Meeting Climate Targets: The Role of Fossil Research Subsidies

Sonja Dobkowitz
DIW Berlin

FSR Climate Annual Conference 2023, Florence
November 27, 2023

Motivation

- How to best meet emission targets in line with climate goals?

Motivation

- How to best meet emission targets in line with climate goals?
    - On the one hand, reduce the use of fossil fuels,... $\Rightarrow$ carbon tax

Motivation

- How to best meet emission targets in line with climate goals?
  - On the one hand, reduce the use of fossil fuels,... $\Rightarrow$ carbon tax
  - ... while keeping productivity high $\Rightarrow$ green research subsidies

Motivation

- How to best meet emission targets in line with climate goals?
  - On the one hand, reduce the use of fossil fuels,... $\Rightarrow$ carbon tax
  - ... while keeping productivity high $\Rightarrow$ green research subsidies
- Less attention in economic debate: fossil research taxes/ subsidies

Motivation

- How to best meet emission targets in line with climate goals?
    - On the one hand, reduce the use of fossil fuels,... $\Rightarrow$ carbon tax
    - ... while keeping productivity high $\Rightarrow$ green research subsidies
- Less attention in economic debate: fossil research taxes/ subsidies
    - too little new innovation in green sector (IEA, 2020) $\Rightarrow$ tax fossil-related research?

Motivation

- How to best meet emission targets in line with climate goals?
  - On the one hand, reduce the use of fossil fuels,... $\Rightarrow$ carbon tax
  - ... while keeping productivity high $\Rightarrow$ green research subsidies
- Less attention in economic debate: fossil research taxes/ subsidies
  - too little new innovation in green sector (IEA, 2020) $\Rightarrow$ tax fossil-related research?
  - then again:

Motivation

- How to best meet emission targets in line with climate goals?
  - On the one hand, reduce the use of fossil fuels,... $\Rightarrow$ carbon tax
  - ... while keeping productivity high $\Rightarrow$ green research subsidies
- Less attention in economic debate: fossil research taxes/ subsidies
  - too little new innovation in green sector (IEA, 2020) $\Rightarrow$ tax fossil-related research?
  - then again:
    - (i) researchers in established sectors can build on deep pool of knowledge, and

Motivation

- How to best meet emission targets in line with climate goals?
  - On the one hand, reduce the use of fossil fuels,... ⇒ carbon tax
  - ... while keeping productivity high ⇒ green research subsidies
- Less attention in economic debate: fossil research taxes/ subsidies
  - too little new innovation in green sector (IEA, 2020) ⇒ tax fossil-related research?
  - then again:
    - (i) researchers in established sectors can build on deep pool of knowledge, and
    - (ii) non-green knowledge facilitates green innovation tomorrow

Motivation

- How to best meet emission targets in line with climate goals?
  - On the one hand, reduce the use of fossil fuels,... $\Rightarrow$ carbon tax
  - ... while keeping productivity high $\Rightarrow$ green research subsidies
- Less attention in economic debate: fossil research taxes/ subsidies
  - too little new innovation in green sector (IEA, 2020) $\Rightarrow$ tax fossil-related research?
  - then again:
    (i) researchers in established sectors can build on deep pool of knowledge, and
    (ii) non-green knowledge facilitates green innovation tomorrow
    $\Rightarrow$ subsidize fossil-related research?

Motivation

- How to best meet emission targets in line with climate goals?
  - On the one hand, reduce the use of fossil fuels,... $\Rightarrow$ carbon tax
  - ... while keeping productivity high $\Rightarrow$ green research subsidies
- Less attention in economic debate: fossil research taxes/ subsidies
  - too little new innovation in green sector (IEA, 2020) $\Rightarrow$ tax fossil-related research?
  - then again:
    (i) researchers in established sectors can build on deep pool of knowledge, and
    (ii) non-green knowledge facilitates green innovation tomorrow
    $\Rightarrow$ subsidize fossil-related research?
- What is the optimal mix of research and carbon taxes to meet emission targets?

This paper

- Quantitative model building on Fried (2018) calibrated to the US 2015-2019

This paper

- Quantitative model building on Fried (2018) calibrated to the US 2015-2019
  - three research sectors: green, fossil, and non-energy sector

This paper

- Quantitative model building on Fried (2018) calibrated to the US 2015-2019
  - three research sectors: green, fossil, and non-energy sector
  - knowledge spillovers:

This paper

- Quantitative model building on Fried (2018) calibrated to the US 2015-2019
  - three research sectors: green, fossil, and non-energy sector
  - knowledge spillovers:
    a) within sector: researchers learn from knowledge accumulated in their sector

This paper

- Quantitative model building on Fried (2018) calibrated to the US 2015-2019
  - three research sectors: green, fossil, and non-energy sector
  - knowledge spillovers:
    a) within sector: researchers learn from knowledge accumulated in their sector
    b) cross sector: knowledge generated in sector A stimulates innovation in sector B

This paper

- Quantitative model building on Fried (2018) calibrated to the US 2015-2019
  - three research sectors: green, fossil, and non-energy sector
  - knowledge spillovers:
    a) within sector: researchers learn from knowledge accumulated in their sector
    b) cross sector: knowledge generated in sector A stimulates innovation in sector B
- The government chooses the path of carbon taxes and green and fossil research subsidies to maximize welfare.

This paper

- Quantitative model building on Fried (2018) calibrated to the US 2015-2019
  - three research sectors: green, fossil, and non-energy sector
  - knowledge spillovers:
    a) within sector: researchers learn from knowledge accumulated in their sector
    b) cross sector: knowledge generated in sector A stimulates innovation in sector B
- The government chooses the path of carbon taxes and green and fossil research subsidies to maximize welfare.
- An emission limit constrains the government.

Preview of results

- A **fossil research subsidy** optimally complements carbon taxes and green research subsidies.

Preview of results

- A **fossil research subsidy** optimally complements carbon taxes and green research subsidies.
- A fossil research subsidy rises social welfare equivalently to a permanent 3.8% rise in consumption.

Preview of results

- A **fossil research subsidy** optimally complements carbon taxes and green research subsidies.
- A fossil research subsidy rises social welfare equivalently to a permanent 3.8% rise in consumption.
  - Gains: higher technology growth in the future

Preview of results

- A **fossil research subsidy** optimally complements carbon taxes and green research subsidies.
- A fossil research subsidy rises social welfare equivalently to a permanent 3.8% rise in consumption.
  - Gains: higher technology growth in the future
  - Costs: less consumption today due to lower green growth initially

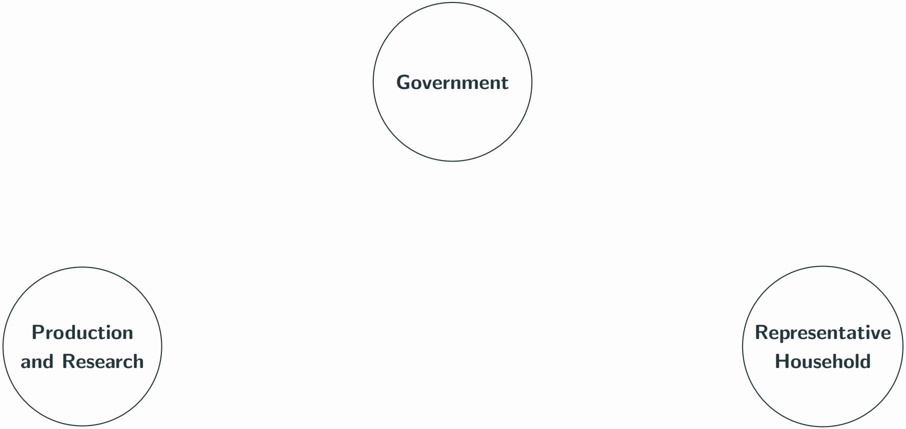
Preview of results

- A **fossil research subsidy** optimally complements carbon taxes and green research subsidies.
- A fossil research subsidy rises social welfare equivalently to a permanent 3.8% rise in consumption.
  - Gains: higher technology growth in the future
  - Costs: less consumption today due to lower green growth initially
- **Cross-sectoral knowledge spillovers are key**: absent such spillovers, we should stop fossil research immediately.

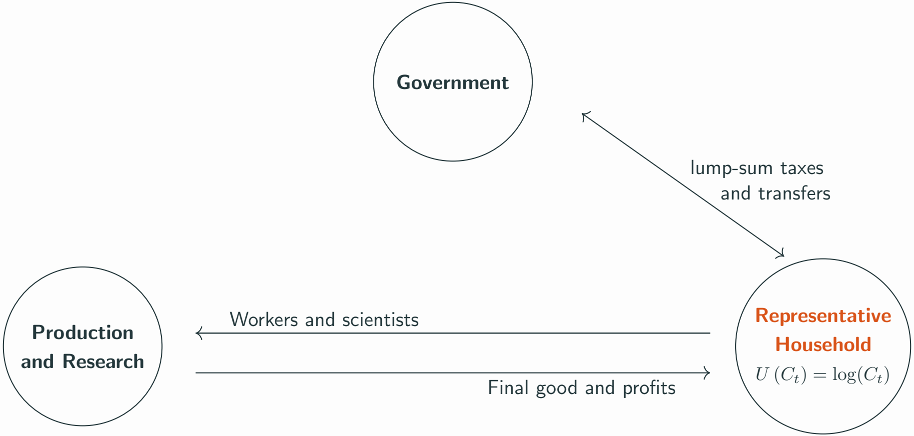
Outline

Model

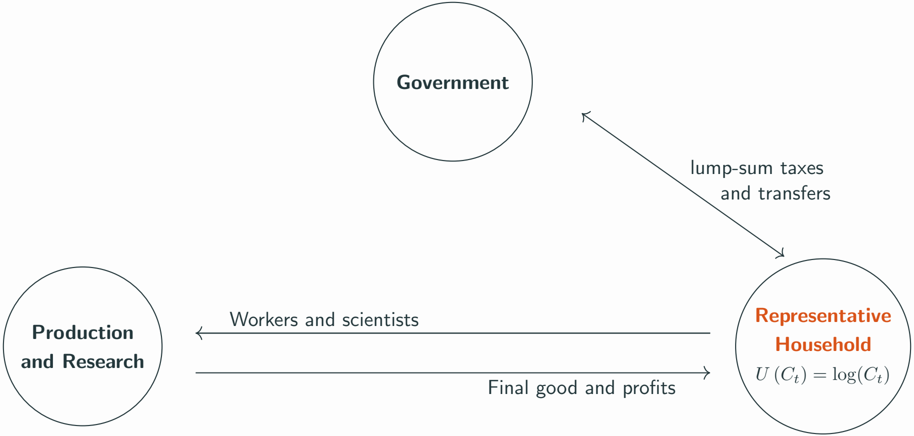
Model


Government
Production
and Research
Representative
Household

Model

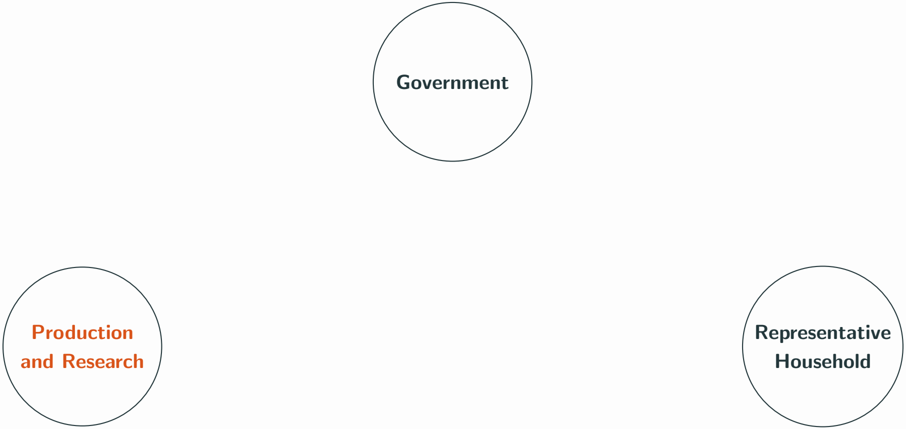

Government
lump-sum taxes
and transfers
Production
and Research
Workers and scientists
Final good and profits
Representative
Household
$U(C_t) = \log(C_t)$

Model



- Markets clear → formal

Model


Government
Production and Research
Representative Household

Production: final and energy good

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

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

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

F_t: fossil energy
G_t: green energy
N_t: non-energy

p_{Gt}: price green
p_{Ft}: price fossil
τ_{Ft}: carbon tax

δ_y: weight on energy
ε_y: elasticity of substitution E_t and N_t
ε_e: elasticity of substitution F_t and G_t

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

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

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

l_{Jt} : labor

x_{Jit} : machines

p_{xJit}: 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

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

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

$$(2)\; A_{Jit} = f_{Jt}(s_{Jit})$$

- monopolistic competition
- one-period patents

ζ_{Jt}: subsidy machines
p_{xJit}: price machine
A_{Jit}: productivity machine i

w_{st}: wage scientists
τ_{sJt}: research subsidy
s_{Jit}: scientists

Innovation

Innovation

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

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

A_{Jt}: sector-specific knowledge

A_t: aggregate knowledge

γ : productivity of scientists

ρ_J: number of research processes in sector J

η : returns to research

ϕ : relative importance knowledge spillovers

Innovation

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

1. within-sector knowledge spillovers ("Path dependency" e.g. Acemoglu et al., 2012; Aghion et al., 2016)
2. decreasing returns to research, $\eta < 1$ ("Stepping on toes" e.g. Jones and Williams, 1998)

A_{Jt}: sector-specific knowledge

A_t: aggregate knowledge

γ : productivity of scientists

ρ_J: number of research processes in sector J

η : returns to research

ϕ : relative importance knowledge spillovers

Innovation

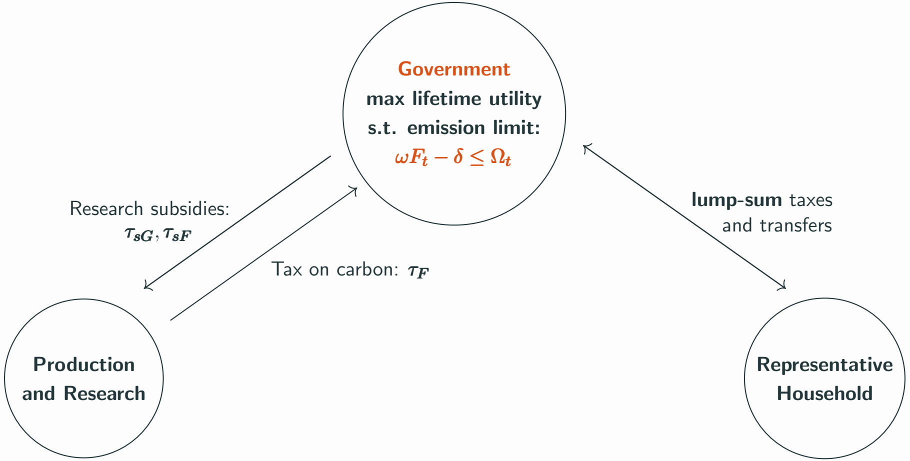
$$A_{Jit} = A_{Jt-1}\left(1 + \gamma \left(\frac{s_{Jit}}{\rho_J}\right)^{\eta} \left(\frac{A_{t-1}}{A_{Jt-1}}\right)^{\phi}\right)$$

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

A_{Jt}: sector-specific knowledge
A_t: aggregate knowledge
γ : productivity of scientists

ρ_J: number of research processes in sector J
η : returns to research
ϕ : relative importance knowledge spillovers

Model



Ω_t: emission limit $\quad$ ω : emissions per F $\quad$ δ : natural carbon sinks

→ formal

Calibration

Calibration

- Calibration to the US in 2015-2019

Calibration

- Calibration to the US in 2015-2019
- Emission limit → graph

Calibration

- Calibration to the US in 2015-2019
- Emission limit → graph
  - **global** CO_2 emissions consistent with $1.5°$C climate target from IPCC AR6

Calibration

- Calibration to the US in 2015-2019
- Emission limit → graph
  - **global** CO_2 emissions consistent with $1.5°$C climate target from IPCC AR6
  - **equal-per-capita** distribution of emissions

Calibration

- Calibration to the US in 2015-2019
- Emission limit → graph
  - **global** CO_2 emissions consistent with $1.5°$C climate target from IPCC AR6
  - **equal-per-capita** distribution of emissions
- Important parameters → all parameters

Calibration

- Calibration to the US in 2015-2019
- Emission limit → graph
  - **global** CO_2 emissions consistent with $1.5°C$ climate target from IPCC AR6
  - **equal-per-capita** distribution of emissions
- Important parameters → all parameters

Calibration

- Calibration to the US in 2015-2019
- Emission limit → graph
  - **global** CO_2 emissions consistent with $1.5°$C climate target from IPCC AR6
  - **equal-per-capita** distribution of emissions
- Important parameters → all parameters

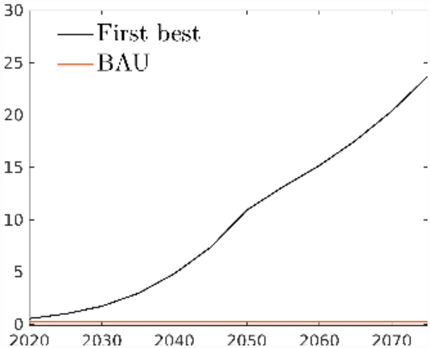
Parameter	Value	Meaning	Target	Literature
η	0.61	returns to research	R&D investment in fossil sectors (NCSES)	0.1879 (Hart, 2019) 0.79 (Fried, 2018)
ϕ	0.11	cross-sector knowledge spillovers	growth in green energy patents (EPO, 2021)	0.1 (Hart, 2019) 0.3124 (Aghion et al., 2016)
$\frac{A_{G0}}{A_{F0}}$	0.02	relative knowledge stock	fossil energy share in output (EIA, 2023)	0.4 (Fried, 2018) 0.68 (Acemoglu et al., 2016)

Results

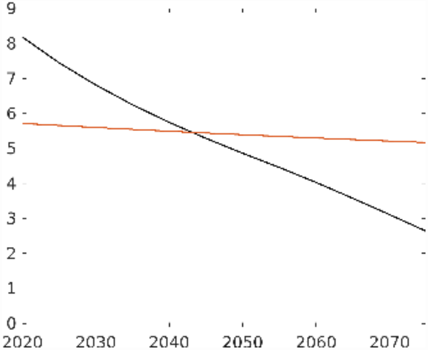
First-best and business-as-usual allocation

First-best and business-as-usual allocation

(a) Green-to-fossil energy ratio



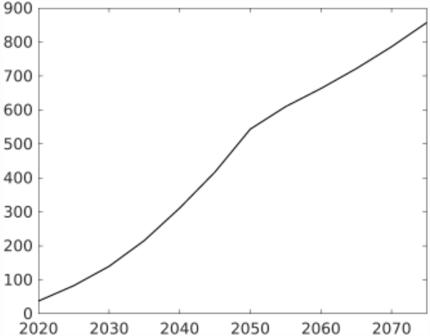
(b) Fossil-to-green research



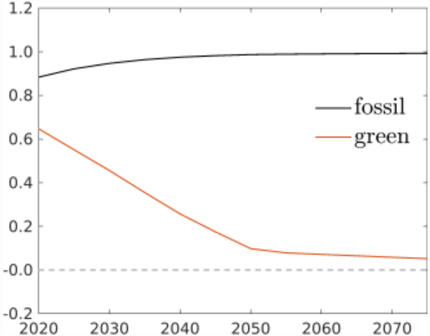
- rising share of green-to-fossil energy
- **smooth** reduction in share of fossil researchers

Optimal Policy

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



(b) Research subsidies



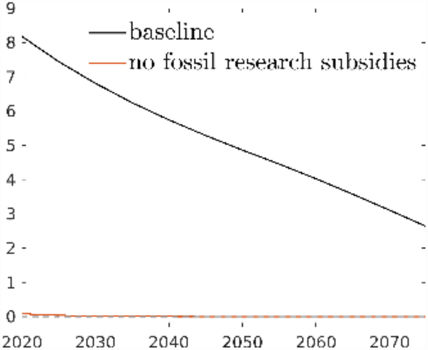
- high and increasing carbon tax (Barrage (2020): carbon tax between 100 and 800 US$)
- high fossil research subsidies

→ renormalized subsidies, → no target

Gains and costs of fossil research subsidy

Gains and costs of fossil research subsidy

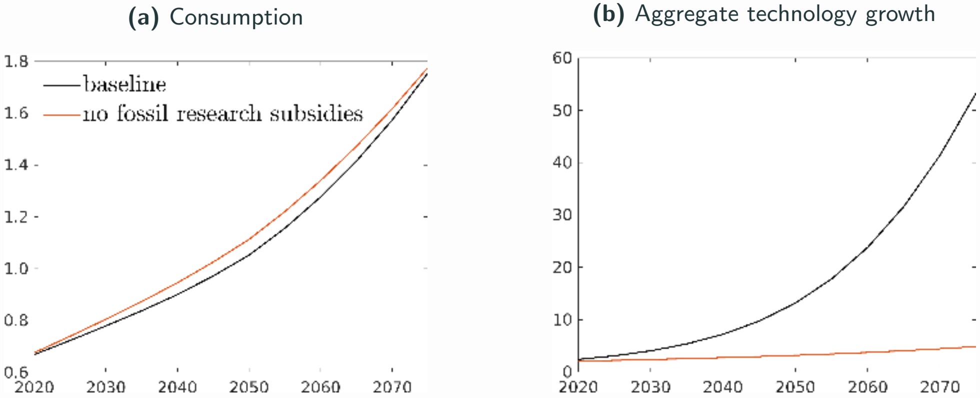
Figure: Fossil-to-green research



- without fossil tax, no fossil research activity anymore
- dilemma: carbon tax directs research away from fossil sector

→ effect carbon tax

Gains and costs of fossil research subsidy

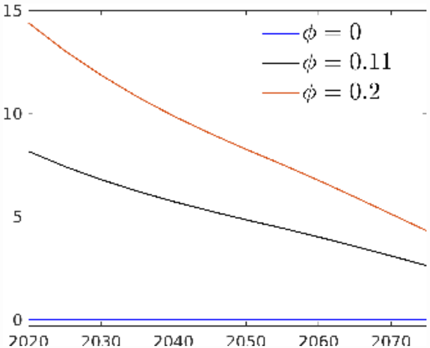


- reduce consumption today to profit from higher growth tomorrow
- total welfare gains: CEV of 3.8%. Costs in initial 100 years: CEV of -0.6%

→ additional graphs

Cross-sectoral knowledge spillovers are key

Figure: Fossil-to-green research



- knowledge spillovers allow to profit from otherwise "stranded assets"
- absent cross-sectoral spillovers, we should stop fossil research immediately

→ robustness

Conclusion

Conclusion

- I study the optimal mix of taxes on carbon and research subsidies to meet emission targets.

Conclusion

- I study the optimal mix of taxes on carbon and research subsidies to meet emission targets.
- Fossil research subsidies complement the environmental policy to profit from otherwise "stranded assets" in the form of fossil-related knowledge.

Conclusion

- I study the optimal mix of taxes on carbon and research subsidies to meet emission targets.
- Fossil research subsidies complement the environmental policy to profit from otherwise "stranded assets" in the form of fossil-related knowledge.
- Cross-sectoral knowledge spillovers are key to this result.

References

Acemoglu, D., Aghion, P., Bursztyn, L., and Hemous, D. (2012). The environment and directed technical change. *American Economic Review*, 102(1):131–166.

Acemoglu, D., Akcigit, U., Hanley, D., and Kerr, W. (2016). Transition to Clean Technology. *Journal of Political Economy*.

Aghion, P., Dechezleprê, A., Hé, D., Martin, R., Reenen, J. V., Acemoglu, D., Burgess, R., Greenstone, M., Hassler, J., Henderson, R., and Judd, K. (2016). Carbon Taxes, Path Dependency, and Directed Technical Change: Evidence from the Auto Industry. *Journal of Political Economy*, 124(1).

Barbieri, N., Marzucchi, A., and Rizzo, U. (2023). Green technologies, interdependencies, and policy. *Journal of Environmental Economics and Management*, 118.

Barrage, L. (2020). Optimal Dynamic Carbon Taxes in a Climate-Economy Model with Distortionary Fiscal Policy. *Review of Economic Studies*, 124(2):1–39.

EIA (2023). Monthly Energy Review August 2023. `https://www.eia.gov/totalenergy/data/monthly/`, (Accessed on 06 September 2023).

Fried, S. (2018). Climate policy and innovation: A quantitative macroeconomic analysis. *American Economic Journal: Macroeconomics*, 10(1):90–118.

Hart, R. (2019). The Association of Environmental and Resource Economists. *The Association of Environmental and Resource Economists*, 6:135–175.

Jones, C. I. and Williams, J. C. (1998). Measuring the Social Return to R&D. *The Quarterly Journal of Economics*, 113(4):1119–1135.

Jones, L. E., Manuelli, R. E., and Rossi, P. E. (1993). Optimal Taxation in Models of Endogenous Growth. *Journal of Political Economy*, 101(3):485–517.

United States Environmental Protection Agency (EPA) (2022). Trends in Greenhouse Gas Emissions. `https://nepis.epa.gov/Exe/ZyPDF.cgi/P1011XV3.PDF?Dockey=P1011XV3.PDF` (Accessed on 02 February 2022).

Van Vuuren, D. P., Stehfest, E., Gernaat, D. E., Van Den Berg, M., Bijl, D. L., De Boer, H. S., Daioglou, V., Doelman, J. C., Edelenbosch, O. Y., Harmsen, M., Hof, A. F., and Van Sluisveld, M. A. (2018). Alternative pathways to the 1.5 °c target reduce the need for negative emission technologies. *Nature Climate Change*, 8(5):391–397.

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

Effect of carbon tax on the allocation of scientists

$$\overbrace{\psi_F \underbrace{p_F F}_{\color{orange}\tau_F\uparrow\Rightarrow\downarrow} \frac{\partial A_F}{\partial s_F}}^{\text{wage fossil scientists}} < \overbrace{\psi_G \underbrace{p_G G}_{\color{orange}\tau_F\uparrow\Rightarrow\uparrow} \frac{\partial A_G}{\partial s_G}}^{\text{wage green scientists}}$$

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

$p_J J$: revenues sector J

ψ_J : sector-specific constant

A_J: productivity sector J

s_J : scientists sector J

Effect of carbon tax on the allocation of scientists

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

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

$p_J J$: revenues sector J

ψ_J : sector-specific constant

A_J: productivity sector J

s_J : scientists sector J

$\rightarrow$ back

In a nutshell: Government trade-off and instruments

- 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

$\rightarrow$ back

Why is targeting fossil research important to efficiently lower emissions? $\Rightarrow$ introducing a third research sector makes these instruments necessary. Mimiking fossil research taxes with carbon and green research subsidies would

- fossil tax: allows to push reserach away from fossil sector while not distorting non-energy research (biggest research area)
- fossil subsidy: foster fossil research while not increasing non-energy research

Government

$$\max_{\{\tau_{Ft}\}_{t=0}^{\infty},\{\tau_{sFt}\}_{t=0}^{\infty},\{\tau_{sGt}\}_{t=0}^{\infty}} \quad \sum_{t=0}^{\infty} \beta^t \log\left(C_t\right)$$

s.t. (1) $T_t = \tau_{Ft} F_t + T_{\pi t}(\tau_{sGt}, \tau_{sFt})$

(2) behavior of firms and households

(3) resource constraints

β : household discount factor

T_π: profits minus subsidies from machine producers

Government

$$\max_{\{\tau_{Ft}\}_{t=0}^{\infty},\{\tau_{sFt}\}_{t=0}^{\infty},\{\tau_{sGt}\}_{t=0}^{\infty}} \quad \sum_{t=0}^{\infty} \beta^t \log\left(C_t\right)$$

s.t. (1) $T_t = \tau_{Ft} F_t + T_{\pi t}(\tau_{sGt}, \tau_{sFt})$

(2) behavior of firms and households

(3) resource constraints

(4) $\omega F_t - \delta \leq \Omega_t$ (dynamic emission target)

β : household discount factor

T_π: profits minus subsidies from machine producers

Ω_t: net emission limit

ω : emissions per unit of fossil

δ : natural carbon sinks (forests, moors)

→ back

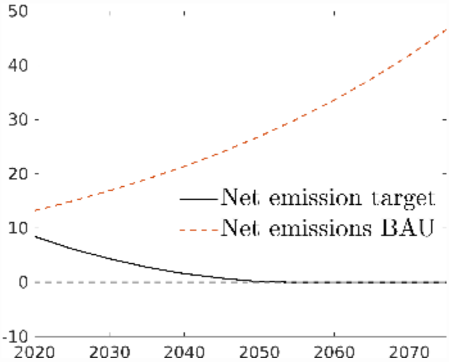
Markets

Hours workers	$H_t = L_{Ft} + L_{Gt} + L_{Nt}$
Hours scientists	$S_t = \int_0^1 (s_{Fit} + s_{Git} + s_{Nit})\, di$
Final good	$Y_t = C_t + \int_0^1 (x_{Fit} + x_{Git} + x_{Nit})\, di$

→ back

Emission target

Figure: Net CO_2 emission target in Gt



→ back

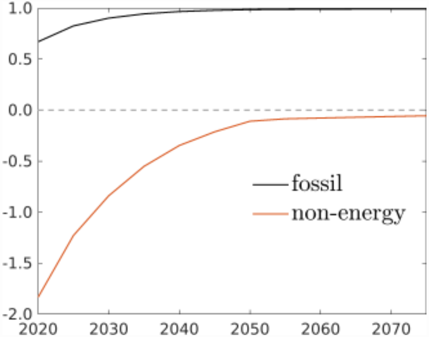
Parameters

Parameter	Value	Target Source
Household		
β	0.93	Barrage (2020)
$\bar{H}$	1.00	14.5 hours per day (Jones et al., 1993)
$\bar{S}$	0.01	share of researchers (Fried, 2018)
Research		
η	0.61	R&D investment in fossil sectors (NCSES)
(ρ_F, ρ_G, ρ_N)	(0.01, 0.01, 1.00)	Fried (2018)
ϕ	0.11	green energy patent growth (EPO, 2021)
γ	1.68	growth in all patents (EPO, 2021)
Production		
$(\varepsilon_y, \varepsilon_e)$	(0.05, 1.50)	Fried (2018)
$(\alpha_F, \alpha_G, \alpha_N)$	(0.75, 0.87, 0.36)	BLS Green Jobs and Compensation of employees by NAICS
δ_y	0.29	energy expenditure share (EIA, 2023)
Initial TFP		
$(A_{F0}^{1-alpha_f}, A_{G0}^{1-alpha_g}, A_{N0}^{1-alpha_n})$	(3.00, 1.11, 0.98)	fossil to green energy output ratio, normalization GDP
Emissions		
δ	3.19	in $GtCO_2$ (EPA, 2022)
ω	211.37	EPA (2022)

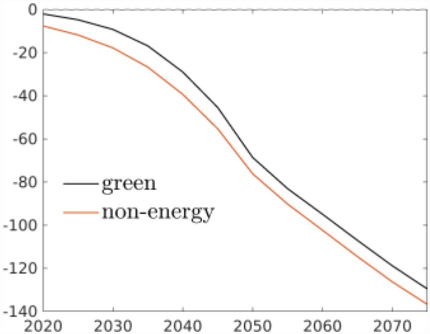
→ back

Optimal Policy

(a) Subsidies relative to green research



(b) Subsidies relative to fossil research

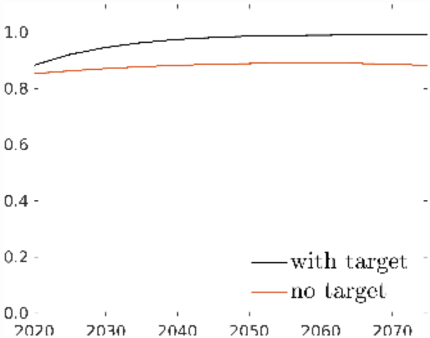


- relative to the green research: fossil research subsidy and non-energy research tax
- relative to fossil research: tax on green and non-energy sector

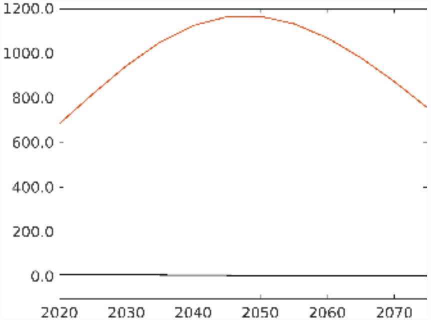
→ back

Optimal policy with and without target

(a) Fossil research subsidy



(b) Fossil-to-green research

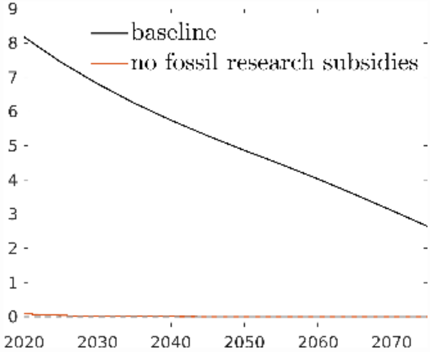


- with target: higher fossil tax to counter carbon tax
- without target: higher share of fossil research

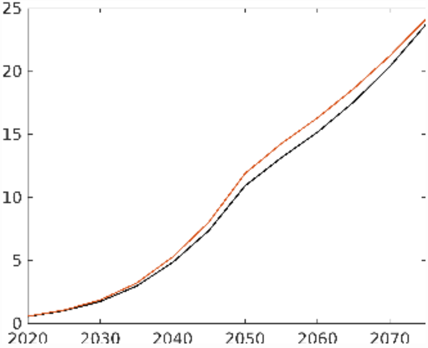
→ back

Gains and costs of fossil research subsidy

(a) Fossil-to-green research



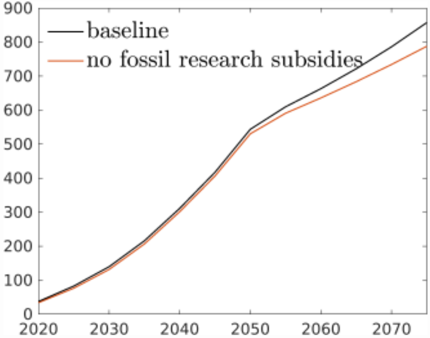
(b) Green-to-fossil energy ratio



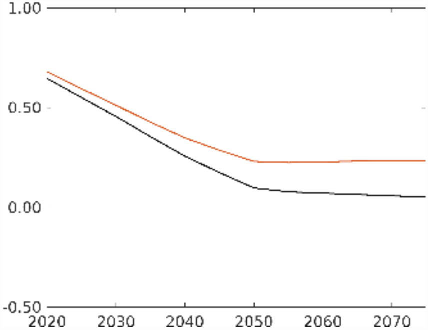
→ back

Gains and costs of fossil research subsidy: Optimal policy

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



(b) Green research subsidies

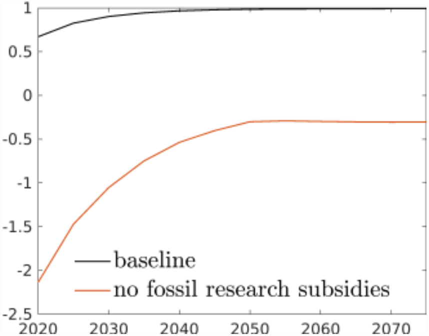


- higher carbon tax to counter fossil research subsidy
- subsidize green sector more to lower non-energy research

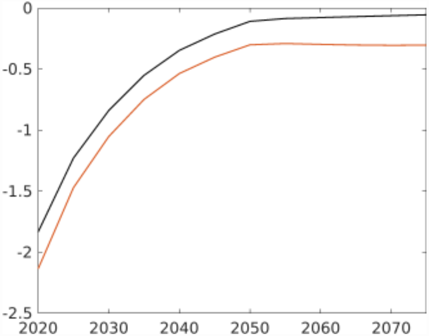
→ back

Gains and costs of fossil research subsidy: Optimal policy

(a) Fossil subsidy relative to green



(b) Non-energy subsidy relative to green

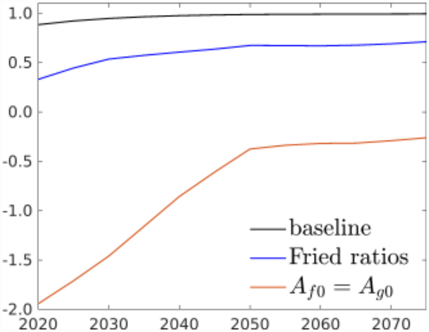


- without fossil research subsidy: same tax on fossil and non-energy research
- with fossil research subsidy: lower non-energy research using fossil tax

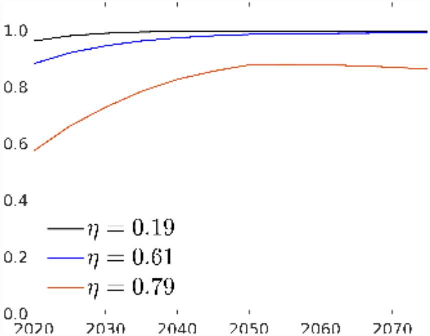
→ back

Robustness: Fossil research subsidies

(a) Knowledge stocks



(b) Fossil research subsidies

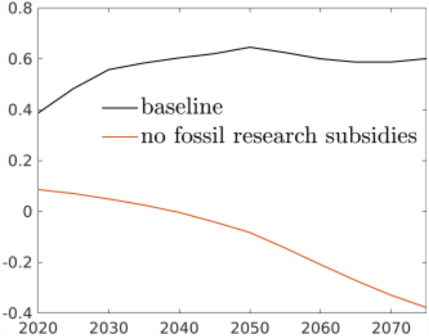


- the least advanced fossil sector, the smaller fossil research subsidy. Fossil research tax to boost non-energy research.
- the stronger "stepping on toes" effect, the higher fossil research subsidies

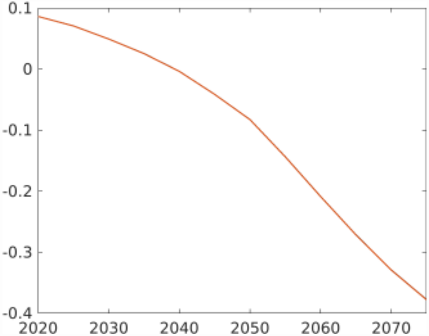
→ back

Initial values from Fried: renormalized subsidies

(a) Fossil subsidy relative to green



(b) Non-energy subsidy relative to green



- with fossil tax: fossil sector subsidized
- equivalent taxation of non-energy sector

→ back