Market Power, Innovation, and the Green Transition

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Introduction

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- Paris agreement, net-zero targets

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- Some rms rely more on fossil fuels than others (lock-in)
- Winners and losers within industries

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How does market power affect the transition from a dirty to a clean economy?

Contribution and results

Contribution to the literature:

- Empirical evidence on market power and the direction of innovation: cannot be explained by current theories
- A theoretical model that incorporates empirical findings and explores the relevance for climate policy

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Preview of findings:

- Data: market leaders are, on average, more invested in dirty technologies than their direct competitors
- Theory: climate policy can lead to a strategic increase in dirty innovation by some rms because of the \escape competition e ect"
- Calibration: ambitious climate policy leads to a (mostly clean) research boom and lower aggregate markups along the green transition

Literature

- Directed technical change and the environment
  - Theory: direction of innovation responds to relative prices, market sizes, and stocks of knowledge (path dependence)

    Smulders and de Nooij (2003); Acemoglu et al. (2012, 2016), Aghion et al. (2024)
  - Empirics: DTC mechanisms and policies affect innovation

    Jaffe and Palmer (1997); Newell et al. (1999); Popp (2002); Linn (2008); Noailly and Smeets (2015); Aghion et al. (2016); Calel and Dechezleprêtre (2016); Rozendaal and Vollebergh (2024)
  - Porter hypothesis: environmental regulation and competitiveness

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  - Porter hypothesis: environmental regulation and competitiveness

    Porter (1990); Porter and van der Linde (1995)
- Market power and innovation
  - Growth through creative destruction: technology ladders

    Schumpeter (1942); Aghion and Howitt (1992); Grossman and Helpman (1991)
  - Competition *( )* innovation; strategic interaction

    Blundell et al. (1995); Aghion et al. (2005); Akcigit and Ates (2023)

Motivating evidence

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Establish the following facts:

1. The direction of innovation is path dependent
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Evidence suggests that market leaders are more invested in dirty technologies than their competitors

- More di cult to make them switch to clean

Data from Orbis IP and Historical

- 130 million patent applications; 1.4 million inventions
- Classi ed as clean, dirty, neutral following Jee and Srivastav (2023)
- Mostly energy, manufacturing, transport technologies
- Link between rms' patents and balance sheets

Data | Shares clean dirty | Totals clean dirty | Types of clean technologies | Types of dirty technologies | Gray as a share of dirty | Patents by applicant country | Patents by applicant sector

Path dependence in innovation

Knowledge stocks: $K_{it}^{T} = P_{it}^{T} + (1-\delta)K_{it\ \ 1}^{T}$, with $T \in \{C, D\}$

Innovation $\text{gap}_{it} = \sinh\ ^{1}(P_{it}^{C}) - \sinh\ ^{1}(P_{it}^{D})$

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The direction of innovation is path dependent:

- Clean patenting depends positively on K^{C} and negatively on K^{D}
  Regression table
- Vice versa for dirty patenting
- In line with the literature

Which firms are most invested in dirty technologies?

I define:

- Leaders: top 10 rms in terms of revenue in country-sector-year
- Laggards: rms in ranks 11-20

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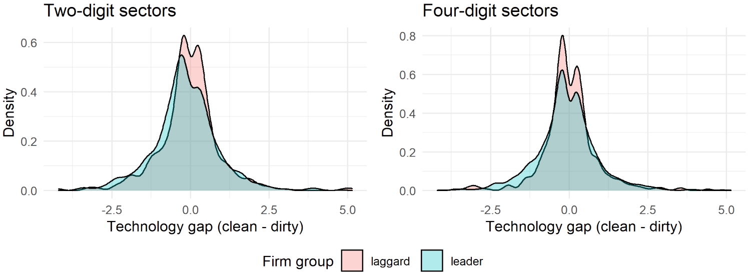

Figure: Distribution of the technology gap for leaders and laggards in 2018

Which firms are most invested in dirty technologies?

Within a country-industry-year, technology gap correlates negatively with:

- Firm size, pro tability and age [Regression table]
- Being a market leader [Regression table]

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Suggests that:

- Large firms need a stronger incentive to switch to clean than smaller firms
- Climate policy can affect market power

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- Large firms need a stronger incentive to switch to clean than smaller firms
- Climate policy can affect market power

Cannot be explained by the current literature, so let's incorporate these findings in a model

- What does this mean for climate policy?

Model overview

Continuous time endogenous growth model:

- Representative consumer
- Final good consists of a continuum of intermediates
- Exponential-quadratic damages from climate change (Nordhaus and Mo at, 2017)
- Temperature linear in historical emissions (Dietz and Venmans, 2019)

Details

Model overview

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Details

Each intermediate input sector has:

- Two firms that compete on prices (limit pricing) (Akcigit and Ates, 2023)
- Good produced using either a clean or a dirty technology
- Stepwise innovation in clean and dirty
- Knowledge diffusion

Production | Innovation | Technology gaps | Static decision | Dynamic decision

Technology gaps

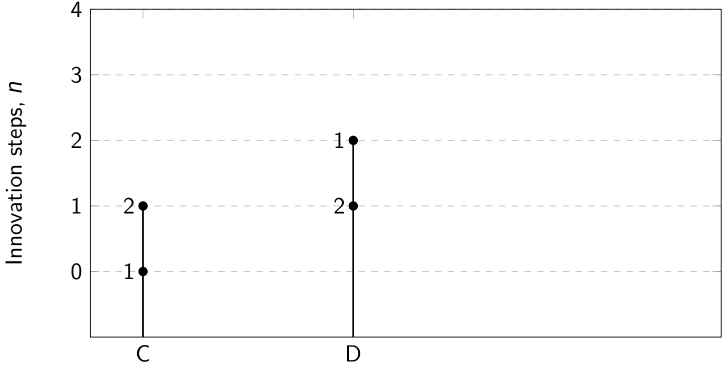
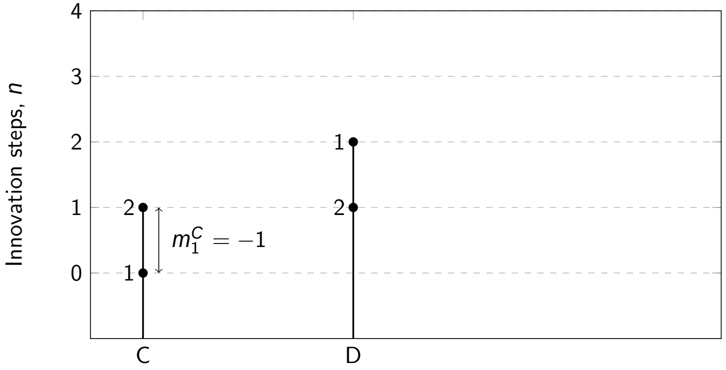


Figure: Own, clean and dirty technology gaps

Technology gaps



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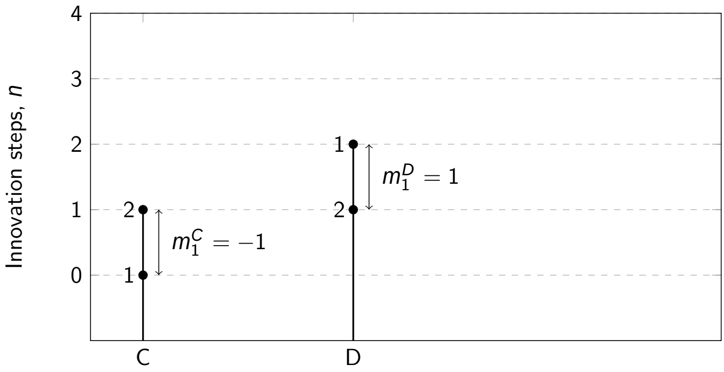

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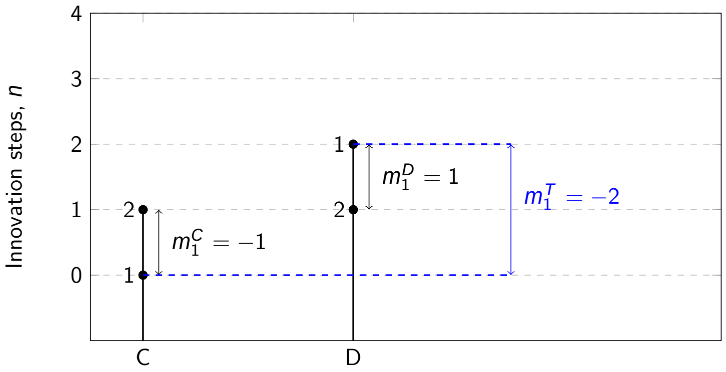

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The effect of a tax

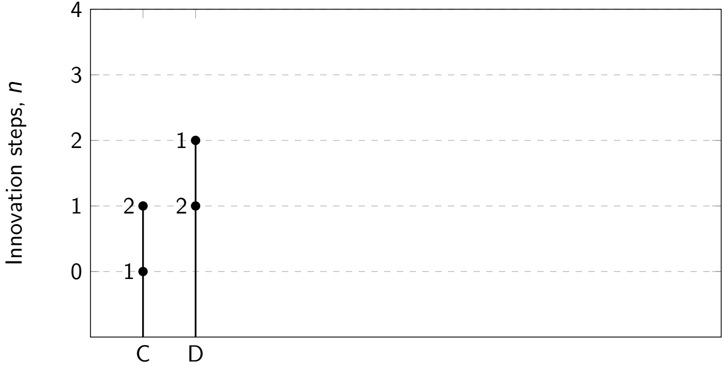

Figure: A carbon tax affects the effective technology gap

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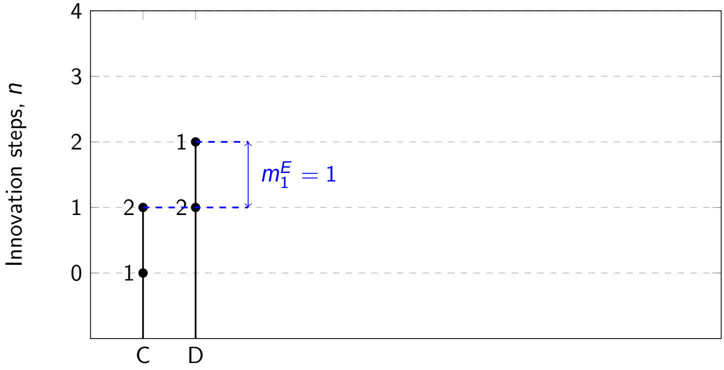

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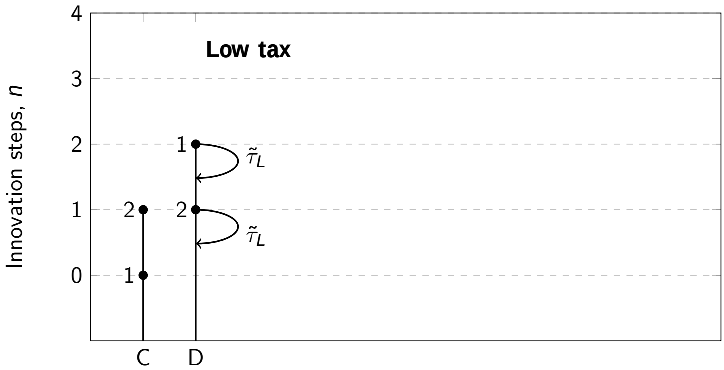

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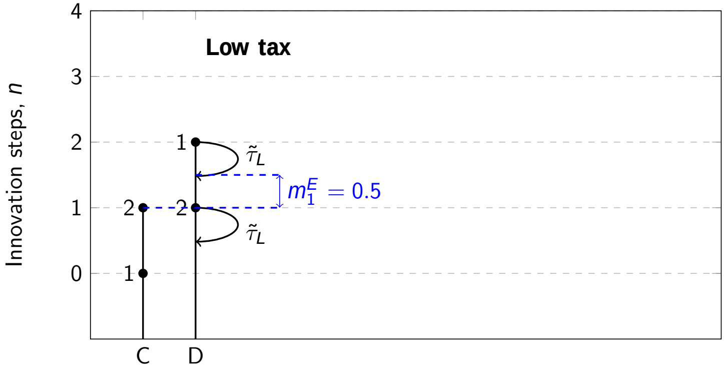

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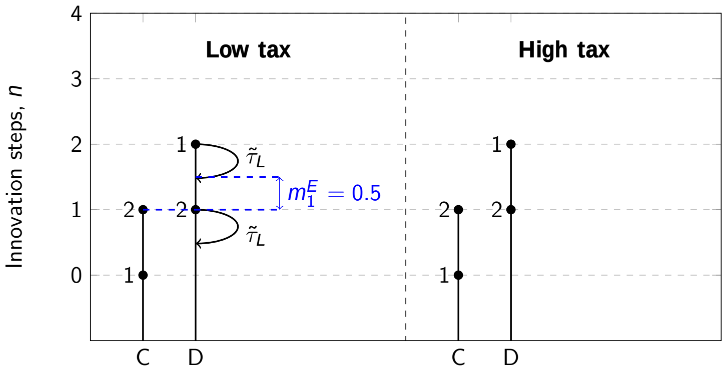

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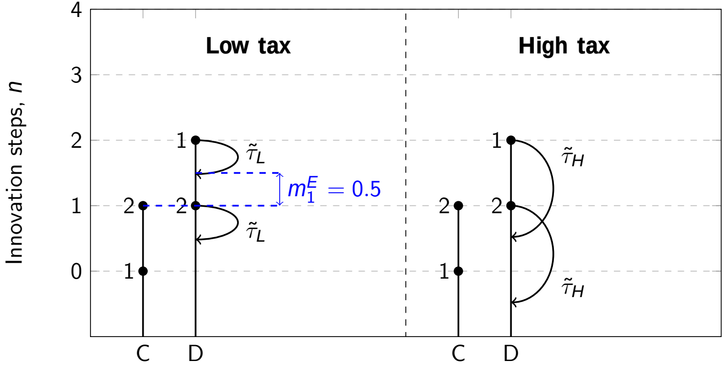

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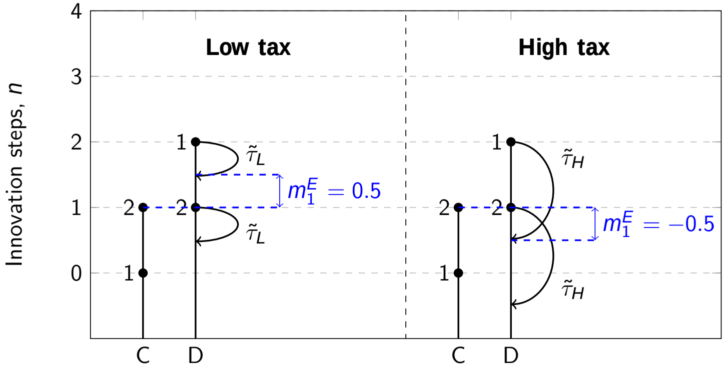

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Stepwise innovation

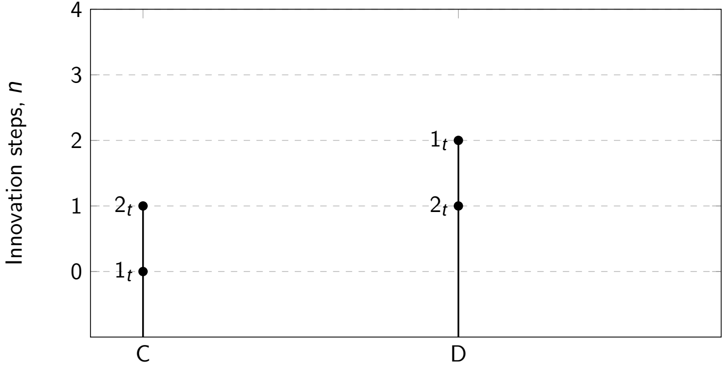
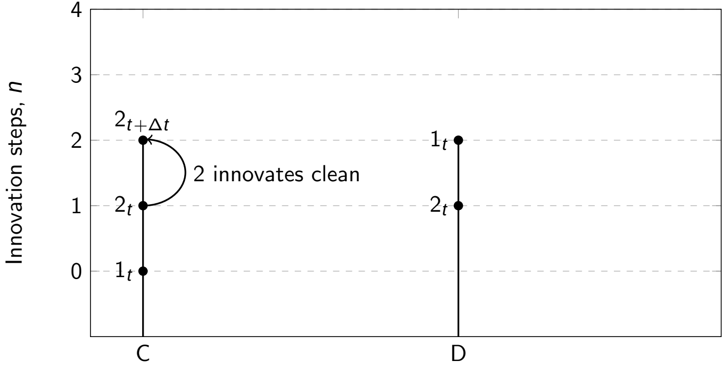


Figure: Clean and dirty innovation

Stepwise innovation



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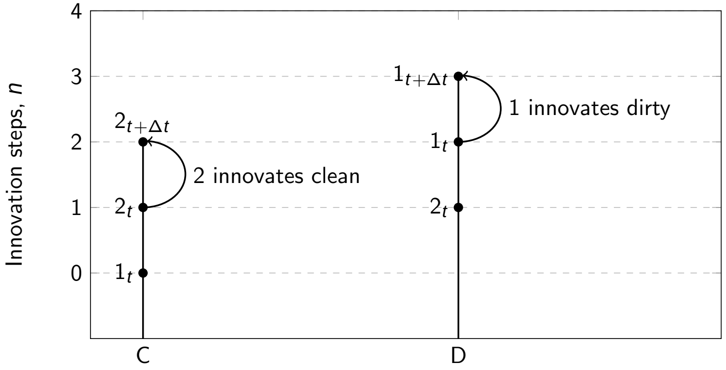

Figure: Clean and dirty innovation

A partial equilibrium result

The increase or introduction of a carbon tax in a single sector can increase a firm's dirty innovation efforts:

- Tax decreases e ective technology gap
- Increased competition and innovation due to escape competition e ect (Aghion et al., 2005)

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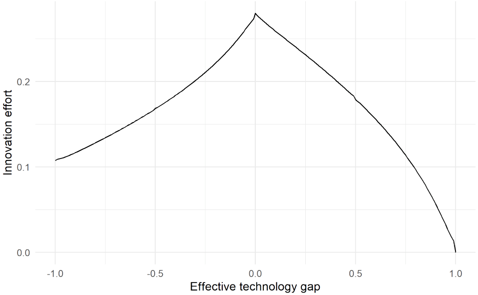

Figure: Innovation efforts for different technology gaps

Calibration

Solve for the general equilibrium in closed form

General equilibrium | BGP | μ_{mt} by group | $w_t, \omega_t, Y_t, E_t, R_t^C, R_t^D$ | Law of motion $Q_t, \psi_{klmt}, \mu_{mt}$

Calibrate model to world economy in 2010s

- External parameters from the literature
- Initial conditions based on patent and nancial data
- Internal calibration of remaining parameters following Akcigit and Ates (2023)

External parameters | Initial conditions | Calibration results and model fit

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Two quantitative exercises:

- Simulate BGP: business as usual
- Transition after large carbon tax increase in 2024 (Paris goal in 2100)

Balanced growth path

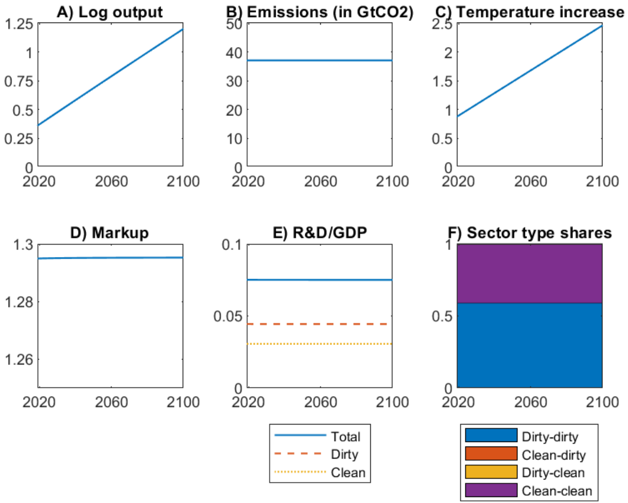

Figure: Balanced growth path simulated forward

The effects of a carbon tax

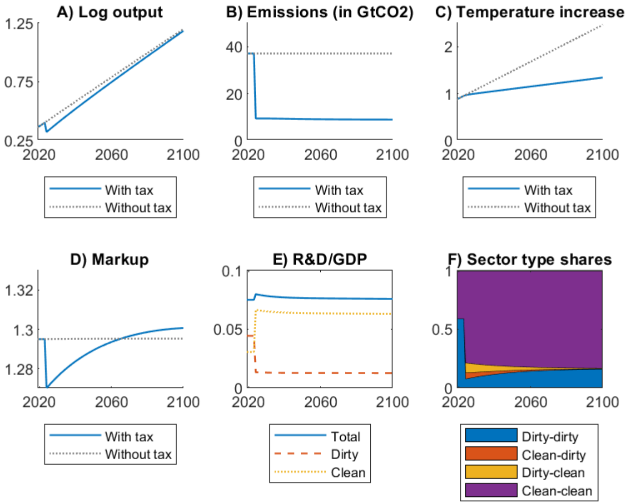

Figure: Transition after a large carbon tax increase in 2024

Conclusions

- Data suggests that market leaders are more invested in dirty technologies than their competitors
- Model shows how this impacts the green transition
  - Some rms increase their dirty innovation
  - Increased innovation and competition along the transition
- Suggests that transition may be less costly than anticipated
  - But it may not be so simple (overinvestment in R&D)
- Considering the strategic incentives for large incumbents is key for a successful green transition

Thanks!

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  - Counts of triadic patent families to avoid double counting and low quality inventions
  - Classi ed as clean, dirty, neutral following Jee and Srivastav (2023)
  - Mostly energy, manufacturing, transport technologies
  - Link to nancial data

Orbis Historical

- Balance sheet and other financial data for millions of firms
  - 2010-2018
  - Mostly developed countries
  - Revenue, employees, pro t, age, sector
  - Issues with coverage and representativeness
  - Focus on matched rms and top rms per sector

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Clean and dirty patenting

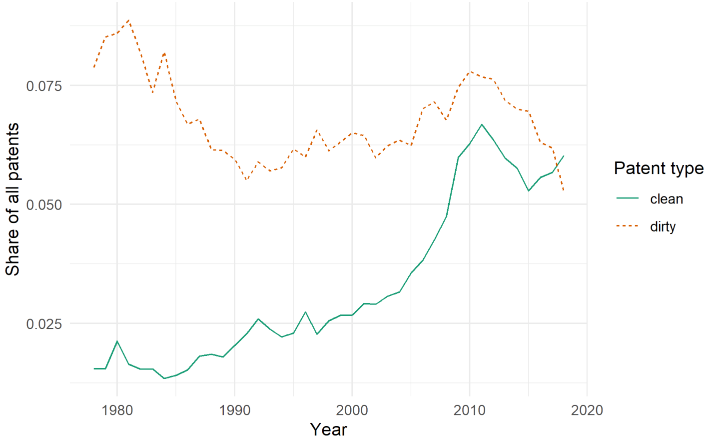

Figure: Share of clean and dirty patents over time

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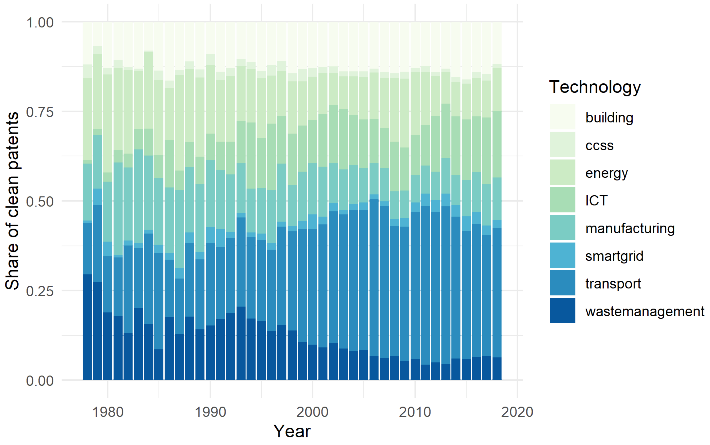
Figure: Different types of clean technologies



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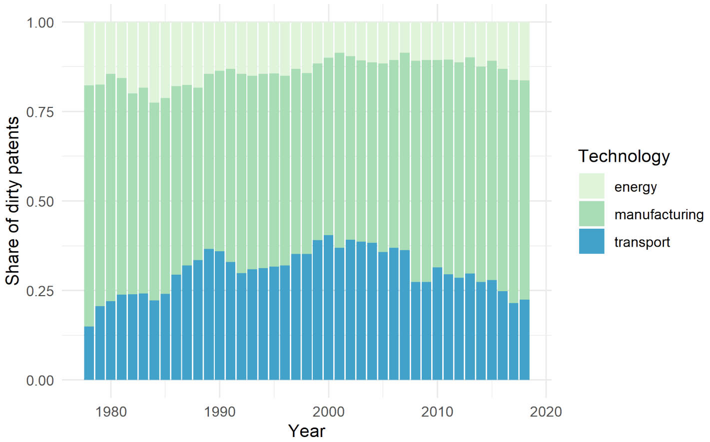

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Figure: Share of gray patents among dirty patents

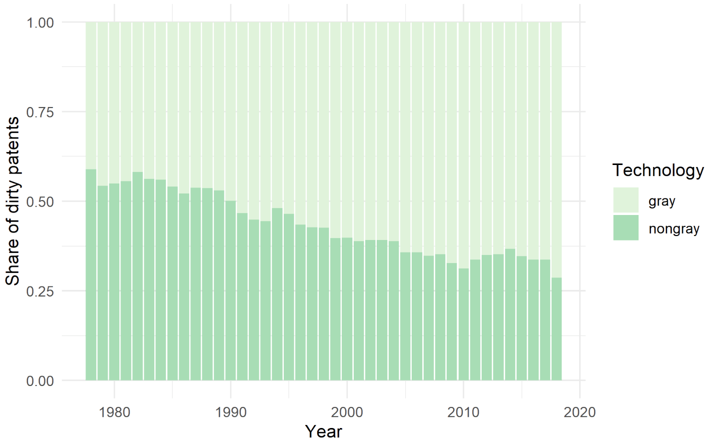

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Figure: Total clean and dirty patents over time

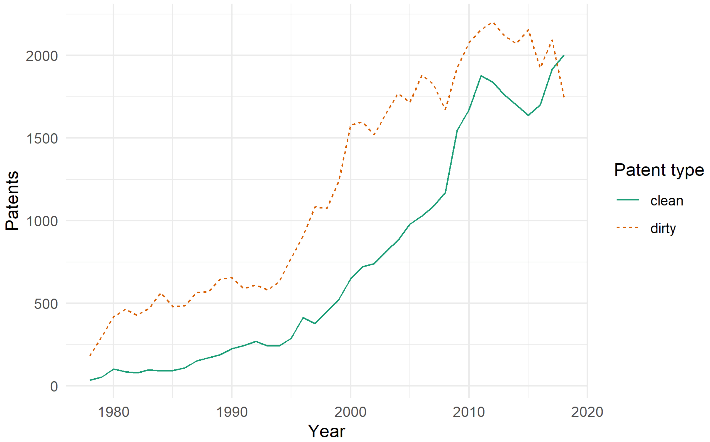

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Figure: Patents by applicant country

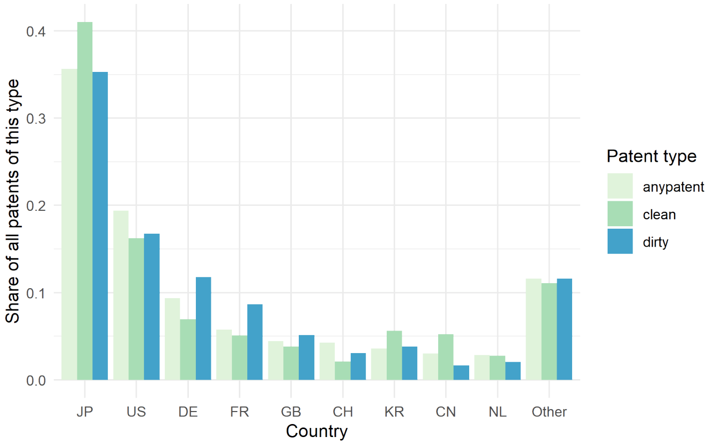

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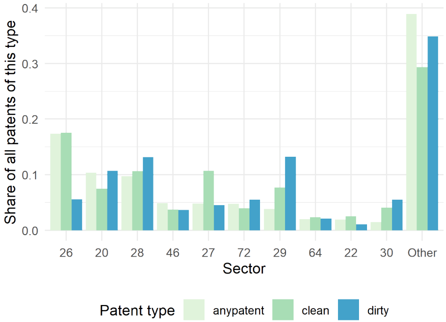
Figure: Patents by applicant sector



Sectors are classified using the NACE Rev. 2 classification. The sectors in the figure are the following. 26: Manufacture of computer, electronic and optical products; 20: Manufacture of chemicals and chemical products; 28: Manufacture of machineryand equipment n.e.c.; 46: Wholesale trade, except of motor vehicles and motorcycles; 27: Manufacture of electrical equipment; 72: Scientific research and development; 29: Manufacture of motor vehicles, trailers and semi-trailers; 64: Financial service activities, except insurance and pension funding; 22: Manufacture of rubber and plastic products; 30: Manufacture of other transport equipment.

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Table: Path dependence in innovation

	(1) Clean	(2) Dirty	(3) Innovation gap (clean-dirty)	(4) Innovation gap (clean-dirty)
Log K^C	0.525	-0.196	0.020	
	(0.021)	(0.013)	(0.003)	
Log K^D	-0.032	0.879	-0.041	
	(0.021)	(0.017)	(0.002)	
Technology gap (clean-dirty)				0.241
				(0.007)
Estimator	Poisson	Poisson	OLS	OLS
(Pseudo) R^2	0.55	0.58	0.12	0.24
Observations	6,624,288	6,624,288	4,215,743	4,112,920

Notes: All independent variables are first lags. OLS regressions include country-sector-year fixed effects (sectors defined at the four-digit level). Further controls in columns 1 through 3 are the stock of patents in any category and dummies that are 1 if the stock variables equal zero (one dummy for each stock). Further controls in column 4 are the stock of patents in any category, a dummy that is 1 if the stock of patents is zero, and a dummy that is 1 if the technology gap is zero. Standard errors are clustered at the firm level. The sample covers the years 1978-2018.

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Table: Technology gaps and market power

	(1)	(2)	(3)	(4)
	Technology gap (clean-dirty)			
Log revenue	-0.005		-0.004	
	(0.002)		(0.002)	
Log employment	0.001		-0.001	
	(0.002)		(0.002)	
Profit margin	0.000		0.000	
	(0.000)		(0.000)	
Log age	0.002		0.003	
	(0.002)		(0.003)	
Leader		-0.045		-0.023
		(0.011)		(0.006)
Laggard		-0.008		-0.003
		(0.008)		(0.005)
Sectors (for leader and f.e.)	Two-digit	Two-digit	Four-digit	Four-digit
R^2	0.06	0.05	0.16	0.13
Observations	223,088	401,587	208,462	380,164

Notes: All regressions are OLS with country-sector-year fixed effects. Column 2 and 4 define leaders as the top 10 firms in their two-digit and four-digit sector in terms of revenue, respectively. Fixed effects are defined at the two-digit sector in columns 1 and 2 and at the four-digit level in columns 3 and 4. All independent variables are contemporaneous values. Standard errors are clustered at the firm level. The sample covers the years 2010-2018.

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Table: Heterogeneity in technology gaps (four-digit sectors)

	(1)	(2)	(3)	(4)
	Technology gap (clean-dirty)			
Log revenue	-0.003			
	(0.001)			
Log employment		-0.004		
		(0.001)		
Profit margin			-0.000	
			(0.000)	
Log age				-0.004
				(0.001)
R^2	0.13	0.14	0.15	0.10
Observations	372,506	342,421	262,588	835,951

Notes: All regressions are OLS with country-sector-year fixed effects. Fixed effects are defined at the four-digit sector. All independent variables are contemporaneous values. Standard errors are clustered at the firm level. The sample covers the years 2010-2018.

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Preferences, final good, global warming

Representative consumer: $U_t = \int_{s=t}^{1} \exp\big(\quad (s \quad t)\big) \ln(C_s) ds$,

Labor L is supplied inelastically to production or R&D, $L_t = 1$

Final good: $\ln Y_t = \quad \frac{\gamma}{2} T_t^2 + \int_0^1 \ln y_{jt} dj$,

with damages from global warming T, scaled by

Global warming: $\dot{T}_t = ''(\ S_t \quad T_t)$,

with the linear e ect of cumulative emissions $S_t = \int_0^t E_s ds$ on temperature and '' a delay parameter (Dietz and Venmans, 2019)

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Intermediate good sectors

Firms: each sector j consists of two rms, i and i, which compete on prices

Production: $y_{ijt} = y^C_{ijt} + y^D_{ijt} = q^C_{ijt} l^C_{ijt} + q^D_{ijt} \min \left\{ l^D_{ijt}; \frac{e_{ijt}}{\kappa} \right\};$

with q productivity, l labor, e emissions, C clean, D dirty

Total costs: $TC_{it} = w_t l^C_{it} + w_t l^D_{it} + {}^E_t e_{it} = w_t l^C_{it} + w_t (1 + {}_t) l^D_{it};$

with w wage and ${}^E_t = {}_t w_t$ carbon price relative to labor

Marginal costs: $MC_{it} = \min f MC^C_{it}; MC^D_{it} g = \min \left\{ \frac{w_t}{q^C_{it}}; \frac{w_t(1+\kappa\tau_t)}{q^D_{it}} \right\}$

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Innovation

Innovation steps: in case of a successful innovation, $q^F_{i(t+\Delta t)} = \quad q^F_{it}$,

where $F \in \{C; D\}$

So, $q^F_{it} = \quad ^{n^F_{it}}$, where n^F_{it} is the number of innovation steps that rm i has taken for technology F (assuming $q^F_{i0} = 1$)

Innovation costs: $R_{it} = \quad \frac{x^{\beta}_{it}}{\beta} w_t$,

where x is the innovation arrival rate

Knowledge di usion: catch up with leader with exogenous arrival rate (technology gap becomes 0)

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Technology gaps

Own, clean, dirty:

Own technology gap: $m^T_{it} = n^C_{it} \quad n^D_{it}$
Clean technology gap: $m^C_{it} = n^C_{it} \quad n^{C}{}_{it}$
Dirty technology gap: $m^D_{it} = n^D_{it} \quad n^{D}{}_{it}$

Firm i uses clean to produce i $\quad m^T_{it} + \tilde{\tau}_t \quad 0$ with $\tilde{\tau}_t \quad \frac{\ln(1+\kappa\tau_t)}{\ln(\lambda)}$

E ective technology gap:

$$m^E(m^C_{it}; m^D_{it}; m^T_{it}; \quad _t) = \begin{cases} m^C_{it} & \text{if} \quad m^T_{it} + \tilde{\tau}_t \quad 0; \quad m^{T}{}_{it} + \tilde{\tau}_t \quad 0 \\ m^D_{it} + m^T_{it} + \tilde{\tau}_t & \text{if} \quad m^T_{it} + \tilde{\tau}_t \quad 0; \quad m^{T}{}_{it} + \tilde{\tau}_t < 0 \\ m^C_{it} \quad m^T_{it} \quad \tilde{\tau}_t & \text{if} \quad m^T_{it} + \tilde{\tau}_t < 0; \quad m^{T}{}_{it} + \tilde{\tau}_t \quad 0 \\ m^D_{it} & \text{if} \quad m^T_{it} + \tilde{\tau}_t < 0; \quad m^{T}{}_{it} + \tilde{\tau}_t < 0 \end{cases}$$

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Static competition

Demand: $y_{jt} = \frac{Y_t}{p_{jt}}$

Bertrand competition: limit pricing:

$$p_{jt} = \begin{cases} MC \quad {}_{it} & \text{if} \quad m^E_{it} \quad 0 \\ MC_{it} & \text{if} \quad m^E_{it} \quad 0 \end{cases}$$

Only market leader makes a pro t:

$$(m^E_{it}) = \begin{cases} (p_{jt} \quad MC_{it})y_{it} = \left(1 \quad \frac{1}{\lambda^{m^E_{it}}}\right)Y_t & \text{if} \quad m^E_{it} > 0 \\ 0 & \text{if} \quad m^E_{it} \quad 0 \end{cases}$$

Also gives each rm's output, labor demand and emissions

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Innovation decision

Direction:

- Currently clean rms ($m_{it}^{T} + \tilde{}_t \quad 0$) innovate in clean technology
- Currently dirty rms ($m_{it}^{T} + \tilde{}_t < 0$) innovate in dirty technology

Intensity: maximize NPV of pro ts given current e ective technology gap m

A normalized value function for each possible m: $v_{mt} = V_{mt}/Y_t$

For leaders ($m > 0$):

$$v_{mt} \quad v_{mt} = \max_{x_{mt}} \Big\{ 1 \quad \frac{1}{m} \quad \frac{x_{mt}^{\beta}}{} \, !_t + x_{mt}[v_{m+1,t} \quad v_{mt}]$$

$$+ \, x \quad {}_{mt}[v_{m \quad 1,t} \quad v_{mt}] + \quad [v_{0,t} \quad v_{mt}] \Big\}$$

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General equilibrium

Define:

- Maximum e ective gap $\overline{m}$
- Maximum distance between clean and dirty $\overline{m}^T$
- Aggregate productivity index $Q_t = \exp\left(\int_0^1 \ln(q_{Ljt})dj\right)$
- Gap size distribution to keep track of technology gaps (3 state variables per sector): $_{klmt} = \int_0^1 1\left\{m^T_{Ljt} = k \wedge m^T_{Fjt} = l \wedge m^E_{Ljt} = m\right\}dj$
- E ective gap size distribution $_{mt} = \sum_{k=\ \overline{m}^T}^{\overline{m}^T} \sum_{l=\ \overline{m}^T}^{\overline{m}^T} \ _{klmt}$ (by group)

Gives closed form solutions for $\omega_t, E_t, w_t, Y_t, R^C_t, R^D_t$

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Balanced growth

Along the balanced growth path...

- The e ective gap distribution is constant
- The gap between clean and dirty within sectors is growing
- There are no \mixed sectors" due to knowledge di usion
- TFP growth is constant (but, if $E_t > 0$, output growth is not)

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$$
{}^{DD}_{mt} = \sum_{k\,2\,M^D_t} \sum_{l\,2\,M^D_t} {}_{klmt};
$$

$$
{}^{CD}_{mt} = \sum_{k\,2\,M^C_t} \sum_{l\,2\,M^D_t} {}_{klmt};
$$

$$
{}^{DC}_{mt} = \sum_{k\,2\,M^D_t} \sum_{l\,2\,M^C_t} {}_{klmt};
$$

$$
{}^{CC}_{mt} = \sum_{k\,2\,M^C_t} \sum_{l\,2\,M^C_t} {}_{klmt};
$$

$$
{}_{1t} = \sum_{m\,2\,M_t} {}^{DD}_{mt};
$$

$$
{}_{2t} = {}_{1} + \sum_{m\,2\,M_t} {}^{CD}_{mt};
$$

$$
{}_{3t} = 1 \sum_{m\,2\,M_t} {}^{CC}_{mt}
$$

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$$! _t = \left(\sum_{k\,2\,M_t} \frac{\overset{DD}{kt} + \overset{CD}{kt}}{(1 + \quad _t)\quad ^k} + \frac{\overset{DC}{kt} + \overset{CC}{kt}}{k} \right) \left(1 \quad \sum_{k\,2\,M_t} \quad _{kt} (x^{\beta}_{Ljt} + x^{\beta}_{Fjt}) \right)^{\quad 1};$$

$$E_t = \frac{\quad}{! _t} \sum_{k\,2\,M_t} \frac{\overset{DD}{kt}}{(1 + \quad _t)\quad ^k} + \frac{\overset{DC}{kt}}{k};$$

$$w_t = \frac{Q_t \quad \sum_{k\,2\,M_t} \mu_{kt} k \exp\left(\quad \frac{\gamma}{2} T_t^2 \right)}{(1 + \quad _t)^{\theta_{2t}}};$$

$$Y_t = \frac{w_t}{! _t};$$

$$G_t = \quad _t w_t E_t$$

$$R_t^C = \frac{w_t}{\quad} \sum_{k\,2\,M_t} \quad \overset{CD}{kt} x^{\beta}_{kt} + \quad \overset{DC}{kt} x^{\beta}{}_{kt} + \quad \overset{CC}{kt} (x^{\beta}_{kt} + x^{\beta}{}_{kt});$$

$$R_t^D = \frac{w_t}{\quad} \sum_{k\,2\,M_t} \quad \overset{DD}{kt} (x^{\beta}_{kt} + x^{\beta}{}_{kt}) + \quad \overset{CD}{kt} x^{\beta}{}_{kt} + \quad \overset{DC}{kt} x^{\beta}_{kt}$$

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$$\ln(Q_{t+\Delta t}) \quad \ln(Q_t) = \Big[2 \quad {}_{0t} x_{0t} + \sum_{k\,2\,M \quad 1t} \quad {}_{kt} x_{kt} + \quad {}_{pt}(x_{pt} + (1 \quad p)x \quad {}_{pt})$$

$$+ \quad {}_{1} \quad {}_{pt}(x_{1} \quad {}_{pt} + p x_{p} \quad {}_{1t})\Big] \ln(\quad) \quad t + o(\quad t)$$

$$\frac{{}_{k,l,m,t+\Delta t} \qquad {}_{k,l,m,t}}{t} = 1\{k + 1 + \tilde{}_t < 0\} \quad {}_{k+1,l,m} \quad {}_{1,t} x_{m} \quad {}_{1,t}$$

$$+ 1\{k \quad 1 + \tilde{}_t > 0\} \quad {}_{k} \quad {}_{1,l,m} \quad {}_{1,t} x_{m} \quad {}_{1,t}$$

$$+ 1\{l + 1 + \tilde{}_t < 0\} \quad {}_{k,l+1,m+1,t} x \quad {}_{m} \quad {}_{1,t}$$

$$+ 1\{l \quad 1 + \tilde{}_t > 0\} \quad {}_{k,l} \quad {}_{1,m+1,t} x \quad {}_{m} \quad {}_{1,t}$$

$$\quad {}_{k,l,m,t}(x_{m,t} + x \quad {}_{m,t} + \quad) + \frac{o(\quad t)}{t}$$

$$\frac{{}^{FF}_{m,t+\Delta t} \qquad {}^{FF}_{m,t}}{t} = {}^{FF}_{m} \quad {}_{1,t} x_{m} \quad {}_{1,t} + {}^{FF}_{m+1,t} x \quad {}_{m} \quad {}_{1,t}$$

$$\quad {}^{FF}_{m,t}(x_{m,t} + x \quad {}_{m,t} + \quad) + \frac{o(\quad t)}{t}$$

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Calibration

Assume world economy is on a BGP in 2010s

Parameter	Value	Description	Source
ρ	1%	Rate of time preference	Acemoglu et al. (2016)
β	1/0.35	R&D cost curvature	Akcigit and Ates (2023)
γ	0.01	Climate damage elasticity	Dietz and Venmans (2019); Nordhaus and Moffat (2017)
ζ	0.00048×1.1	TCRE	Dietz and Venmans (2019); Matthews et al. (2009)
ε	0.5	Initial pulse-adjustment time-scale of the climate system	Dietz and Venmans (2019); Ricke and Caldeira (2014)

Table: Externally calibrated parameters

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Calibration

Initial conditions:

- Initial share of clean and dirty rms
- Emissions since 1850 to compute initial (2019) temperature
- Initial gap distribution
  - De ne leaders as rm with highest absolute value of m^T (as de ned in empirical section)
  - Classify sectors as clean or dirty based on leader
  - Laggard is second rm in terms of m^T
  - Fill in $_{m=0,t=0}$ using BGP e ective gap distribution

Calibration

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Internal calibration procedure similar to Akcigit and Ates (2023):

- For given $f\ ;\ ;\ ;\ g$, nd BGP e ective gap size distribution
- Compute model moments
- Minimize di erence with data moments

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Calibration

Parameter	Value	Description
λ	1.0656	Innovation step size
δ	0.0374	Diffusion arrival rate
α	44.4299	R&D scaling parameter
κ	68.5578	Emission scaling parameter

Table: Internally calibrated parameters

Moment	Model	Data	Source
Average markup (2015)	1.2953	1.29	Díez et al. (2021)
Profit share (2018)	19%	19%	Eggertsson et al. (2021)
Productivity growth (avg. 2011-2019)	1.0738%	1.0738%	OECD
Emissions (2019, in $GtCO_2$)	37.0826	37.0826	Friedlingstein et al. (2022)

Table: Model fit

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