

Meeting Climate Targets: The Optimal Fiscal Policy Mix

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DIW Berlin

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 - A carbon tax fosters both green R&D and learning, but excessive use is costly.
- ⇒ **What is the optimal fiscal mix to support the transition to net-zero emissions?**

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 - (ii) Types of labor hard to distinguish. (Vona et al., 2019; Scholl et a., 2023)

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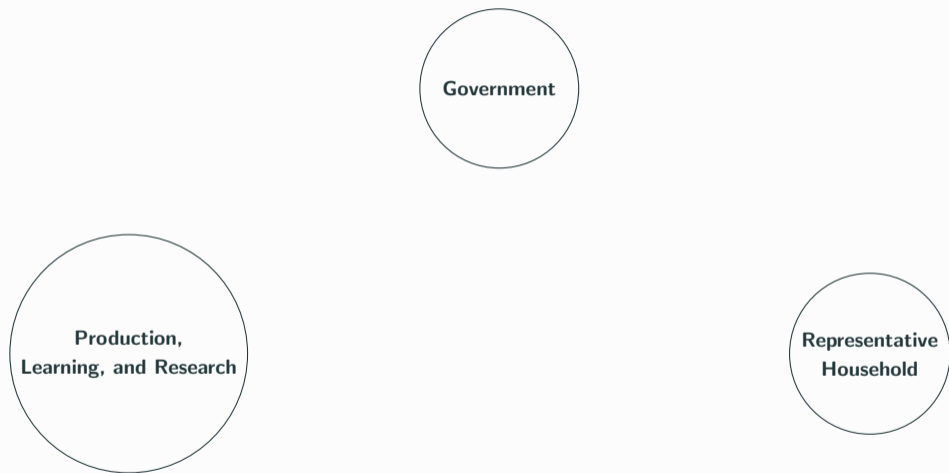
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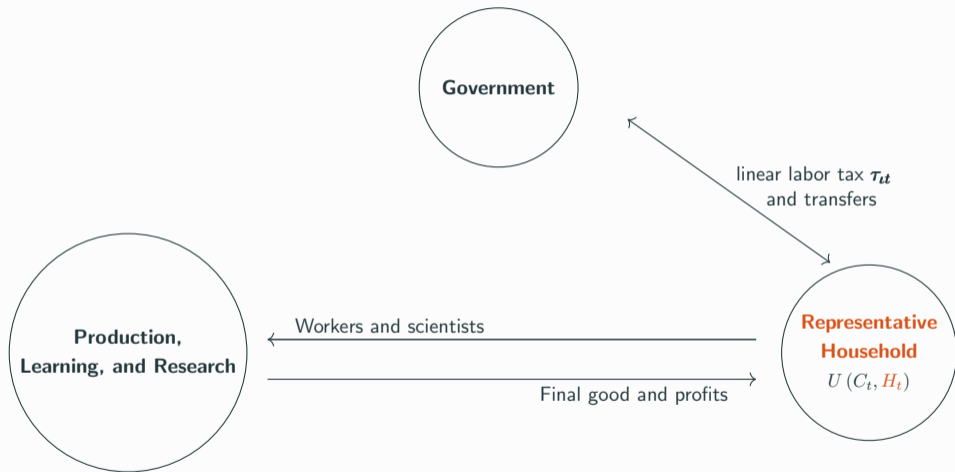
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 - In the long run, the carbon tax exceeds the social cost of carbon to boost green learning-by-doing and research.
 - In the short-run, when the green sector is still relatively unproductive, the carbon tax falls short of the social cost of carbon.
 - Labor income taxes are lowered in all periods to foster especially green learning-by-doing.

Model

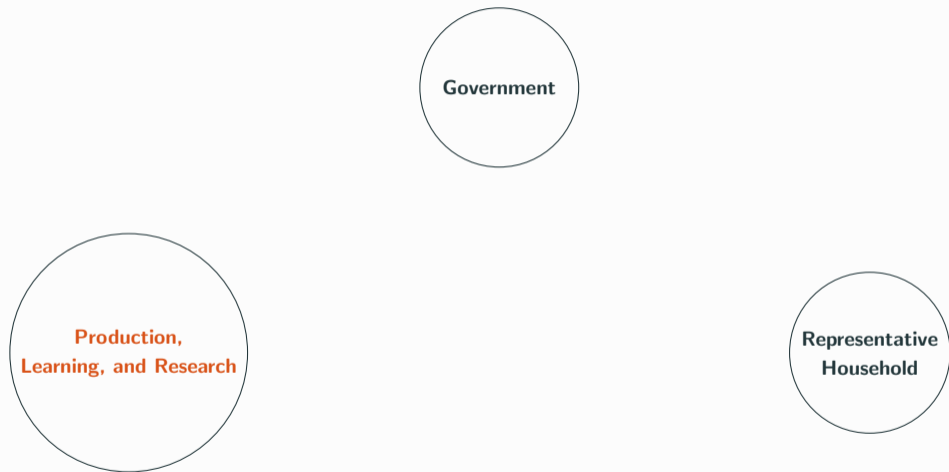
Model



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Production: final and energy good

$$\text{Final good} \quad Y_t = \left(\delta_y^{\frac{1}{\varepsilon_y}} E_t^{\frac{\varepsilon_y-1}{\varepsilon_y}} + (1 - \delta_y)^{\frac{1}{\varepsilon_y}} N_t^{\frac{\varepsilon_y-1}{\varepsilon_y}} \right)^{\frac{\varepsilon_y}{\varepsilon_y-1}}$$

$$\text{Energy} \quad E_t = \left(F_t^{\frac{\varepsilon_e-1}{\varepsilon_e}} + G_t^{\frac{\varepsilon_e-1}{\varepsilon_e}} \right)^{\frac{\varepsilon_e}{\varepsilon_e-1}}$$

$$\text{Demand energy producers} \quad \frac{F_t}{G_t} = \left(\frac{p_{Gt}}{p_{Ft} + \tau_{Ft}} \right)^{\varepsilon_e}$$

F_t : fossil energy

p_{Gt} : price green

δ_y : weight on energy

G_t : green energy

p_{Ft} : price fossil

ε_y : elasticity of substitution E_t and N_t

N_t : non-energy

τ_{Ft} : carbon tax

ε_e : elasticity of substitution F_t and G_t

Production: intermediate goods $J \in \{N(\text{on} - \text{energy}), F(\text{ossil}), G(\text{reen})\}$

$$\max_{\{x_{Jit}\}_{i=0}^1, l_{Jt}} p_{Jt} J_t - w_t l_{Jt} - \int_0^1 p_{x_{Jit}} x_{Jit} di$$

$$\text{s.t. } J_t = l_{Jt}^{1-\alpha_J} \int_0^1 A_{Jit}^{1-\alpha_J} x_{Jit}^{\alpha_J} di$$

l_{Jt} : labor

x_{Jit} : machines

$p_{x_{Jit}}$: price machine

A_{Jit} : productivity

machine i

J : sector N, F, or G

w_t : wage labor

α_J : capital share

Production: machines and innovation

$$\max_{p_{xJit}, s_{Jit}} p_{xJit}(1 + \zeta_{Jt})x_{Jit} - x_{Jit} - w_{st}(1 - \tau_{sJt})s_{Jit}$$

$$\text{s.t. (1) } x_{Jit} = \left(\frac{\alpha_J p_{Jt}}{p_{xJit}} \right)^{\frac{1}{1-\alpha_J}} l_{Jt} A_{Jit}$$

$$(2) A_{Jit} = Q_{Jt}^{\iota_L} K_{Jt}^{\iota_K}$$

- monopolistic competition
- one-period patents

ζ_{Jt} : subsidy machines
 p_{xJit} : price machine
 w_{st} : wage scientists
 τ_{sJt} : research subsidy

s_{Jit} : scientists
 A_{Jit} : productivity machine i
 K_{Jit} : knowledge stock firm Ji
 Q_J : expertise in J
 ι_K and ι_L : elasticity of technology

Learning-by-doing

$$A_{Jit} = Q_{Jit}^{\iota_L} K_{Jit}^{\iota_K}$$

$$Q_{Jit} = Q_{Jit-1} + J_{it-1}$$

- Expertise increases with output (Fischer and Newell, 2008)
- $\iota_L < 1 \Rightarrow$ Less mature sectors learn more quickly

A_{Jit} : productivity firm i in J

K_{Jit} : technology firm i in J

J_{it} : Output firm i in sector J

Q_{Jit} : workers' expertise in firm i in J

ι_L : elasticity of productivity to expertise

ι_K : elasticity of productivity to technology

Knowledge

$$K_{Jit} = K_{Jt-1} \left(1 + \gamma \left(\frac{s_{Jit}}{\rho_J} \right)^\eta \left(\frac{K_{t-1}}{K_{Jt-1}} \right)^\phi \right)$$

1. **within-sector knowledge spillovers** ("Path dependency" e.g. Acemoglu et al., 2012; Aghion et al., 2016)

K_{Jt} : sector-specific knowledge

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γ : productivity of scientists

ρ_J : number of research processes in sector J

η : returns to research

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2. decreasing returns to research, $\eta < 1$ (“Stepping on toes” e.g. Jones and Williams, 1998)
3. **cross-sectoral knowledge spillovers** (e.g. Aghion et al., 2016; Hart, 2019; Barbieri et al., 2023)

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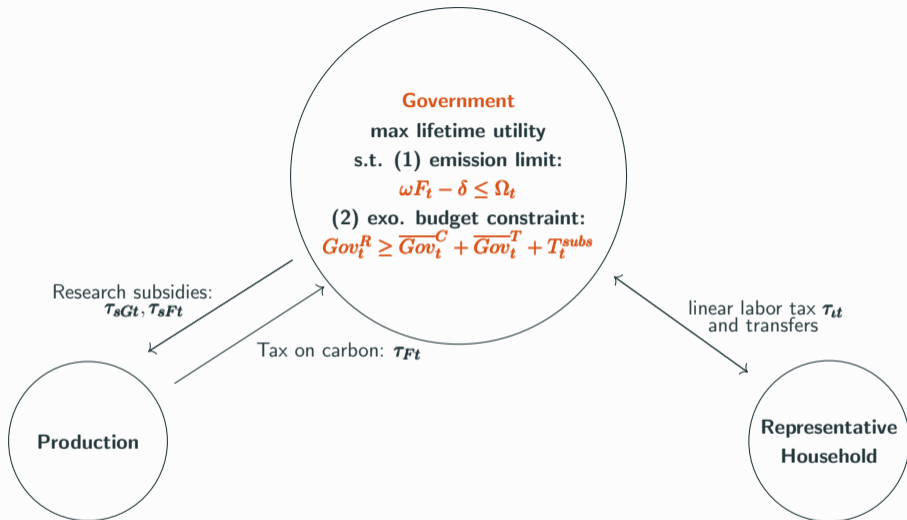
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Model



Ω_t : emission limit
 ω : emissions per F
 δ : carbon sinks

$Gov_t^R = \tau_{lt} w_t H_t + \tau_{Ft} F_t$
 \overline{Gov}_t^C : gov. consumption
 \overline{Gov}_t^T : gov. minimum transfers

$T_t^{subs} =$
 $\tau_{sFt} w_{st} S_{ft} + \tau_{sGt} w_{st} S_{Gt}$

Calibration

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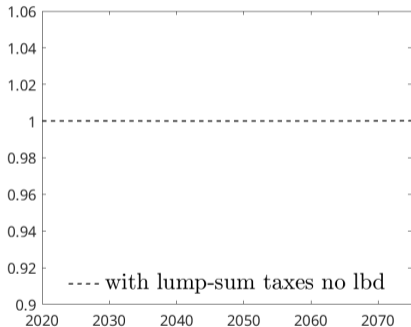
- Calibration to the US in 2015-2019
- Emission limit
 - **global** CO₂ emissions consistent with 2°C climate target (IPCC AR6)
 - **equal-per-capita** distribution of emissions across economies (UN population projections)
- Important parameters → all parameters, → evolution of knowledge

Parameter	Value	Meaning	Target	Literature
η	0.41	returns to research	} growth in knowledge stocks (PATSTAT) and R&D investment (NCSES)	0.1879 (Hart, 2019)
				0.79 (Fried, 2018)
ϕ	0.62	cross-sector knowledge spillovers		0.1 (Hart, 2019)
				0.3124 (Aghion et al., 2016)
$\frac{K_{G0}}{K_{F0}}$	0.67	relative knowledge stock		0.5 (Fried, 2018)
ι_L	0.15	elasticity of productivity to expertise	Fischer and Newell (2008)	0.4 (Fried, 2018)
				0.68 (Acemoglu et al., 2016)

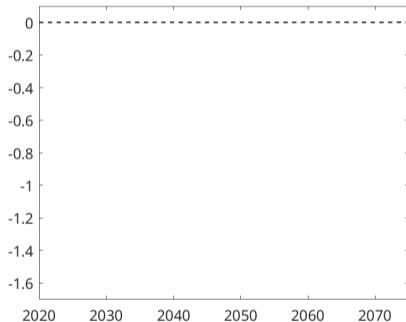
Results

The Optimal Fiscal Mix

(a) Carbon versus Pigouvian Tax



(b) Labor income tax
change to no-target in % pt.

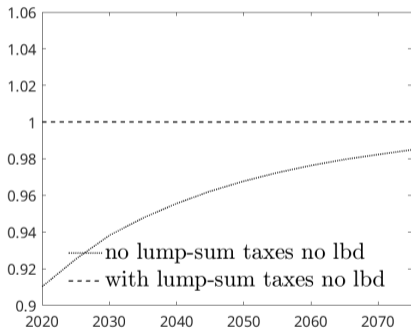


- To support green learning, the government raises carbon taxes above Pigouvian taxes and cuts labor taxes more.

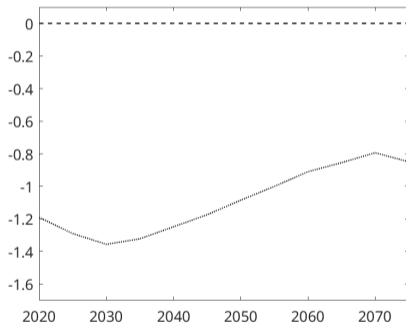
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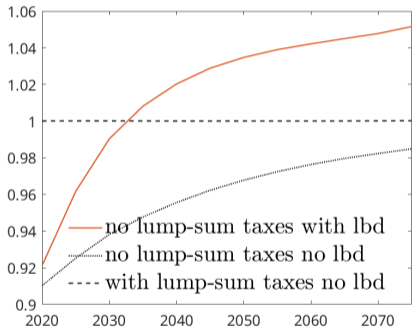


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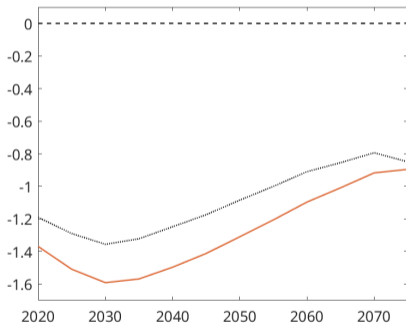
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→ learning, → levels, → ls and no lbd, → lump-sum financed research subsidies

Conclusion

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- I study the optimal fiscal mix to support implementing emission targets with learning-by-doing and directed technical change.
- The optimal fiscal mix internalizes its effect on learning-by-doing and research:
 - Labor income taxes are diminished, and the fiscal mix relies more on carbon taxes.
 - In the long run, carbon taxes exceed the Pigouvian tax to boost green learning-by-doing and energy research.

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Effect of carbon tax on the allocation of scientists

$$\overbrace{\psi_F p_F F \frac{\partial A_F}{\partial s_F}}^{\text{wage fossil scientists}} = \overbrace{\psi_G p_G G \frac{\partial A_G}{\partial s_G}}^{\text{wage green scientists}}$$

$p_J J$: revenues sector J

ψ_J : sector-specific constant

A_J : productivity sector J

s_J : scientists sector J

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- carbon tax lowers wages of fossil researchers and raises wages of green researchers

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 \underbrace{\psi_F \underbrace{p_F F}_{\tau_F \uparrow \Rightarrow \downarrow} \underbrace{\frac{\partial A_F}{\partial s_F}}_{s_F \downarrow \Rightarrow \uparrow}}_{=} & = & \underbrace{\psi_G \underbrace{p_G G}_{\tau_F \uparrow \Rightarrow \uparrow} \underbrace{\frac{\partial A_G}{\partial s_G}}_{s_G \uparrow \Rightarrow \downarrow}}
 \end{array}$$

- carbon tax lowers wages of fossil researchers and raises wages of green researchers
- scientists transition from fossil to green sector (decreasing returns to research)

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In a nutshell: Carbon Tax and Allocation of Research

- Goal of government intervention
 - a) lower emissions
 - b) keep productivity high
- Carbon tax
 - a) reduces emissions by lowering fossil demand
 - b) directs research across sectors
 - if want to foster **green** research \Rightarrow higher carbon tax \Rightarrow costly in terms of output
 - if want to foster **fossil** research \Rightarrow smaller carbon tax \Rightarrow but too high emissions
- Fossil research subsidy used to counter effect of carbon tax on fossil research

Markets

Hours workers $H_t = L_{Ft} + L_{Gt} + L_{Nt}$

Hours scientists $S = \int_0^1 (s_{Fit} + s_{Git} + s_{Nit}) di$

Final good $Y_t = C_t + \int_0^1 (x_{Fit} + x_{Git} + x_{Nit}) di + Gov_t^C$

→ back

Government

$$\max_{\{\tau_{Ft}\}_{t=0}^{\infty}, \{\tau_{Lt}\}_{t=0}^{\infty}, \{\tau_{sFt}\}_{t=0}^{\infty}, \{\tau_{sGt}\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \beta^t \left(\log(C_t) - \chi \frac{H_t^{1+\sigma}}{1+\sigma} \right)$$

- s.t.
- (1) $\overline{Gov}_t^C + \overline{Gov}_t^T + T_t^{subs} = \tau_{it} w_t H_t + \tau_{Ft} F_t$
 - (2) $\omega F_t - \delta \leq \Omega_t$ (dynamic emission target)
 - (3) $T_t^{subs} = \tau_{sGt} w_{st} S_{Gt} + \tau_{sFt} w_{st} S_{Ft}$
 - (4) behavior of firms and households
 - (5) resource constraints

β : household discount factor

\overline{Gov}_t^C : exo. gov. consumption

\overline{Gov}_t^T : exo. gov. transfers

Ω_t : net emission limit

ω : emissions per unit of fossil

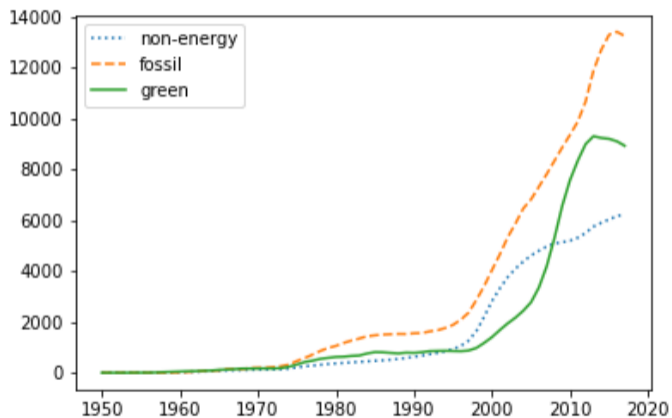
δ : natural carbon sinks (forests, moors)

Model and mechanisms

Learning and Research

- **Concave learning-by-doing**: sectors with low experience learn more quickly.
- Research and knowledge spillovers:
 - **Within-sector spillovers**: more innovation today makes spurs future research.
 - **Cross-sector spillovers**: innovation in one sector stimulates research in others.
 - **Stepping on toes**: diminishing returns to research within each sector favor smooth R&D allocation.
- Learning-by-doing and within-sector knowledge spillovers generate **fossil lock-in**.
- Limited-horizon **patents** justify research subsidies.

Knowledge stocks in the US



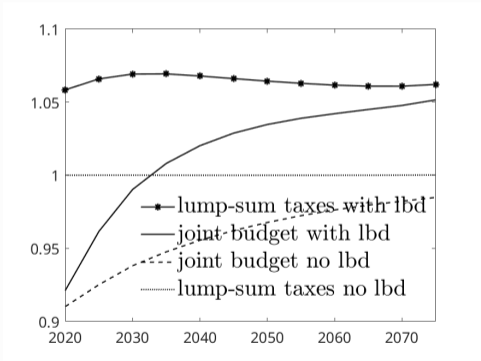
Parameters

Parameter	Target	Value
<i>Household</i>		
σ	Chetty et al. (2011)	1.33
χ	average hours worked per economic time endowment by worker: 0.34 (OECD, 2021)	9.53
Discount factor β	Barrage (2020)	0.93
Working time endowment \bar{H}	14.5 hours per day (Jones et al., 1993)	1.00
S	Fried (2018)	0.003
<i>Research</i>		
Returns to research η	} growth in knowledge stocks and R&D	0.41
Knowledge spillovers ϕ		0.62
Scientists' productivity γ		4.99
Sector size (ρ_F, ρ_G, ρ_N)	Fried (2018)	(0.01, 0.01, 1.00)
Initial knowledge stock (K_{F0}, K_{G0}, K_{N0})	knowledge stock in 2010-2014	(125.38, 100, 63.60)
Expertise (Q_F^k, Q_G^k, Q_N^k)	matching knowledge stock and output	(2.11, 0.85, 1.20)
Elasticity of productivity to knowledge ($\iota_{L,iK}$)	Fischer and Newell (2008)	(0.15, 0.15)
Depreciation knowledge stock (5 years) δ_K	Noailly and Smeets (2015)	0.56
<i>Production</i>		
Elasticities of substitution ($\varepsilon_y, \varepsilon_e$)	Fried (2018), Papageorgiou et al. (2017)	(0.05, 1.50)
Weight on energy in final good δ_y	expenditure share on energy (EIA, 2023)	0.21
Capital shares ($\alpha_F, \alpha_G, \alpha_N$)	BLS and Green Jobs and Compensation of employees	(0.75, 0.86, 0.36)
<i>Government</i>		
Policy instruments ($\tau_{i0}, \tau_{F0}, \tau_{sF0}, \tau_{sG0}$)	Fed St. Louis Gov Expenditures, R&D investment (NCSES)	(0.41, 0, 0.53, 0.32)
<i>Emissions</i>		
Carbon sinks δ	EPA (2022)	3.19
Emissions per fossil energy ω	EPA (2022)	308.56

→ back

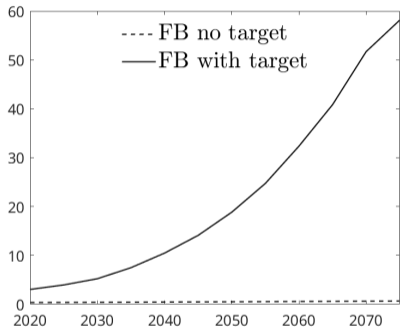
The Optimal Fiscal Mix

(a) Carbon versus Pigouvian Tax

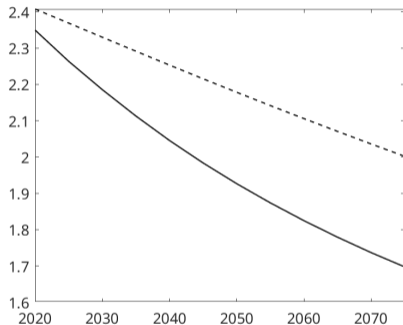


Optimal implementation of the emission target

(a) Green-to-fossil Energy



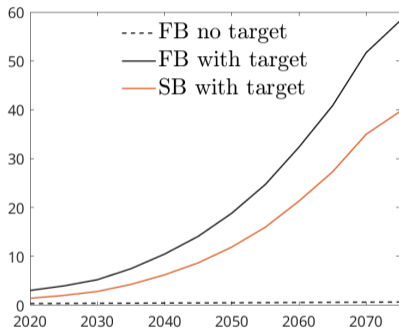
(b) Fossil-to-green expertise



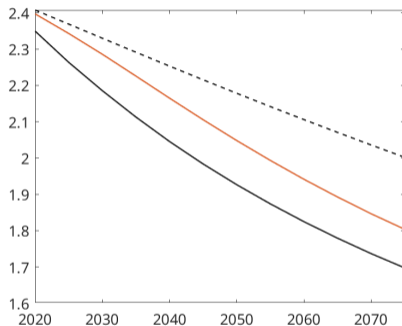
- Rising share of green-to-fossil energy and **more expertise on green technologies**

Optimal implementation of the emission target

(a) Green-to-fossil Energy



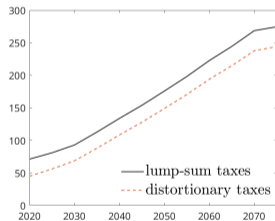
(b) Fossil-to-green expertise



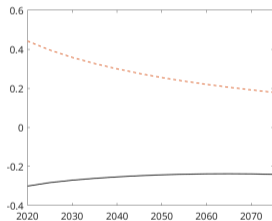
- Rising share of green-to-fossil energy and **more expertise on green technologies**.
- Second-best: Implement target at lower output and higher fossil share \Rightarrow **dampens green learning-by-doing**.

Optimal implementation in levels: lump-sum versus distortionary

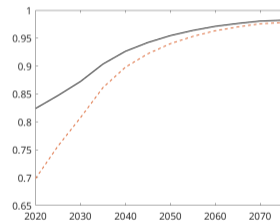
(a) Tax per ton of carbon, 2022 US\$



(b) Labor income tax

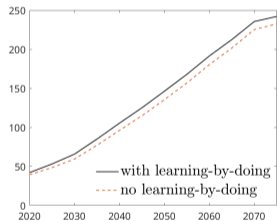


(c) Fossil-to-green subsidy

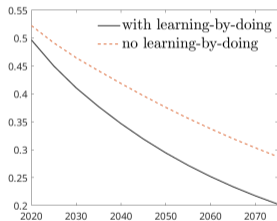


Optimal implementation in levels: learning-by-doing

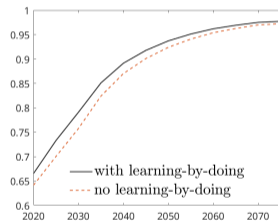
(a) Tax per ton of carbon,
2022 US\$



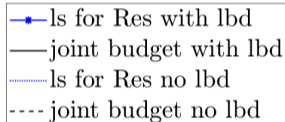
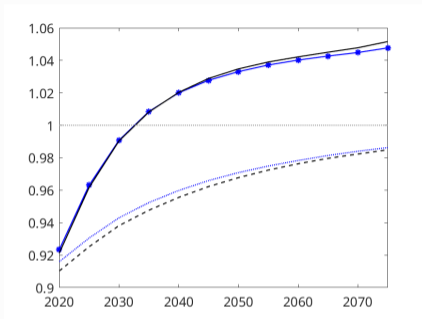
(b) Labor income tax



(c) Fossil-to-green subsidy



With lump-sum financed research subsidies



- When research subsidies have to be financed with distortionary instruments \Rightarrow lower carbon tax to lower fiscal distortions.
- Learning-by-doing explains the excessive carbon tax in the long run;
- Only negligible importance of use of carbon tax to direct research to energy sector (but only when lbd makes labor tax more costly!)