Smart Cap

Larry Karp[1] & Christian Traeger[2,3,4]

[1] ARE, UC Berkeley
[2] Economics, University of Oslo, Norway
[3] ifo Institute for Economic Research, Germany
[4] Frisch Center, Norway

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Background

40 countries + subnational entities implemented either a

- **carbon tax** (price regulation) or
- **cap and trade system** (quantity regulation)

- EU ETS current market value of ˜ 40 Billion USD, California regional ETS value of ˜ 6.5 Billion USD

Following the Paris Agreement

- **88 countries** consider implementing either a tax or a cap and trade
- World Bank & Ecofys (2018) lists 27 immediate initiatives considering introduction of either; 7 labeled undecided & 13 at country level

Issues with current cap & trade systems

- Prices dropped substantially and repeatedly as a result of
    - Macroeconomic recession
    - Unforeseen cost reductions including **technological progress** and asymmetric information
- Slow policy (regulatory) response (e.g. (ineffective) backloading and Market Stability Reserve)
- Cheap abatement left on the table
- Long-standing concern that taxes are more efficient than more wide-spread cap & trade

Background & Contribution I

Would be nice to implement first best or closer to first best policy:

Background I: Hybrid policies combining tax & cap

- **Theory: How to reveal necessary information**
  Kwerel (1977), Dasgupta et al. (1980), Kelly & Boleslavsky (2014)
  -> First best or closer to first best in principle, but somewhat complicated
- **Practice:** Cap & Trade combined with effective tax at **price floor or ceiling**
  Roberts & Spence (1976), Weitzman (1978), Pizer (2002), Fell et al (2012)
  -> Practical, but still inefficient (partly implemented in a few examples)

Contribution I:

- "Perfect hybrid system"
  - uses existing market for information aggregation
  - reaches first best (at least in principle)
- Closest papers: Requate Unold (2001), Kollenberg & Taschini (2016)

Background & Contribution II

Weitzman: Static setting, but climate change is **stock pollution** problem

Background II: Ranking taxes vs quantities for stock $CO2$

- Hoel & Karp (2001,2002), Pizer (2002), Newell & Pizer (2003), Karp & Zhang (2005), Kelly (2005), Fisher & Springborn (2011), Heutel (2012), Stavins (2020)

-> Find that *taxes are more efficient*

Frequent explanation:

- For $CO2$ MD (i.e. SCC) slope $\ll$ MB slope $\longrightarrow$ Taxes more efficient

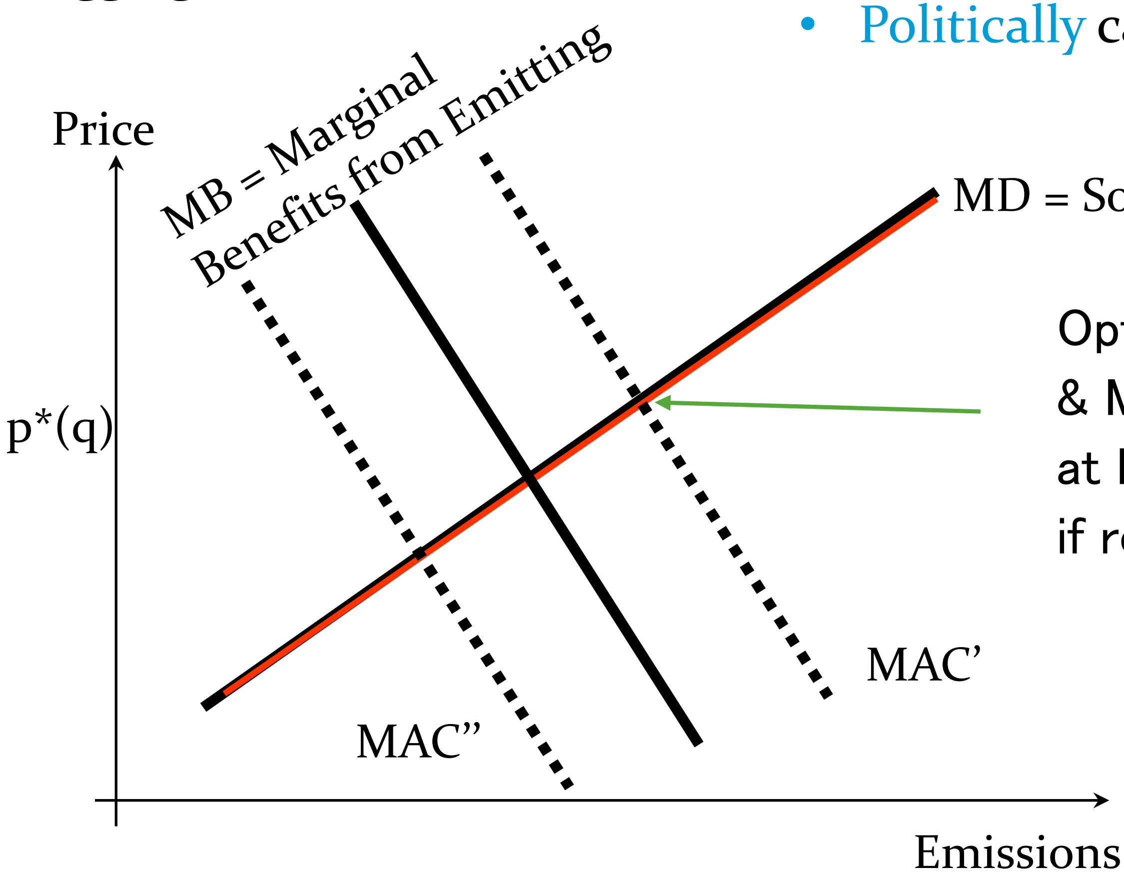
Contribution II:

- *It's not about the MD/SCC slope (similar point made by Pizer & Prest 2020)*
- *What is the right non-linear price-quantity relation? How steep is it?*
- *How is it affected by slow technology diffusion?*

I - The Static World

"SMART TAX": red line

Announced tax is a function of aggregate emissions



Issues with "**smart tax**" (**non-linear tax**):

- Individual firm has little information about expected aggregate emissions and, thus, price
- Politically cap & trade seems preferred

Optimal Allocation & Market Equilibrium at high MB realization if red line=smart tax

Requate & Unold (2001): implement through options

I - The Static World: The Smart Cap

The Smart Cap: A cap'n trade implementation of the smart tax

- Distributes Q allowances
- Announce a "redemption function" *q(p):*

  Each allowance gives claim to emitting $q(p)$ emissions,
  where p is the *equilibrium market price of certificates*
- use cap trading market to trade certificates

Equations needed to calculate (first best) redemption function:

Emission Supply (Smart Cap) = Total Emissions:

$Q\,q(p) = E$ (market clearing)

Optimal Emissions Price = Marginal Damages (in static model, MD given):

$$\frac{p}{q(p)} = MD(\,E\,) = MD(\,Qq(p)\,)$$

I - The Static World: The Smart Cap

Note: $$q'(p) = \frac{1}{MD'(E)\,E+MD(E)}$$ where $E = Q\,q(p)$.

- higher MD, or more convex damages (MD')

  –> smart **cap** is **less responsive** to the price of certificates

Two special cases:

- A *flat MD curve* $(MD'(E) = 0)$ implies a linearly expanding smart cap

  A hybrid cap would have to be adjusted infinitely sensitively

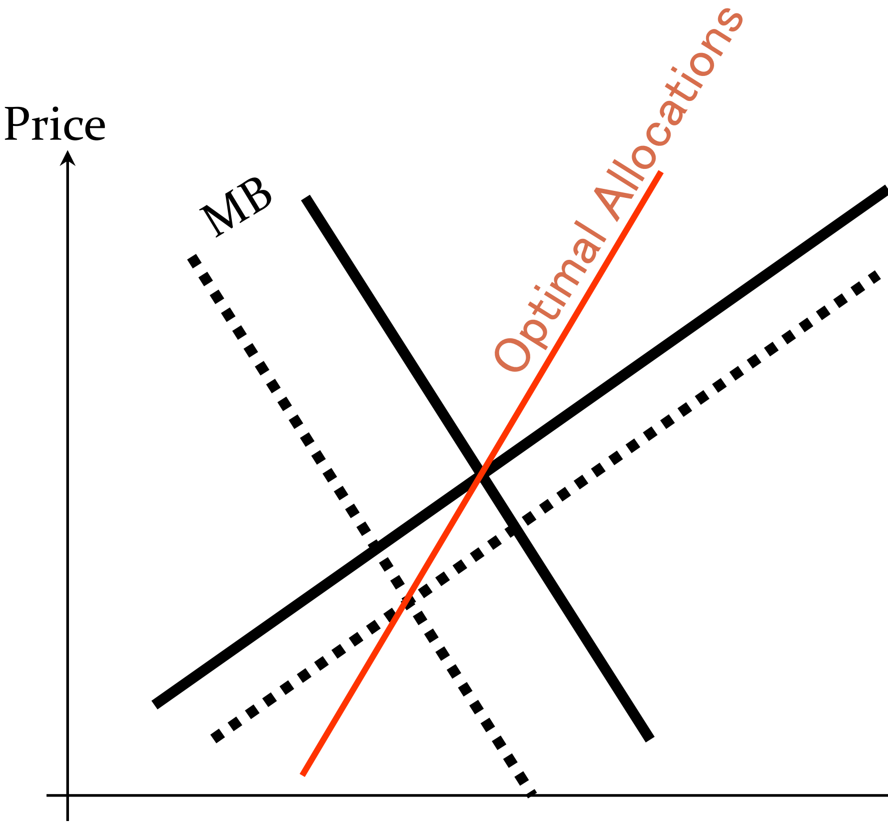
  - *actively adjusting a hybrid cap is hard!*
  - automatic adjustment of *smart* cap is *easy*!

- For $MD'(E) \to \infty$ cap is irresponsive to price (standard cap)

II.1 - Dynamic World: Intuition (smart tax)

Intuition: Assume a green technology innovation

- Lowers abatement costs and thus MB curve, thereby
- Reducing future equilibrium emissions, thereby
- Reducing marginal damages of a ton of CO_2 emitted today



MD curve

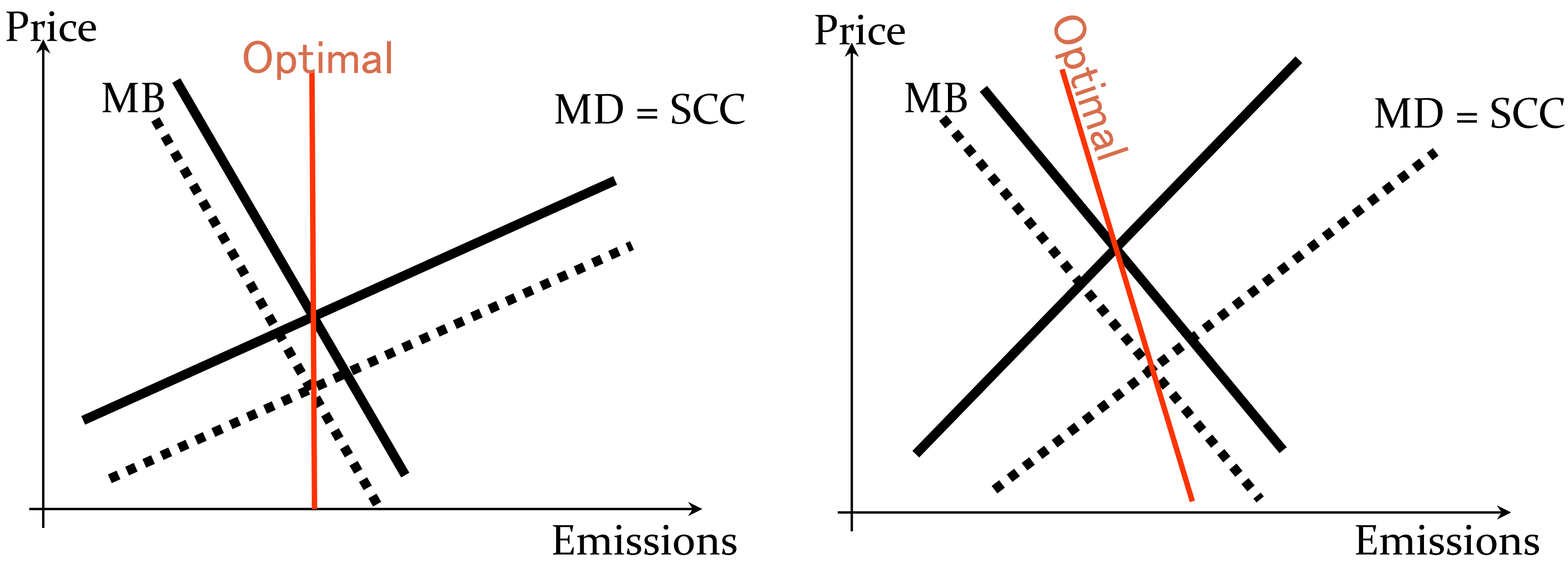
- Is *no longer* policy benchmark (precisely: None of the MD curves)
- Slope relative to MB curve is *no longer* tax vs quantity efficiency measure

Related: Stavins (1996), Weitzman (1974): correlated shocks to MD and MB curve

II.1 - Dynamic World: Intuition (smart tax)

Other scenarios:

- Left: Flat MD curve, yet cap and trade delivers first best
- Right: Optimal nonlinear tax "Price(Emissions)" can even slope down



Can these scenarios really happen? What can we say quantitatively?

II.2 - Dynamic World: The Linear Quadratic Model

Dynamic model: The **stocks**:

- pollution stock: $S_{t+1} = \delta S_t + E_t$ (later we use TCRE model)
- exogenous "technology" trend h_t (for quantitative results we assume falling at 1% per year)
- Stochastic deviation from the trend: $\theta_t = \rho\theta_{t-1} + \varepsilon_t$ with $\rho > 0$ and $\mathbb{E}_t(\varepsilon_t) = 0$
  For technology: $\rho \approx 1$

Information: The *policy maker knows* θ_{t-1} but *not* ε_t when setting period t policy

Generally **technology diffuses over time**.

Main "technical" modeling novelty: A simple analytically tractable model of **partial adoption**:

- firms in period t use adopted technology level: $\hat{\theta}_t \equiv \rho\theta_{t-1} + \alpha\varepsilon_t$
  - If $\alpha = 1$ immediate full adoption,
  - Assume $\alpha \in (0,1]$: *share of current innovation adopted within a commitment period*

The simple model has two advantages:

- We do not need a third state variable (a mess for analytics!)
- What will really matter about technology diffusion is:
  how much is adopted in current regulatory period versus the future: precisely α

II.2 - Dynamic World: The Linear Quadratic Model

We assume the widespread ***linear quadratic specification of payoffs***

- f: cost convexity
- b: damage convexity

Technology: lower = better = easier to get by without emissions

- $\hat{\theta}_t$: technology's stochastic component (adopted)
- $\hat{h}_t$: technology trend (adopted)

Flow payoffs (*discount factor β*):

$$\underbrace{(\hat{h}_t + \hat{\theta}_t)E_t - \tfrac{f}{2}E_t^2}_{\text{emission benefits}} \quad \underbrace{- \frac{b}{2}S_t^2}_{\text{stock damages}}$$

We solve the resulting infinite horizon dynamic programming problem.

II.2 - Dynamic World: The Linear Quadratic Model

Assumption: Convex damages (positive slope of MD curve) and $\rho > 0$.

Proposition 1: Under immediate full adoption of technological innovation (α=1)

- the smart tax always has a positive slope
- the smart tax increases more steeply in present emissions than the SCC (SCC for any given shock realization)

Proposition 2 (general α): For any well-defined model specification

- exists α^{crit} in (0,1) such that the slope of the smart tax SCC* is
  - positive for $\alpha > \alpha^{crit}$ and steeper than the slope of SCC
  - negative for $\alpha < \alpha^{crit}$
  - at $\alpha = \alpha^{crit}$ standard cap is first best & smart tax is vertical
- The smart tax supports the optimal emission level as a globally stable competitive equilibrium.

II.2 - Dynamic World: The Linear Quadratic Model

Assumption: Convex damages (positive slope of MD curve) and $\rho > 0$.

Proposition 3 (Smart Cap):

If $\alpha > \alpha^{crit}$ (smart tax has positive slope), then the redemption function (formula see paper) implements the first–best emission level as a stable competitive equilibrium. The redemption function increases in the certificate price.

If $\alpha < \alpha^{crit}$ (smart tax has negative slope), then the redemption function (formula see paper) implements the first–best emission level as a stable competitive equilibrium on a limited domain. The redemption function falls in the certificate price.

Note:
Questions about market power or "banking & borrowing"?
Please ask in discussion ☺

II.3 - Dynamic World: Quantification

Climate: we use the TCRE model:

- Temperature is proportional to cumulative historic emissions (IPCC 2013)
- Even if approximation, better temperature dynamics than DICE
- $S_{t+1} = \delta S_t + E_t$: S_t are cumulative emissions/temperature and δ =1

Damage:

- Baseline scenario: calibration to DICE's 1% damage at 2C warming
- *Concerned* scenario: no damages at current 1C, 5% at 3C (*more convex*)

Technology "scenario calibration":

- Assumption: technological innovation $\hat{\theta}_t \equiv \rho\theta_{t-1} + \alpha\varepsilon_t$)=1
- We estimate adopted share α of innovation during 5 year commitment period:
  - Regressing US business as usual emissions (pre 2010) on
  - Green patents (registered in Japan, US, & EU)

  Result: base period 1990–2010 $\alpha \approx 0.25$ – longer periods partly larger.

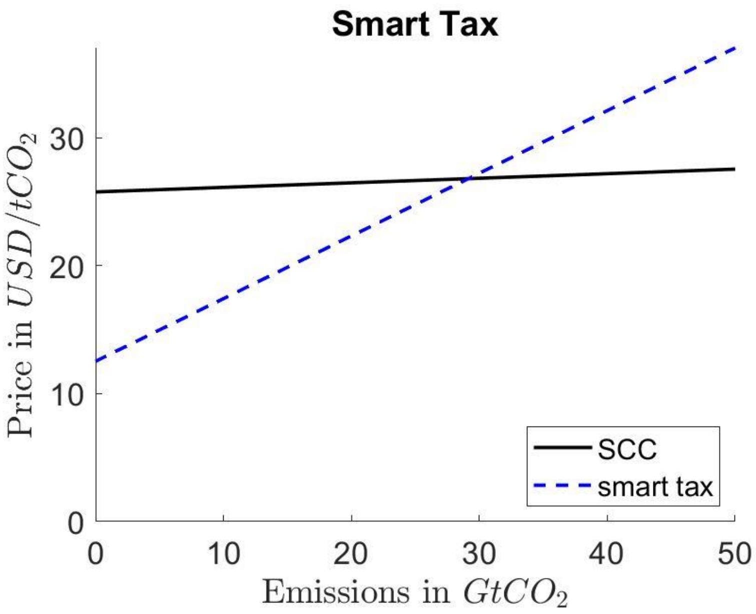
Annual rate of pure time preference: 1.5%

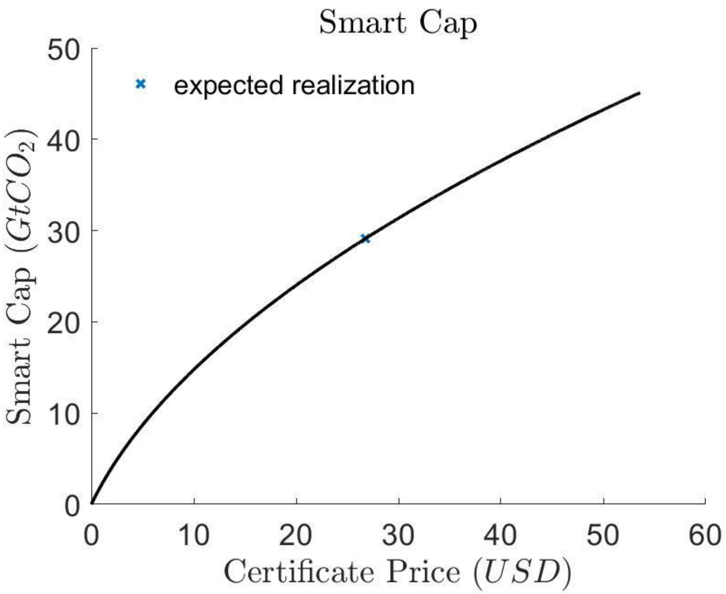
II.3 - Dynamic World: Quantitative Results

1. Immediate Full Adoption of Technological Innovation (α=1):

Notes:

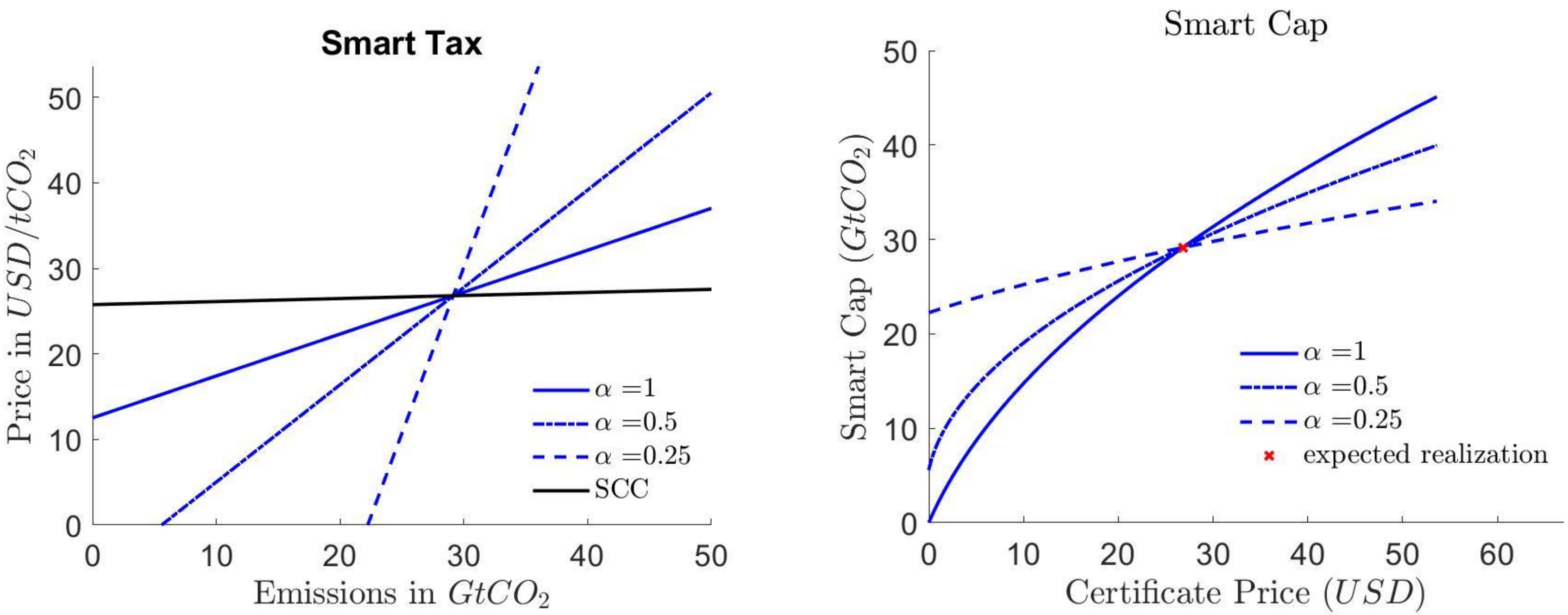
- The SCC line in the smart tax graph assumes expected realization (for other realizations is shifts up and down keeping the slope)
- The smart cap graph depicts total cap (*Q*Redemption Fct*). It assumes: *certificate number Q = optimal emissions under expected realization*





II.3 - Dynamic World: Quantitative Results

2. Partial Adoption of Technological During Commitment Period



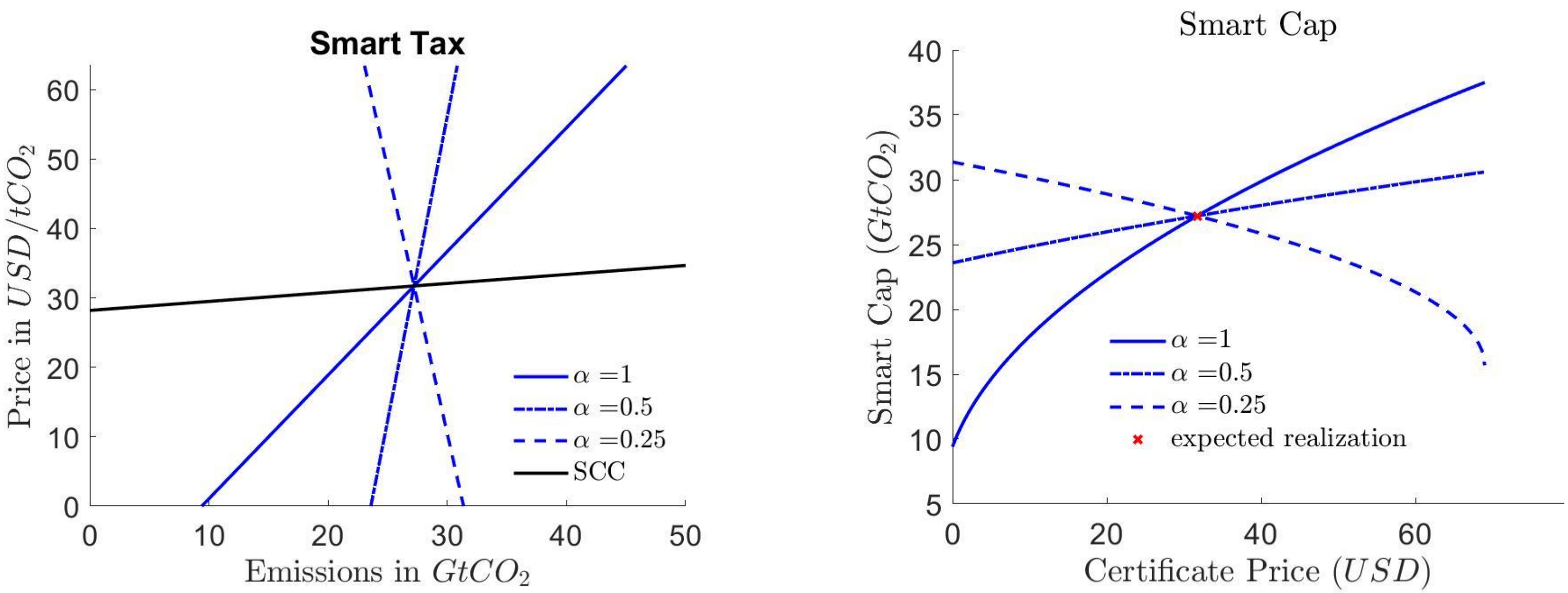
with partial adoption during commitment period:

- Smart tax becomes steeper: Price more responsive to quantity change
- Smart cap becomes less responsive: Quantity becomes less responsive

Lower adoption share α (more delayed adoption) makes standard "fix" (or dumb ☺) cap more attractive.

II.3 - Dynamic World: Quantitative Results

3. The "concerned" scenario: More convex damages:



Here with $\alpha = 0.25$ smart tax and redemption function are decreasing. Both policy instruments still result in stable competitive equilibria.

- Here a better than expected green realization lowers future emissions and, thus, SCC more than current marginal abatement costs.
- As a result firms are allowed to emit more if price falls

Clearly here standard cap is better than tax.

Other nice features of “smart”

Psychological/moral incentive issue of the ***standard cap***:

- If we abate, others will emit more → Eliminates moral incentive to reduce emissions, converting it into a mere price incentive.

Smart cap addresses the moral incentive:

- If we abate, price drops, (smart) cap contracts (at least for increasing smart cap).

Similar: **Developing world & offsetting** (e.g. clean development mechanism)

- Critique with offsetting that it keeps price down and too little is done at home
- Yet: very useful for efficient global CO2 reductions!

With smart cap:

- Offsetting drops price and contracts local smart cap (price drop more moderate, more overall abatement going on)

Smart cap offers an “**optimal compromise**”

- *Firms* are better *protected* from *too high price* shocks
- *Social/Environmental concern* more *protected* from *too low* a carbon *price*

Practical Points regarding Implementation

Trading “certificates” rather than “tons of CO_2”:

- Similar to existing ITQs in fishery (Individual transferable fishing quotas)
- There we trade shares of a (fish–) pie whose *size* is *directly set* by policy maker
- Here: trade shares of a (carbon–) pie whose size is endogenously set by the market
- For major markets arbitrageurs can/will offer “ton CO_2 certificates/derivatives”

EU ETS has an institutional “issue” with price instruments (unanimity):

- smart cap remains a quantity regulation, yet even more efficient than a tax

In case trading a “non–ton” still politically infeasible:

- *At least use smart tax for individual certificate auctions*
  announce offer curve early on so markets anticipate
- If also that is too much asked:
  At the very least let auctioned quantity be a function of the price of previous auction(s)

Still major efficiency improvement, even if some delay (but anticipation should counteract) and certificates already on the market not affected.

Conclusions

Dynamic “Taxes vs Quantities” & abatement technology shocks

- Cost shocks shift “MD curve” (here = social cost of carbon)
- Smart tax (non–linear tax) = optimal price–quantity response
- Smart tax generally steeper than “MD curve”, can even
  - be vertical –> std cap first best
  - slope down

Smart Cap:

- Implements optimal non–linear tax with minimal information requirement
- Is a compromise between cap & tax both economically & politically
- Employs & only slightly modifies existing institutions
- Better incentive structure than standard cap & hybrid system

Market Power

Assume regulator faces a monopsonist:

1. Smart cap q (p) designed for full competition:
Monopsonist exercises market power by reducing level of emissions below first best *if and only if*
slope of corresponding smart tax is positive.

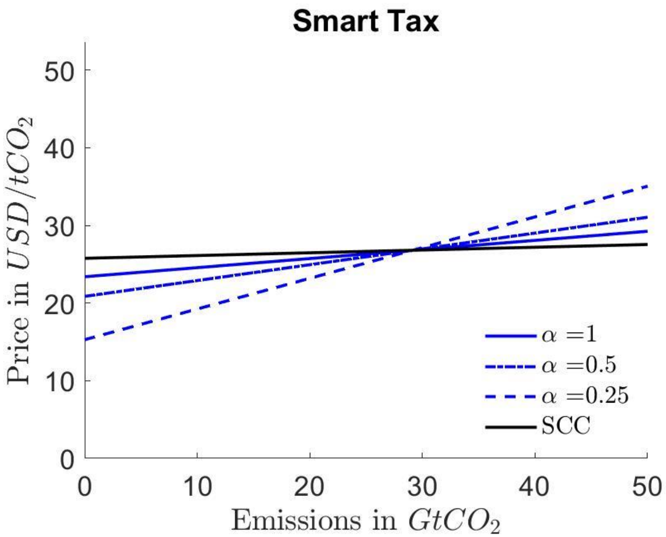
2. The policy maker can induce an optimal emission allocation using a smart cap designed for market power.
There is some degree of freedom how to design it in the case of a monopoly, changing revenue allocation.

$$B'(E) = \frac{p^E}{\varepsilon_{q,p}} = p^E \frac{1+\varepsilon_{\mathrm{E,p^E}}}{\varepsilon_{\mathrm{E,p^E}}}$$

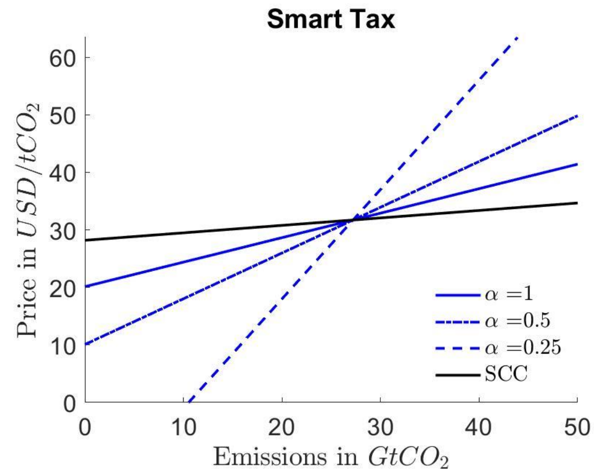
- $\varepsilon_{q,p}$ is the elasticity of certificates to certificate price
- $\varepsilon_{\mathrm{E,p^E}}$ is the elasticity of emissions (tC) to emissions price
- upward sloping smart tax ("normal case"):
$\varepsilon_{\mathrm{E,p^E}} > 0$ and $\varepsilon_{q,p} < 1$

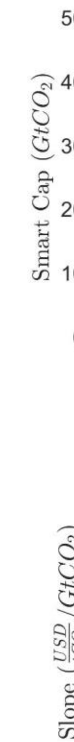
II.3 - Dynamic World: Quantitative Results

4. The *persistence of technology is crucial* for the extent of the slope increase. More moderate persistence of ρ=0.75 over the 5 year commitment period reduces the slope increase substantially



Concerned Scenario (more convex damages)





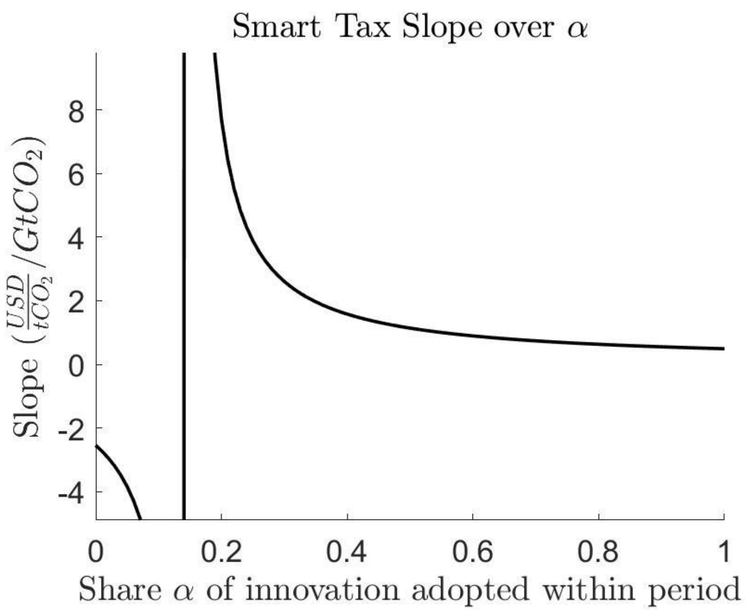
Only in concerned scenario for α = 0.25 still standard cap better than tax.

Note: Reduction of the *discount rate* has opposite effect, generally turning slopes steeper. For r.p.t.p = 0.5%, ρ=1, and α = 0.25, the standard cap is approximately first best in baseline

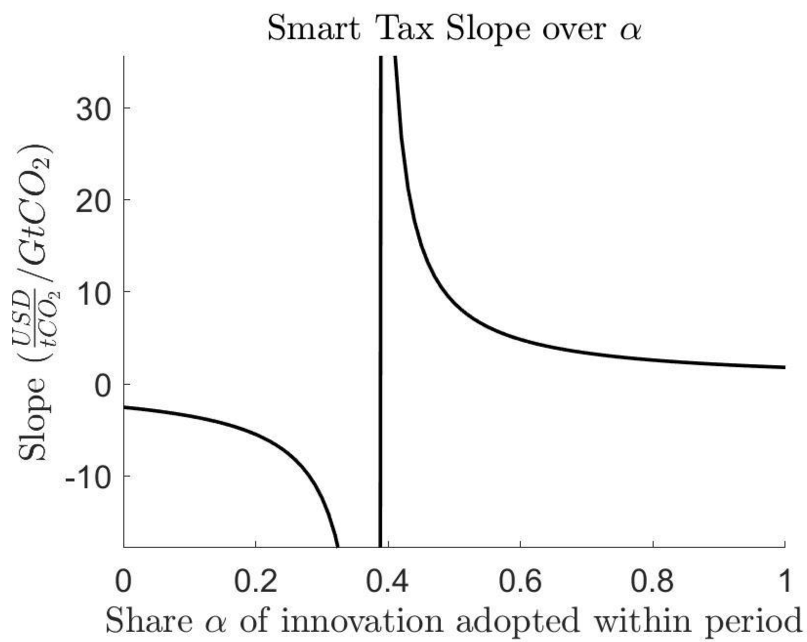
II. Dynamic World: Quantitative Results -- Additional

3. The Smart Tax slope in "baseline" and "concerned" scenario over α

Baseline Scenario



Concerned Scenario



The poles correspond to the vertical smart tax (and a linear smart cap) and the situation where the classic "fix" cap and trade system is first best.

Banking, borrowing, trading within commitment periods

Standard cap and trade systems

- often permit banking of certificates across periods
- good for smoothing shocks

Smart cap endogenously adjusts to shocks

-> **Do not need banking and borrowing** for this purpose

Intertemporal certificate trading can still become relevant to

- filter out short-term business cycle shocks as compart to technology shocks

if not allowed to condition redemption function on macro indicator (better!)

Also commitment periods might be lengthy for administrational reasons.

- **Intertemporal arbitrage** implies that certificate price rises at rate of interest
- Generally **not socially optimal**

Can we construct a smart cap that conserves first best with intertemporal arbitrage?

Trading across periods

Assumption:

- Linear quadratic dynamic model from before
- Full immediate technology adoption (α=1)
- Simplifying assumption:
  Possible to condition redemption function on global carbon stock

  Alternative: Simply neglect sub-period endogeneity

Reasoning:

- Certificate prices rise at the rate of interest $\neq$ social optimum
- -> We need different redemption function for each period

Notation:

- Q is overall cap across trading periods $t=1,\cdots,T$,
  [then new commitment period (infinite time horizon)]
- $q_t(p_t)$ is redemption function in period t based on certificate price in t

Trading across periods

Proposition 4:

When permitting for banking and borrowing across periods 1,⋯,T, the first best solution can be achieved by setting

- *redemption functions* $q_1(p_1)$, $q_2(p_2)$, $\cdots$, $q_T(p_T)$
- *and a joint total certificate cap* $Q(p_1, p_2, \cdots, p_T)$.

In general, the first best cannot be achieved with a constant Q.

Comments:

- The redemption function $q_t(p_t)$ determines the certificate to emission exchange ratio in period t
- Market clearing is now $\sum_{t=1}^{T} \frac{E_t}{q_t} = Q$