\frac{1}{\rho + \delta_H}\right) y_H$, MC = MB

Shift in preferences (greening)

P falls – induced technological change – also affects MAB.

$$y_P = \left(\frac{1}{\rho + \delta_N}\right)(u_N / u_C + y_N)$$

With pollution-saving technology: crowding in of output and consumption

- ITC increases MAB – optimal environmental policy more stringent

With pollution-using technology: crowding out of output and consumption

- Economy is less productive, so smaller marginal damage from pollution
  - Economy is less productive,
    so smaller marginal damage from pollution (y_N lower)
  - Consumption is scarcer,
    so WTP for environmental quality is lower (u_C larger, u_N/u_C smaller)
- ITC reduces marginal benefits from abatement
- ITC makes optimal environmental policy less stringent

This MAB effect does not show up

- in *partial equilibrium* models
- in *static* models

Conclusions

Main insights

- We need to distinguish pollution-using technologies from pollution-saving technologies
- In some respect they are surprisingly similar:
  - even with pollution-using technology, ITC may *reduce* MAC
    - Le Chatelier principle might work
  - but then this comes at the cost of crowding out, which…
    - is costly if technology is underprovided (investment externalities)
    - and reduces marginal benefits of abatement, so that optimal environmental policy is less stringent
- In relevant situations, pollution-using technology has very different effects:
  - with externalities, ITC may *increase* MAC
    - Le Chatelier might break down

Checklist for modellers

- Is new technology pollution using or saving in the models?
- Do investment externalities lead to too much or too little innovation?
- Is there feedback (from investment to marginal damage)?
- Is the model dynamic or is there discounting?

Extensions

- Simultaneous innovation opportunities (both pollution-using and pollution-saving).

- Analytics of timing of abatement

- Non-marginal changes, in particular,…
    - … starting from inefficient situation (with growing emissions), and…
    - … moving to optimal environmental policy.