CONFRONTING THE CARBON PRICING GAP: SECOND BEST CLIMATE POLICY

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Context: Pricing carbon

- Pricing carbon recognized since Pigou, 1921 (100 years ago!) as the most efficient policy instrument in reducing emissions:
  - delivers reductions at lowest cost;
  - generates additional tax/permits revenue;
  - provides incentive to invest for environmental-friendly innovation.

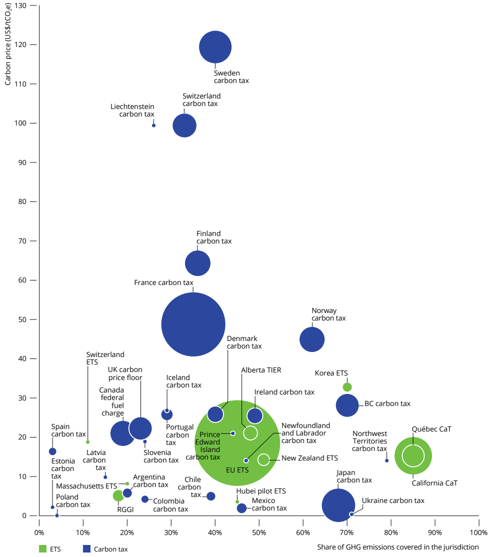
- However almost nobody finds this appealing except economists...

... whereas everybody understands the new costs and the adverse distributional impacts.

The economists' advice faces political economy acceptability constraints

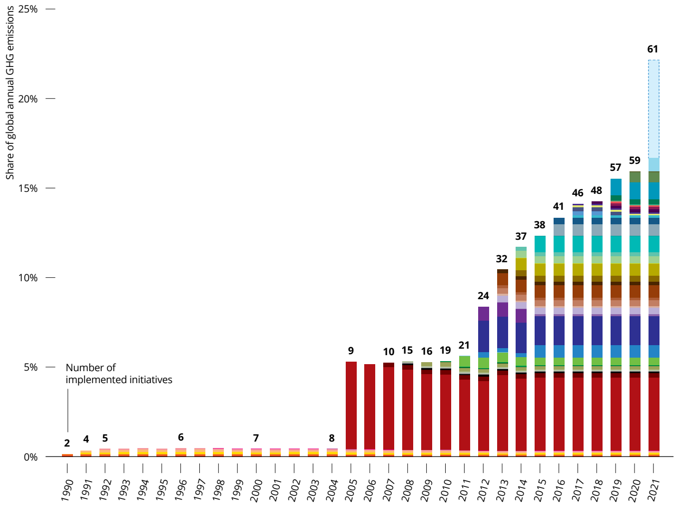
⇒ Insufficient carbon pricing, and adoption of alternative policy instruments:
  - command-and-control;
  - subsidies to the purchase of renewable energy;
  - subsidies to investment in renewable production and storage capacity;
  - renewable technology certificates.

Context: Carbon pricing around the world



Source: World Bank (2020), *State and Trends of Carbon Pricing 2020*

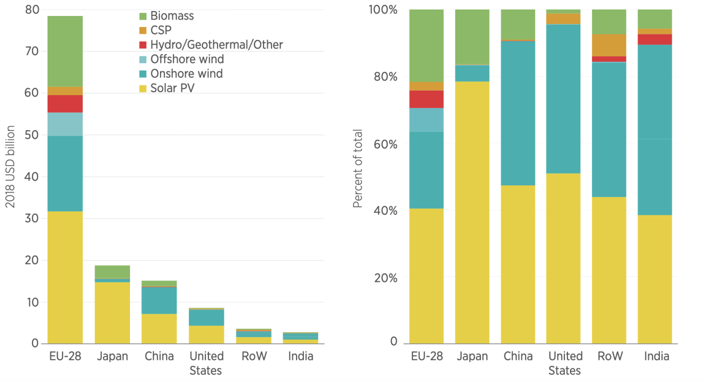
Context: Carbon pricing around the world



Source: World Bank (2020), *State and Trends of Carbon Pricing 2020*

Context: Subsidies to renewables

Figure 5: IRENA subsidy estimates for renewable power generation by country/region and technology, 2017



Note: RoW = Rest of World

Source: IRENA (2020)

What we do

We propose an analytical framework

- Stylized dynamic model of the choice of the electricity mix
- Fossils are abundant, cheap, with excess capacity, but CO_2-emitting
- Carbon budget approach to climate policy (cost-effectiveness) IPCC
- Renewable energy is clean, but requires investment in “green” capital (solar panels, wind turbines and storage equipment)

We use it to

- consider an acceptability constraint leading to a constant carbon tax
- compare second best policies relying on alternative instruments to the social optimum
- conceptualize the carbon pricing gap
- provide illustrative measures of
  - the welfare cost of acceptability
  - the cost of acceptability in terms of public finance

What we find

A climate policy implying decreasing consumption paths is not politically feasible, thus the acceptability constraint takes the form of a non-increasing carbon tax

- prevents us from following the optimal consumption path, which would be decreasing when the use of fossil shrinks along with the carbon budget;
- forces society to invest too much and too early in green capital, in order to cope with the carbon budget constraint;
- may even cause an overshooting in green capital;
- may postpone or put forward fossil phase-out;
- negatively affects welfare through two channels:
  - the distortion in the consumption path
  - the increased cost of investment in green capital
- results in excessive burden for the public budget and reallocation funds.

Literature

- Huge literature on energy transition in macro-dynamic models à la Hotelling. Consider optimum.
- Design of second best climate policy: static IO models (e.g. Requate, 2015, Bennear and Stavins, 2007).
- Stock and Stuart (2021): consider different combinations of clean energy standards, tax credits to investment in low carbon technologies, and carbon tax in partial equilibrium dynamic model of the electricity sector in the US.
- Kalhkul et al. (2013) show numerically that the welfare costs of renewable energy subsidies are multiple times higher than first-best mitigation costs under a carbon price policy.
- Rezai and van der Ploeg (2017) stress that the welfare costs also significantly increase in case of lack of credibility of second best policies.
- Fischer et al. (2021): second best in case there are less instruments than externalities.

Outline

- The model and the optimal energy transition
- The decentralized economy and the first best policy
- The second-best policy with a feed-in-premium and a constant carbon tax
- Illustrative numerical application

The economy

- A representative household with infinite horizon in a closed economy.
- Constant discount rate, $\rho > 0$.
- Instantaneous utility function $z(t) + u(e(t))$, with $u' > 0$ and $u'' < 0$, quasi-linear in the generic consumption good z.
- Electricity consumption $e(t) = x(t) + Y(t)$, where fossil electricity x and renewable electricity Y are perfect substitutes.
- Accumulation of green capital: $\dot{Y}(t) = I(t) - \delta Y(t)$.
- Investment in green capacity implies convex adjustment costs $C(I(t))$.
- Cumulative carbon emissions $X(t)$ s.t. $\dot{X}(t) = x(t)$.
- Climate policy = carbon budget $\overline{X}$.

The optimal energy transition

Social planner maximizes society's net surplus:

$$\max_{x(.),I(.)} \int_0^\infty e^{-\rho t}[u(x(t) + Y(t)) - C(I(t))]dt$$

$$\begin{aligned} &\dot{X}(t) = x(t) && \lambda(t) \text{ carbon value} \\ &\dot{Y}(t) = I(t) - \delta Y(t) && \mu(t) \text{ value of green capital} \\ &X(t) \le \overline{X},\ x(t) \ge 0,\ I(t) \ge 0 && \\ &X(0) = 0,\ Y(0) = Y_0 && \end{aligned}$$

1. Carbon era, $t \in [0, T]$
   - Hotelling rule on the carbon value λ: $\dot{\lambda}(t) = \rho\lambda(t)$
   - The carbon value drives the evolution of electricity consumption and of the social value of green capital μ:

     $$e(t) = x(t) + Y(t) = u'^{-1}(\lambda(t))$$
     $$\dot{\mu}(t) = (\rho + \delta)\mu(t) - \lambda(t)$$
   - The social value of green capital drives investment: $I(t) = C'^{-1}(\mu(t))$
   - Carbon budget $\overline{X}$ exhausted at the fossil phase-out date T s.t.

     $$\lambda(T) = u'(Y(T))$$

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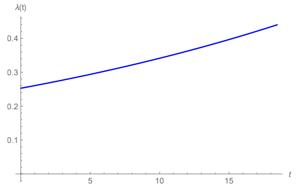
2. Clean era, $t > T$
   - Electricity consumption proportional to green capital: $e(t) = Y(t)$
   - The social value of green capital drives investment: $I(t) = C'^{-1}(\mu(t))$
   - Evolution of the social value of green capital driven by the marginal utility of electricity consumption:

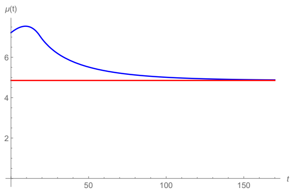
     $$\dot{\mu}(t) = (\rho + \delta)\mu(t) - u'(Y(t))$$

Convergence towards a unique and saddle-path stable steady state (Y^*, μ^*), defined by:

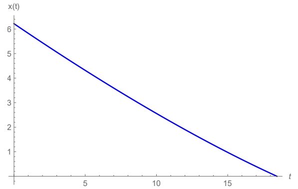
$$\delta Y^* = C'^{-1}(\mu^*)$$
$$(\rho + \delta)\mu^* = u'(Y^*)$$



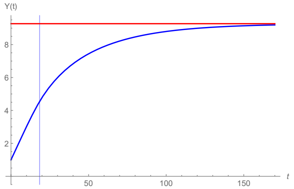
carbon value



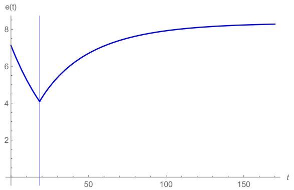
social value of green capital



fossil use



green capital



electricity consumption

Decentralized economy

- Two policy tools available to the regulator:
  - carbon tax $\tau(t)$
  - feed-in-premium (FIP) for renewable electricity $\sigma(t)$
    (or subsidy to investment in green capital $s(t)$)
- Public budget balanced, with lump-sum transfers $\mathcal{T}$ to households:

$$\tau(t)x(t) = \sigma(t)Y(t) + \mathcal{T}(t)$$

- Households' electricity demand: $e(t) = u'^{-1}(p_e(t))$
- Behavior of the profit-maximizing representative electricity producer:

$$\begin{aligned} p_e(t) &= p_x(t) + \tau(t) \quad \text{for } x(t) > 0 \\ C'(I(t)) &= \mu_d(t) \\ \dot{\mu}_d(t) &= (\rho+\delta)\mu_d(t) - [p_e(t) + \sigma(t)] \end{aligned}$$

  with μ_d the private value of green capital.

- Fossil producers: no scarcity rent + no extraction cost ⇒ $p_x(t) = 0$.

detail

First best policy

Optimal climate policy

- Charge a carbon tax equal to the optimal carbon value

$$\tau^{fb}(t) = \lambda(t), \;\; t \leq T$$

  increasing at the social discount rate;

- Do not use any feed-in-premium: $\sigma^{fb}(t) = 0$.

- Increasing carbon tax & declining consumption path
  ⇒ potential acceptability issue and political opposition
  Yellow vests movement.

⇒ What climate policy if the regulator can only commit to a **constant** carbon tax?

Second best policy with a constant carbon tax and a FIP

- Consumers, electricity producers and the regulator play a Stackelberg policy game, where the leader is the regulator.
- As a first mover, the regulator announces a climate policy and credibly commits to implement it:
  - a carbon tax at an exogenous "acceptable" constant level $\tilde{\tau}$
  - a path of the FIP $\sigma(t)$.
- Households decide how much electricity to consume, and electricity producers choose the electric mix and green investment.
- Game solved by backward induction:
  the regulator, knowing the agents' best responses to her policy, chooses the FIP path maximizing her objective function while complying with the carbon budget, conditional on $\tilde{\tau}$.

Second best policy with a constant carbon tax and a FIP

Regulator's program during the carbon area

$$\max_{\sigma(.)} \int_0^{\widetilde{T}} e^{-\rho t} \left[u(u'^{-1}(\widetilde{\tau})) - C(C'^{-1}(\mu_d(t))) \right] dt$$

$$\begin{aligned}
&\dot{X}(t) = u'^{-1}(\widetilde{\tau}) - Y(t) && \zeta_1(t) \\
&\dot{Y}(t) = C'^{-1}(\mu_d(t)) - \delta Y(t) && \zeta_2(t) \\
&\dot{\mu}_d(t) = (\rho + \delta)\mu_d(t) - (\widetilde{\tau} + \sigma(t)) && \zeta_3(t) \\
&X(t) \leq \overline{X} \\
&X(0) = 0 \ , \ \ Y(0) = Y_0 \ , \ \ Y(\widetilde{T}) = u'^{-1}(\widetilde{\tau}), \ \ \mu_d(0) \ \ \text{free}
\end{aligned}$$

Shadow prices:

ζ_1 second best carbon value,
ζ_2 second best (social) value of green capital,
ζ_3 shadow value of the private value of green capital, considered as a (controllable) state variable.

solution

Second best policy with a constant carbon tax and a FIP

Clean era

(i) Date $\widetilde{T}$ at which the regulator lifts the FIP = date of fossil phase-out.

(ii) Clean era the same as at the first best, but starting at a different date from a different green capital stock.

(iii) Initial green capital stock in the clean era, $Y(\widetilde{T}) = u'^{-1}(\widetilde{\tau})$, decreasing in $\widetilde{\tau}$. It is larger than at the first best iff $\widetilde{\tau} < \lambda(T)$ (which must be the case) $\Rightarrow$ over-investment in the carbon era.

(iv) For $\widetilde{\tau} < \underline{\tau} \equiv u'(Y^*)$, $Y(\widetilde{T}) > Y^*$: overshooting of the long term accumulation target, to compensate for the weakness of the carbon tax.

Second best policy with a constant carbon tax and a FIP

Carbon and clean era

(i) The optimal trajectory cannot be implemented.

(ii) At each $\widetilde{\tau}$ corresponds a second best carbon value ζ_1 following the Hotelling rule; $\zeta_1(0)$ decreasing function of $\widetilde{\tau}$.

Carbon pricing gap: difference between the second best carbon value and the effective constant carbon tax, $\zeta_1(0)e^{\rho t} - \widetilde{\tau}$

(iii) Optimal date of the switch to the clean era $\widetilde{T}$ s.t. marginal benefit of delaying fossil phase-out = 0.
Implies the continuity of the private value of green capital μ_d at the date of fossil phase-out.

Second best policy with a constant carbon tax and a FIP

Carbon and clean era,
the policy depends on the level of the carbon tax

(iv)

a. If $\widetilde{\tau} > \overline{\tau}_2 = u'(Y_0)$, fossil is not used and the optimal FIP is nil.

b. If $\widetilde{\tau} \in (\overline{\tau}_1, \overline{\tau}_2]$, fossil is used, but the carbon pricing gap is always negative and therefore the FIP nil. $\overline{\tau}_1$ is defined by $\overline{\tau}_1 = \zeta_1(0)e^{\rho \widetilde{T}}|_{\overline{\tau}_1}$.

c. If $\widetilde{\tau} \in (\overline{\tau}, \overline{\tau}_1]$, the carbon pricing gap is initially negative and the FIP nil, up to the date T_0 when the carbon pricing gap becomes nil. After T_0 the FIP compensates for the carbon pricing gap:

$$\sigma(t) = \zeta_1(t) - \widetilde{\tau}$$

$\overline{\tau}$ is defined by $\overline{\tau} = \zeta_1(0)|_{\overline{\tau}}$.

d. If $\widetilde{\tau} \in (\underline{\tau}, \overline{\tau}]$, with $\underline{\tau} = u'(Y^*)$, the FIP is positive from the start. Green capital monotonically increases toward Y^*.

e. If $\widetilde{\tau} \in (\underline{\tau}_1, \underline{\tau}]$, the FIP is positive from the start, and there is overshooting of green capital, i.e. $Y(\widetilde{T}) > Y^*$.

f. If $\widetilde{\tau} \leq \underline{\tau}_1$, the FIP is capped at a value σ_{max} to prevent an overshooting so large that it would entail disinvestment in the clean era.

Second best policy with a constant carbon tax and a FIP

- Evolution of the private value of green capital driven by the carbon tax:

$$\dot{\mu}_d(t) = (\rho+\delta)\mu_d(t) - \widetilde{\tau}$$

  Not enough in general.

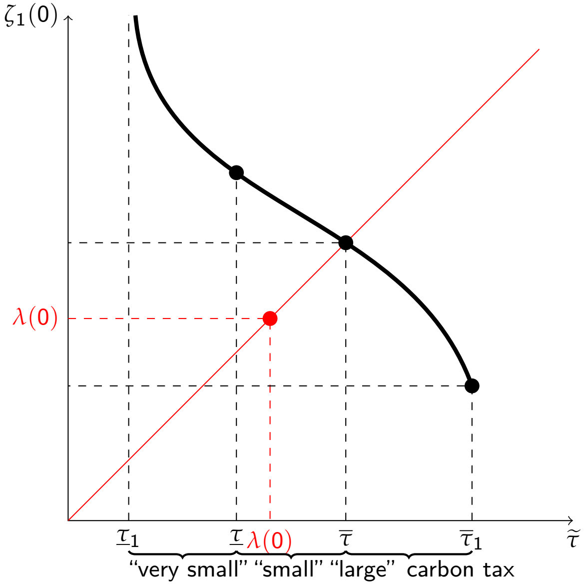
- Evolution of the social value of green capital driven by the second best carbon value:

$$\dot{\zeta}_2(t) = (\rho+\delta)\zeta_2(t) - \zeta_1(0)e^{\rho t}$$

- The difference between the two mirrors the carbon pricing gap.

- "Small" carbon tax, $\widetilde{\tau} \in (\underline{\tau}_1, \overline{\tau}]$: the carbon pricing gap is positive all along, and it has to be filled with the FIP.

- "Large" carbon tax, $\widetilde{\tau} \in (\overline{\tau}, \overline{\tau}_1]$: the carbon pricing gap is initially negative and the FIP nil; it becomes positive at T_0, when the FIP becomes positive as well to fill the gap.



Initial second best carbon value as a function of the carbon tax

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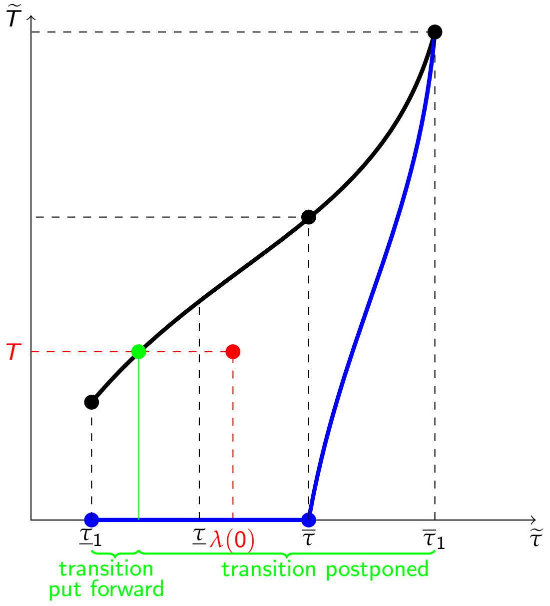

Dates of introduction of the FIP (T_0, blue) and of fossil phase out ($\widetilde{T}$, black) as functions of the carbon tax

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Illustrative numerical application

- CRRA utility function $u(e) = \gamma \frac{e^{1-\frac{1}{\epsilon}}}{1-\frac{1}{\epsilon}}$
- Quadratic investment costs with learning by doing $C(I) = c_1(Y)I + \frac{1}{2}c_2 I^2$ with $c_1(Y) = c_1 Y^{-\beta}$
  → optimal FIP:

$$\sigma(t) = \underbrace{\zeta_1(t) - \widetilde{\tau}}_{\text{carbon pricing gap}} + \underbrace{(-c_1'(Y(t)))I(t)}_{\text{LbD externality subsidy}}$$

- Constant unit extraction cost of fossil fuels c_x
- Renewable capacity Y (GW) → production ϕY (GWh)

Calibration (to be improved) to the European Union energy transition

parameters

Illustrative numerical application to the European Union

	$\lambda(0), \widetilde{\tau}$ €/tCO$_2$	$\zeta_1(0)$ €/tCO$_2$	T_0 years	T, $\widetilde{T}$ years	w %	b %
Optimum	100			31		13.1
SB, large $\widetilde{\tau}$	190	44	49	58	1	6.6
SB, very small $\widetilde{\tau}$	117	122	0	43	1.8	-31.5

For purpose of comparison: $\lambda(T) \Rightarrow 253$ €/tCO$_2$

Welfare cost of acceptability, w: welfare loss at SB compared to optimum (constant additional electricity consumption making households indifferent)

Cost of the SB policy in terms of public budget, b: present value of additional lump sum taxes or transfers in % of the present value of electricity consumption, over the carbon era

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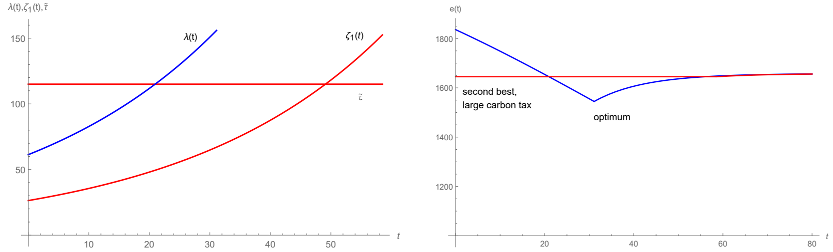
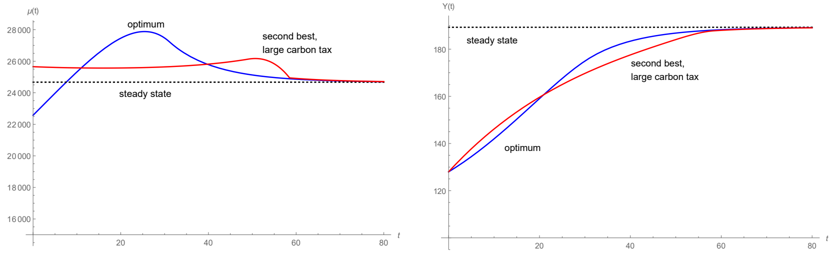


carbon value, carbon tax

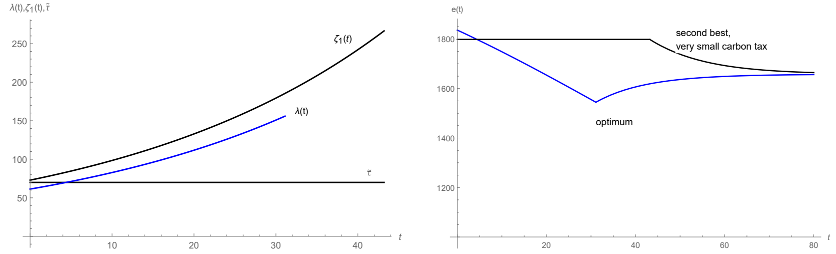
electricity consumption



social and private value of green capital

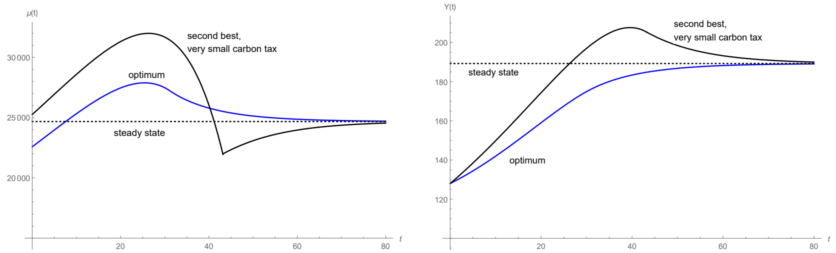
green capital

Optimal vs SB policy with large carbon tax



carbon value, carbon tax

electricity consumption



social and private value of green capital

green capital

Optimal vs SB policy with very small carbon tax

Conclusion

- Confronted with political opposition to the implementation of an efficient direct carbon pricing, policy makers rely on alternative instruments, in particular subsidies to renewables.
- We explore the consequences of this acceptability constraint.
- We compute the carbon pricing gap.
- We evaluate the performance of policy packages (constant carbon tax + subsidies to renewables) in terms of welfare and cost to the public budget.
- We find that if the constant carbon tax is “large” the costs are small, but that for “small” carbon taxes they become large.
- Key mechanism: if fossils cannot be expelled from the market by carbon pricing it is optimal to over-accumulate renewables, which have zero marginal cost (base load), so that residual demand, served by fossils (peak load) decreases.
- Key issue: small carbon tax ⇒ small electricity price in the carbon era ⇒ high electricity consumption; subsidies to renewables do not tackle directly the issue of limiting fossil use and cannot address this problem.

Extensions

- Energy efficiency improvements and increase in electricity uses (transport, housing)
- Other policy instruments, like clean technology standards
- Extension of the model to heterogenous households, to study the distributive consequences of the policy packages

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Thank you !

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