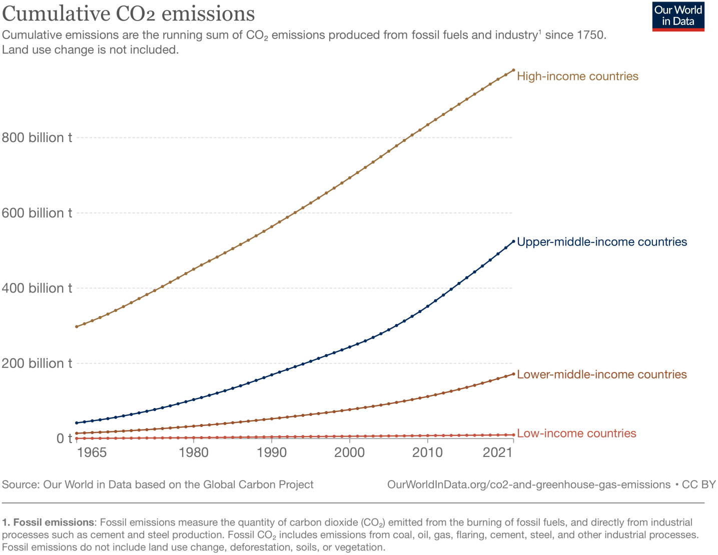
Green energy transition: decarbonisation of developing countries and the role of technological spillovers

Aleksandra Friedl
friedl@ifo.de

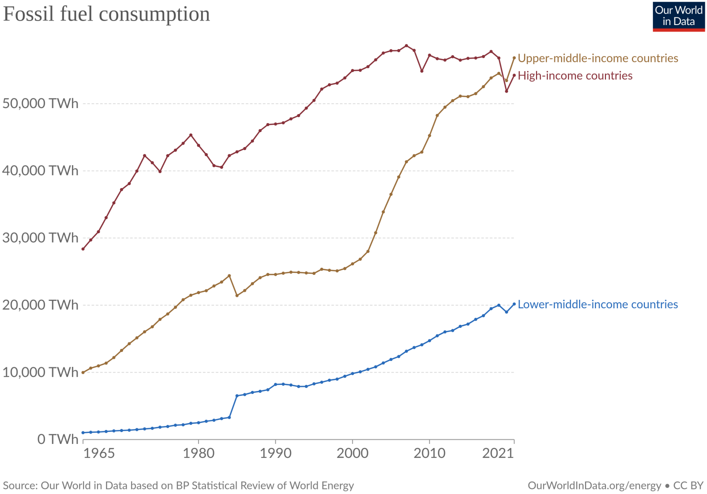
ifo Center for Energy, Climate and Resources
ifo Center for Macroeconomics and Surveys

ifo Institute – Leibniz Institute
for Economic Research at the University of Munich

Motivation and context



Motivation and context



Developing countries: decarbonisation

Decarbonisation in theory

Carbon pricing → Innovation in renewable energy → Green energy transition

Developing countries: decarbonisation

Decarbonisation in theory

Carbon pricing → Innovation in renewable energy → Green energy transition

Reality check I: carbon pricing

- LMIC: 2 countries implemented carbon pricing, 8 more countries are considering it out of total 54 countries
- Reasons: carbon justice

Developing countries: decarbonisation

Decarbonisation in theory

Carbon pricing → Innovation in renewable energy → Green energy transition

Reality check I: carbon pricing

- LMIC: 2 countries implemented carbon pricing, 8 more countries are considering it out of total 54 countries
- Reasons: carbon justice

Reality check II: Innovation in renewable energy

- LMIC, LIC do not innovate in a sense of patenting activity, they **adopt** existing technologies [Aghion and Howitt, 1997] through technological transfer (diffusion or **spillovers**)

Counteracting forces

1. No carbon pricing in developing countries → No incentive to switch to renewable energy

Counteracting forces

1. No carbon pricing in developing countries → No incentive to switch to renewable energy
2. Decarbonization in advanced countries → Renewable energy more productive → Spillovers of renewable energy to developing countries

Research question

- What is **the role and quantitative impact of technological spillovers** on decarbonisation for developing countries?
  - *'Renewable energy path'* or *'Fossil fuel path'* with spillovers, without carbon taxation?
  - Any benefits of carbon taxation and spillovers?

Preview of the *(preliminary)* results

Mechanism

Technological spillovers: **renewable energy grows faster** in the developing countries and **substitutes for the fossil fuels**

Preview of the *(preliminary)* results

Mechanism

Technological spillovers: **renewable energy grows faster** in the developing countries and **substitutes for the fossil fuels**

Outcomes

1. Carbon taxation + technological spillovers = the best for the climate
2. **Technological spillovers can substitute for carbon tax** in developing countries

Contribution to the literature

General IAM literature:

- [Nordhaus, 2017a], [Golosov et al., 2014a], [Hassler et al., 2020], [Dietz et al., 2020], [Barrett, 2021]
- *This paper*: couples explicit energy sources with CMIP5 compliant climate emulator as in [Folini et al., 2021]

Multi-regional IAMs:

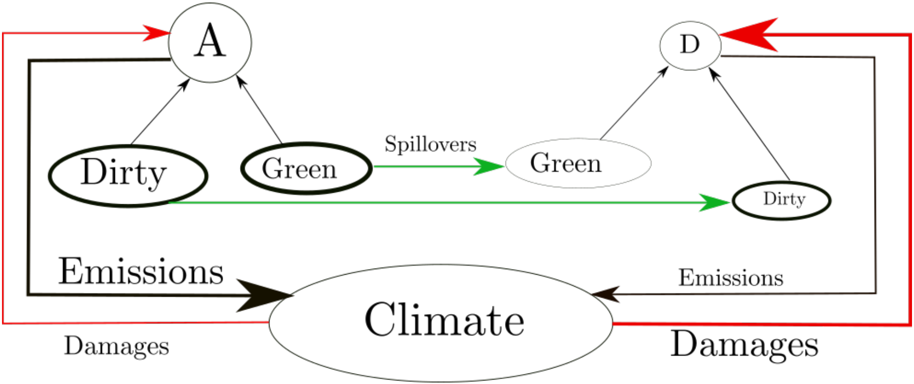
- [Hillebrand and Hillebrand, 2019], [Krusell and Smith, 2016], [Kotlikoff et al., 2019], [Acemoglu, Aghion, Hémous, 2014]]
- *This paper*: two agents model with technological diffusion and developing countries

Solution method for IAMs:

- [Cai et al., 2017], [Traeger, 2014], [Kelly and Kolstad, 1999]
- *This paper*: solves with deep neural net algorithm as in [Azinovic et al., 2019]

Outline of the presentation

Model scheme



Economy

- **2 regions** $i \in \{A, D\}$: **advanced** economy (A), **developing** economy (D), 300 years time horizon
- Representative consumer:

$$W_t^i = \sum_{t=0}^{\infty} \frac{\left(\frac{C_t^i}{L_t^i}\right)^{1-1/\psi}}{1-1/\psi} L_t^i \tag{1}$$

- Production:

$$Y_{i,t}^{\text{gross}} = \left(K_t^i\right)^{\alpha} \left(A_t^i(1-\pi_t^i-\xi_t^i)L_t^i\right)^{1-\alpha-\nu} \left(E_t^i\right)^{\nu} \tag{2}$$

- TFP growth is 2.5% per year for each region, A_0^A and A_0^D are pinned down by the data for 1990
- Labor evolution follows [Nordhaus, 2017b].

CES energy aggregator

- Energy comes from fossil fuels and renewable energy sources in the form of CES aggregator with elasticity 1.1 ($\rho_{CES} = 0.1$) [Papageorgiou et al., 2017], [Jo, 2020]:

$$E_t^i = \left(\kappa_{dt}^i \left(E_{t,dt}^{\mathrm{i}}\right)^{\rho_{CES}} + \kappa_{cl}^i \left(E_{t,cl}^{\mathrm{i}}\right)^{\rho_{CES}}\right)^{1/\rho_{CES}} \tag{3}$$

Advanced economy				Developing economy			
κ_{dt}^A	0.75	κ_{cl}^A	0.25	κ_{dt}^D	0.82	κ_{cl}^D	0.18

Table: Energy parameters.

Energy sources (exogenous TFP)

- Energy from fossil fuels and energy from renewable sources [Golosov et al., 2014b]:

$$E^{\mathrm{i}}_{t,dt} = A^{i}_{dt,0}\left(1 + g^{i}_{dt}\right)^{t} \pi^{i}_{t} L^{i}_{t} \tag{4}$$

$$E^{\mathrm{i}}_{t,cl} = A^{i}_{cl,0}\left(1 + g^{i}_{cl}\right)^{t} \xi^{i}_{t} L^{i}_{t}. \tag{5}$$

Advanced economy				Developing economy			
$A^{A}_{dt,0}$	0.0458	$A^{A}_{cl,0}$	0.0227	$A^{D}_{dt,0}$	0.00712	$A^{D}_{cl,0}$	0.0232
g^{A}_{dt}	1.2%	g^{A}_{cl}	1.4%	g^{D}_{dt}	1%	g^{D}_{cl}	0.1%

Table: Energy parameters.

Technology transfer

- Technological spillovers in both energy sources as in [Barrett, 2021]:

$$A^D_{dt,t+1} = A^D_{dt,0} + \varsigma(A^A_{dt,t} - A^A_{dt,0}) \tag{6}$$

$$A^D_{cl,t+1} = A^D_{cl,0} + \varsigma(A^A_{cl,t} - A^A_{cl,0}). \tag{7}$$

Lower bound		Baseline		Upper bound	
$\underline{\varsigma}$	0.0625	ς	0.09	$\bar{\varsigma}$	0.2

Table: Technological spillovers intensity based on [Eaton and Kortum, 1999], [Comin and Hobijn, 2010], [Dechezleprêtre et al.,2013].

Climate and emissions

- Climate as in [Folini et al., 2021] is shared by both regions
- 3 carbon reservoirs:

$$b_{11}M_t^{AT} + b_{21}M_t^{UO} + \boxed{\sigma_t(E_{dt,t}^{A} + E_{dt,t}^{D})} + E_t^{Land} - M_{t+1}^{AT} = 0 \tag{8}$$

$$b_{12}M_t^{AT} + b_{22}M_t^{UO} + b_{32}M_t^{LO} - M_{t+1}^{UO} = 0 \tag{9}$$

$$b_{23}M_t^{UO} + b_{33}M_t^{LO} - M_{t+1}^{LO} = 0 \tag{10}$$

- 2 layers of temperature:

$$T_t^{AT} + c_1\left(F_{2xco2}\log_2\left(\frac{M_t^{AT}}{M_{eq}^{AT}}\right) + F_{EX,t}\right) - c_1\frac{F_{2xco2}}{T_{2xco2}}T_t^{AT} - c_1c_3\left(T_t^{AT} - T_t^{OC}\right) - T_{t+1}^{AT} = 0 \tag{11}$$

$$T_t^{OC} + c_4\left(T_t^{AT} - T_t^{OC}\right) - T_{t+1}^{OC} = 0 \tag{12}$$

- Carbon intensity σ_t is chosen to match RCP 6.0 and follows the exogenous process as in [Nordhaus, 2018].

Damages and net output

- Damages are quadratic [Nordhaus, 2017b] and heterogeneous:

$$\Omega^i\left(T_{\mathrm{AT},t}\right) = \psi_1^i T_t^{\mathrm{AT}} + \psi_2^i \left(T_t^{\mathrm{AT}}\right)^2 . \tag{13}$$

Advanced economy [Nordhaus, 2017b]				Developing economy [Weitzman, 2012]			
ψ_1^A	0.0	ψ_2^A	0.0236	ψ_1^D	0.0	ψ_2^D	0.0746

Table: Damages parameters.

- Net production:

$$Y_{i,t}^{\mathrm{Net}} = \Omega^i\left(T_{\mathrm{AT},t}\right)\left(K_t^i\right)^{\alpha}\left(A_t^i(1-\pi_t^i-\xi_t^i)L_t^i\right)^{1-\alpha-\nu}\left(E_t^i\right)^{\nu} . \tag{14}$$

Recursive formulation of the model

- Bellman equation subject to constraints for $i \in A, D$:

$$V_t(S_t) = \max_{K^i_{t+1}, \pi^i_t, \xi^i_t} \left\{ \sum_{i \in \{A,D\}} \phi^i \frac{\left(\frac{C^i_t}{L^i_t}\right)^{1-1/\psi}}{1-1/\psi} L^i_t + e^{-\rho} V_{t+1}(S_{t+1}) \right\} \tag{15}$$

$$\text{s.t.} \quad \Omega^i(T_{\mathrm{AT},t}) \left(K^i_t\right)^{\alpha} \left(A^i_t (1-\pi^i_t-\xi^i_t) L^i_t\right)^{1-\alpha-\nu} \left(E^i_t\right)^{\nu} + (1-\delta) K^i_t - C^i_t - K^i_{t+1} = 0 \tag{16}$$

$$1-\pi^i_t \geq 0 \tag{17}$$

$$1-\xi^i_t \geq 0 \tag{18}$$

+ 5 climate equations

- $S_t = (K^A_t, K^D_t, M^{\mathrm{AT}}_t, M^{\mathrm{UO}}_t, M^{\mathrm{LO}}_t, T^{\mathrm{AT}}_t, T^{\mathrm{OC}}_t)$
- ϕ^i are dynamic (time-varying) Negishi weights as in [Nordhaus and Yang, 1996], [Cai et al. 2018], [Dennig and Emmerling, 2017].

Outline of the presentation

What is the problem?

- **Global solution** for an optimisation problem, **7 states** and **6 policies**:

$$p : \mathbb{R}^7 \to \mathbb{R}^6, \; p : S_t \to p(S_t)$$

where $S_t = (K_t^A, K_t^D, M_t^{AT}, M_t^{UO}, M_t^{LO}, T_t^{AT}, T_t^{OC})$,
$p(S_t) = (K_{t+1}^A, K_{t+1}^D, \pi_t^A, \pi_t^D, \xi_t^A, \xi_t^D)$

- **Dynamic Negishi weights** should be computed along the solution of the main problem
- **Non-stationary** problem + **strong non-linearities** due to the interaction of climate and economy

→ Curse of dimensionality

What is a deep neural network?

- **Neural network** is *the universal function approximator*
- A neural net $\mathcal{N}_\rho$ is **characterized by its parameters** ρ

$$p : \mathbb{R}^{N_{in}} \rightarrow \mathbb{R}^{N_{out}},\ p : x \rightarrow p(x)$$
$$\mathcal{N}_\rho : \mathbb{R}^{N_{in}} \rightarrow \mathbb{R}^{N_{out}},\ \mathcal{N}_\rho : x \rightarrow \mathcal{N}_\rho(x)$$

We desire parameters ρ, such that **loss function**

$$||\mathcal{N}_\rho - p||_{\text{some norm}} = 0.$$

DEQN technical details

- DEQN relies on **feedforward neural network (FNN)**
- FNN: L layers, each layer has N_l neurons and an activation function
- I use the neural network with **2** hidden **layers, 512 neurons** each, activated by *relu*.

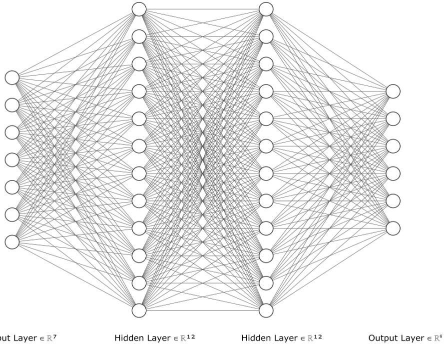


Figure: FNN, the input **x** is an 7−dimensional vector, two hidden layers with (5)12 neurons each, and **p**(**x**) is a 6−dimensional output.

Economic loss function: [Azinovic et al., 2019]

1. From **equilibrium conditions** we know the relationship between the state x_i and the policy function $p(x_i)$:

$$G(x_i, p(x_i)) = 0$$

2. We propose an **economic loss function**

$$l_\rho := \frac{1}{|\mathcal{D}|} \sum_{x_i \in \mathcal{D}} \left(G(x_i, \mathcal{N}_\rho(x_i))\right)^2$$

3. We train the net using **the stochastic gradient descent** such that the policy function produced by the net satisfies equilibrium conditions almost exactly.

How DEQN works

1. Formulate a **set of first-order conditions** $G(x_t, p(x_t)) = 0$
2. Activate **neural net** $\mathcal{N}_\rho(x_t)$ with the **random parameters** ρ [Glorot and Bengio, 2010]
3. Take the starting state of the economy and **simulate** the evolution over time $N_{\text{path length}}$ with the $\mathcal{N}_\rho(x_t)$. We get: $G(x_t, \mathcal{N}_\rho(x_t)) \neq 0$
4. Use the loss function to **update** the neural net parameters ρ

$$l_\rho := \frac{1}{N_{\text{path length}}} \sum_{x_t \text{on sim. path}} \Big(G(x_t, \mathcal{N}_\rho(x_t))\Big)^2$$

5. **Repeat** steps 3 and 4 until $l_\rho \approx 0$.

Advantages of the DEQN approach

- **Alleviates the curse of dimensionality** due to the stochastic gradient descent procedure
- Capable of **approximating policy functions with strong nonlinearities** as the whole ergodic distribution of policy variables is being determined
- Allows to deal with **large state spaces** (up to several hundreds of variables), so we can have multiple-agents in the model as well as fully-fledged climate emulator.

Outline of the presentation

Questions of interest

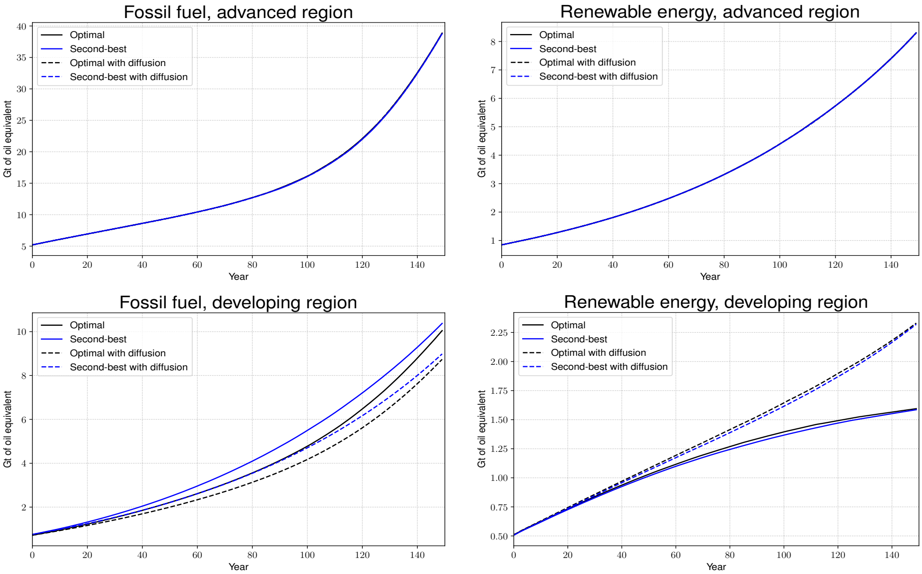
Counteracting forces: a reminder

1. *No carbon pricing in developing countries → No incentive to switch to renewable energy*
2. *Decarbonization in advanced countries → Renewable energy more productive → Spillovers of renewable energy to developing countries*

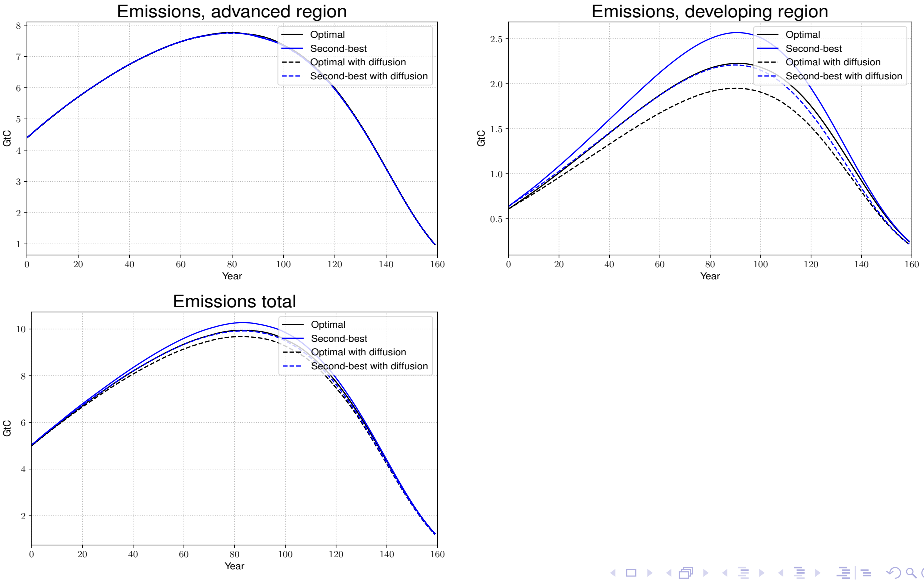
Case of interest

- 'Optimal': carbon tax for all regions only without spillovers
- 'Second-best': carbon tax for advanced regions without spillovers
- 'Second-best' + technological spillovers
- 'Optimal' + technological spillovers

Case of interest: energy usage



Case of interest: emissions



Case of interest: taking stock

- Carbon tax in all regions + spillovers = the best for climate
- Carbon tax in advanced economies + spillovers = a substitute for the carbon tax in developing region

Mechanism

Technological spillovers make renewable energy grow faster and substitute for fossil fuels in developing countries.

Results and limitations

What is **the role and quantitative impact of technological spillovers** in decarbonisation for developing countries?

- Helps decarbonisation
- Can substitute for the carbon taxation in developing countries

Limitations

- Exogenous growth in all TFP processes
- Emission intensity from [Nordhaus, 2017b]

Thank you for your attention!

Optimisation problem

$$V_t\left(S_t^i\right) = \max_{K_{t+1}^i, C_t^i, \pi_t^i, \xi_t^i} \left\{ \sum_{i\in\{a,d\}} \phi^i \frac{\left(\frac{C_t^i}{\varrho_t^i L_t}\right)^{1-1/\psi}}{1-1/\psi} \varrho_t^i L_t + e^{-\rho} V_{t+1}\left(S_{t+1}^i\right) \right\} \quad (19)$$

s.t. $$\Omega^i\left(T_{\mathrm{AT},t}\right)\left(K_t^i\right)^{\alpha}\left(\varphi_t^i A_t (1-\pi_t^i-\xi_t^i)\varrho_t^i L_t^i\right)^{1-\alpha-\nu}\left(E_t^i\right)^{\nu} + (1-\delta) K_t^i - C_t^i - K_{t+1}^i = 0 \quad \left(\lambda_t^i\right) \quad (20)$$

$$1-\pi_t^i \geq 0 \quad \perp \quad \lambda_t^{\pi^i} \geq 0 \quad (21)$$

$$1-\xi_t^i \geq 0 \quad \perp \quad \lambda_t^{\xi^i} \geq 0 \quad (22)$$

$$E_t^i = \left(\kappa_{dt}\left(E_t^{\mathrm{i,dt}}\right)^{\rho_{CES}} + \kappa_{cl}\left(E_t^{\mathrm{i,cl}}\right)^{\rho_{CES}}\right)^{1/\rho_{CES}} \quad (23)$$

$$\mathrm{E}_{t,dt}^{\mathrm{i}} = A_{dt,0}^i\left(1+g_{dt}^i\right)^t \pi_t^i L_t^i \quad (24)$$

$$\mathrm{E}_{t,cl}^{\mathrm{i}} = A_{cl,0}^i\left(1+g_{cl}^i\right)^t \xi_t^i L_t^i \quad (25)$$

$$b_{11}M_t^{AT} + b_{21}M_t^{\mathrm{UO}} + \sigma_t\left(E^{\mathrm{a,dt}} + E^{\mathrm{d,dt}}\right) + E_t^{\mathrm{Land}} - M_{t+1}^{\mathrm{AT}} = 0 \quad \left(\nu_t^{\mathrm{AT}}\right) \quad (26)$$

$$b_{12}M_t^{AT} + b_{22}M_t^{\mathrm{UO}} + b_{32}M_t^{\mathrm{LO}} - M_{t+1}^{\mathrm{UO}} = 0 \quad \left(\nu_t^{\mathrm{UO}}\right) \quad (27)$$

$$b_{23}M_t^{\mathrm{UO}} + b_{33}M_t^{\mathrm{LO}} - M_{t+1}^{\mathrm{LO}} = 0 \quad \left(\nu_t^{\mathrm{LO}}\right) \quad (28)$$

$$T_t^{\mathrm{AT}} + c_1\left(F_{\mathrm{2xco2}}\log_2\left(\frac{M_t^{\mathrm{AT}}}{M_{\mathrm{eq}}^{\mathrm{AT}}}\right) + F_{\mathrm{EX},t}\right) - c_1\frac{F_{\mathrm{2xco2}}}{T_{\mathrm{2xco2}}}T_t^{\mathrm{AT}} - c_1c_3\left(T_t^{\mathrm{AT}} - T_t^{\mathrm{OC}}\right) - T_{t+1}^{\mathrm{AT}} = 0 \quad \left(\eta_t^{\mathrm{AT}}\right) \quad (29)$$

$$T_t^{\mathrm{OC}} + c_4\left(T_t^{\mathrm{AT}} - T_t^{\mathrm{OC}}\right) - T_{t+1}^{\mathrm{OC}} = 0 \quad \left(\eta_t^{\mathrm{OC}}\right) \quad (30)$$

where $S_t = (K_t^A, K_t^D, M_t^{\mathrm{AT}}, M_t^{\mathrm{UO}}, M_t^{\mathrm{LO}}, T_t^{\mathrm{AT}}, T_t^{\mathrm{OC}})$, $i \in \{A, D\}$, $A_t^a = \varphi_t^a A_t$, $A_t^d = \varphi_t^d A_t$, A_t is a world TFP, and $\varrho_t^a L_t^a = L_t, \varrho_t^d L_t^d = L_t$, where L_t is a world

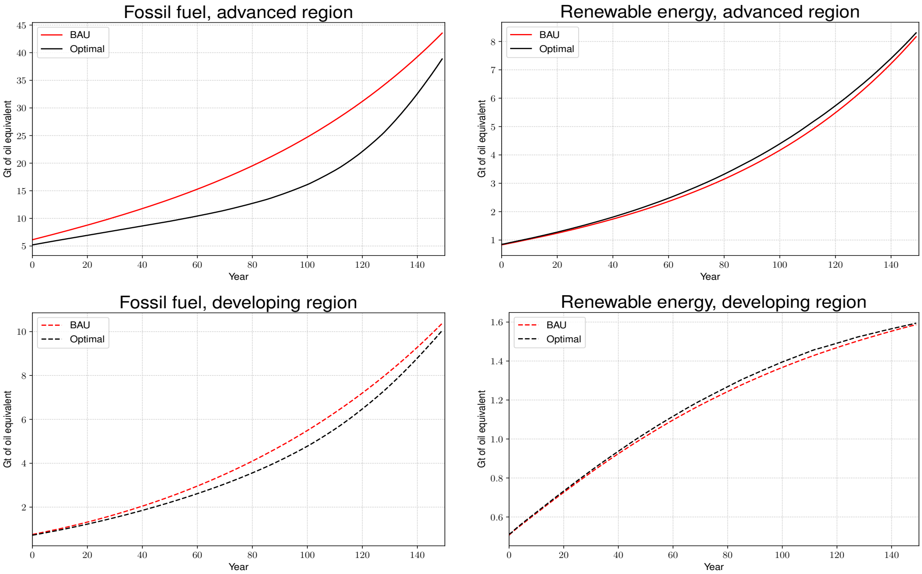
Outline of the presentation

Sanity check

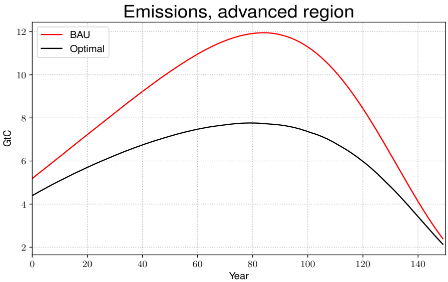
Benchmark case without spillovers

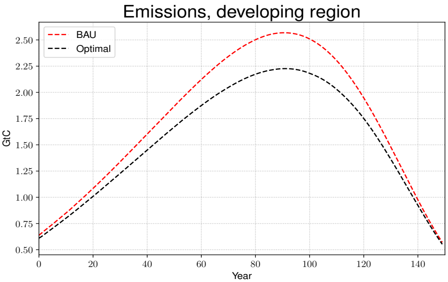
- 'Business-as-usual': no carbon taxation
- 'Optimal': optimal carbon taxation

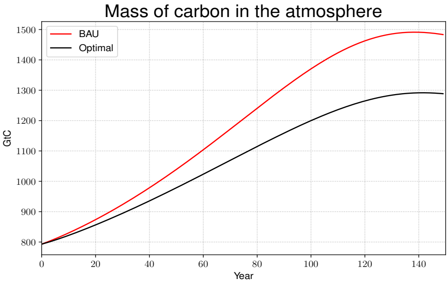
Benchmark case: energy usage

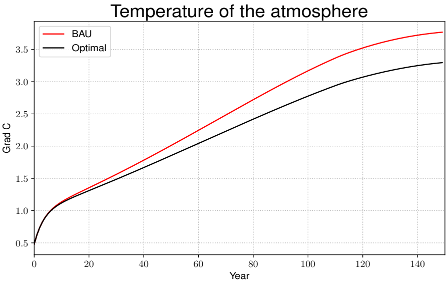


Benchmark case: emissions and climate









Benchmark case: taking stock

- Fossil fuel reduction + renewable energy increase in both regions
- Temperature of the atmosphere is $0.5C^{\circ}$ lower.

Outline of the presentation

Values from the literature

Parameter	Symbol	Value	Source
Pure rate of time preferences	ρ	0.015	[Nordhaus, 2017b]
Capital elasticity	α	0.3	[Nordhaus, 2017b]
Energy elasticity	ν	0.04	[Golosov et al., 2014b]
Intertemporal elasticity of substitution	ψ	1.5	[Cai and Lontzek, 2019]
Capital depreciation rate	δ	0.1	[Nordhaus, 2017b]
CES parameter/elasticity	$\rho^{CES}/\epsilon^{\rho}$	0.1/1.11	[Papageorgiou et al., 2017]
			[Jo, 2020]
Damages in advanced economies	ψ_1^A, ψ_2^A	0.0, 0.00236	[Nordhaus, 2017b]
Damages in developing economies	ψ_1^D, ψ_2^D	0.0, 0.00746	[Weitzman, 2012]
Technological diffusion	ϱ	[0.0625, 0.2]	[Barrett, 2021]

Table: Economic parameters

Data

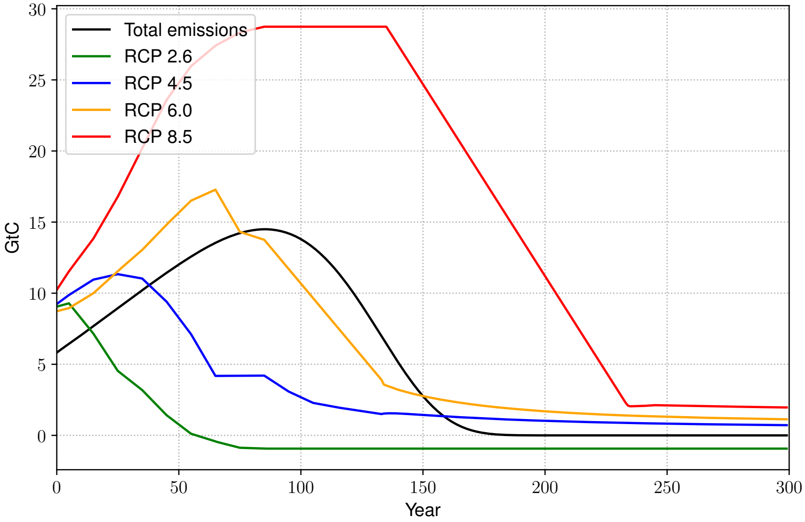
- I use Penn World Table data for capital, World Bank data for output, labor, fossil fuel and renewable energy usage to pin down initial TFP levels in production as well as in energy sectors [1]
- The weights in CES aggregator for both regions are determined according to [Golosov et al., 2014a] with Levelized Cost of Electricity (LCOE) proxies for prices from IEA and IRENA databases

$$\frac{p^i_{dt}}{p^i_{cl}} = \frac{\kappa^i_{dt}}{\kappa^i_{cl}} \left(\frac{E^{i,dt}_t}{E^{i,cl}_t} \right)^{\rho^{CES}-1} . \tag{31}$$

- Emission intensity exogenous evolution is chosen the way to match RCP6.5 data.

[1] Fossil fuel and renewable energy usage is not available for the low-income countries in absolute values, but is available from World Bank data until year 2014 as share of the total energy usage.

Emissions



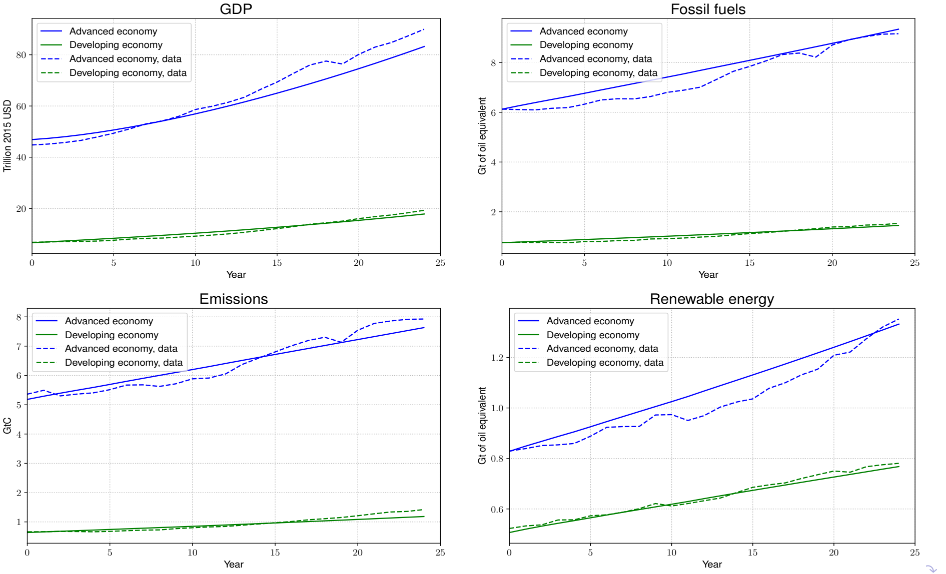
Total emissions
RCP 2.6
RCP 4.5
RCP 6.0
RCP 8.5
GtC
Year
30
25
20
15
10
5
0
0
50
100
150
200
250
300

Values pinned by data

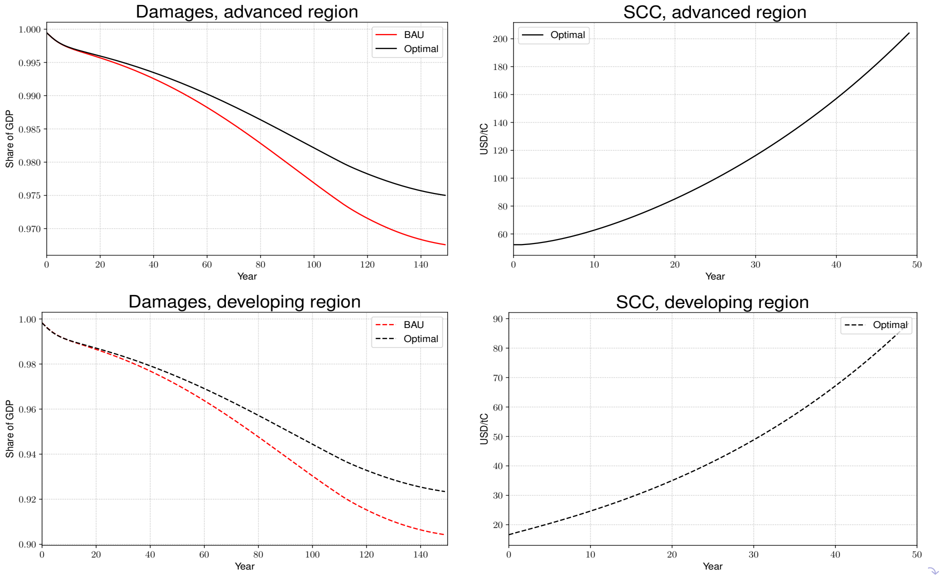
Parameter	Symbol	Value	Source
Initial TFP, A	A_0^A	0.0115	match output in A in 1990
Initial TFP, D	A_0^D	0.00251	match output in D in 1990
TFP growth	g^A	0.025	match GDP growth in A and D
Initial TFP in FF, A	$A_{dt,0}^A$	0.0458	match FF in A in 1990
TFP growth in FF, A	g_{dt}^A	0.012	match FF growth in A in 1990-2014
Initial TFP in RE, A	$A_{cl,0}^A$	0.0227	match RE in A in 1990
TFP growth in RE, A	g_{cl}^A	0.014	match RE growth in A in 1990-2014
Initial TFP in FF, D	$A_{dt,0}^A$	0.00712	match FF in D in 1990
TFP growth in FF, D	g_{dt}^A	0.01	match FF growth in D in 1990-2014
Initial TFP in RE, D	$A_{cl,0}^A$	0.0232	match RE in D in 1990
TFP growth in RE, D	g_{cl}^A	0.001	match RE growth in D in 1990-2014
CES weight of FF, A	κ_{dt}^A	0.75	LCOE, [Golosov et al., 2014a]
CES weight of RE, A	κ_{cl}^A	0.25	–//–
CES weight of FF, D	κ_{dt}^D	0.82	–//–
CES weight of RE, D	κ_{cl}^D	0.18	–//–

Table: Energy parameters

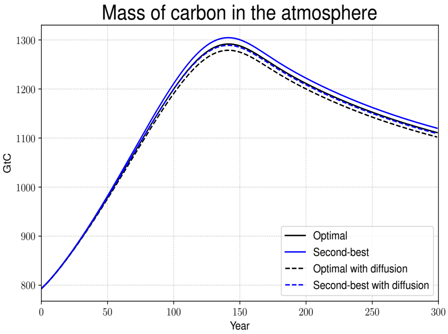
Matched data

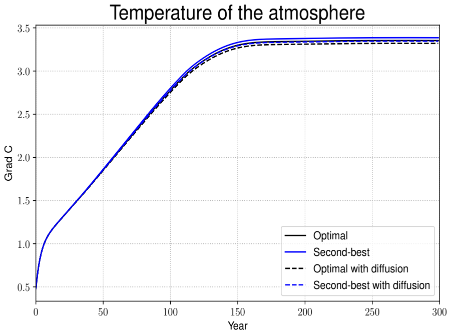


Benchmark case: damages and SCC



Case of interest: climate





World Bank classification by income level

Countries are split in groups based on GNI per capita in 2021:

- Low-income economies: $1,085 or less
- Lower middle-income economies: $1,086 and $4,255
- Upper middle-income economies: $4,256 and $13,205
- High-income economies: $13,205 or more

Back

Low-income economies

Afghanistan	Guinea-Bissau	Somalia
Burkina Faso	Korea, Dem. People's Rep	South Sudan
Burundi	Liberia	Sudan
Central African Republic	Madagascar	Syrian Arab Repub
Chad	Malawi	Togo
Congo, Dem. Rep	Mali	Uganda
Eritrea	Mozambique	Yemen, Rep.
Ethiopia	Niger	Zambia
Gambia, The	Rwanda	
Guinea	Sierra Leone	

Table: Economies with GNI less than $1,086 per capita

Lower-middle-income economies I

Angola	India	Philippines
Algeria	Indonesia	Samoa
Bangladesh	Iran, Islamic Rep	São Tomé and Principe
Benin	Kenya	Senegal
Bhutan	Kiribati	Solomon Islands
Bolivia	Kyrgyz Republic	Sri Lanka
Cabo Verde	Lao PDR	Tanzania
Cambodia	Lebanon	Tajikistan
Cameroon	Lesotho	Timor-Leste
Comoros	Mauritania	Tunisia
Congo, Rep.	Micronesia, Fed. Sts.	Ukraine

Table: Economies with GNI between $1,086 and $4,255 per capita

Lower-middle-income economies II

Côte d'Ivoire	Mongolia	Uzbekistan
Djibouti	Morocco	Vanuatu
Egypt, Arab Rep.	Myanmar	Vietnam
El Salvador	Nepal	West Bank and Gaza
Eswatini	Nicaragua	Zimbabwe
Ghana	Nigeria	
Haiti	Pakistan	
Honduras	Papua New Guinea	

Table: Economies with GNI between $1,086 and $4,255 per capita

Upper-middle-income economies I

Albania	Fiji	Namibia
American Samoa	Gabon	North Macedonia
Argentina	Georgia	Palau
Armenia	Grenada	Paraguay
Azerbaijan	Guatemala	Peru
Belarus	Guyana	Russian Federation
Belize	Iraq	Serbia
Bosnia and Herzegovina	Jamaica	South Africa
Botswana	Jordan	St. Lucia

Table: Economies with GNI between $4,256 and $13,205 per capita

Upper-middle-income economies II

Brazil	Kazakhstan	St. Vincent and the Grenadines
Bulgaria	Kosovo	Suriname
China	Libya	Thailand
Colombia	Malaysia	Tonga
Costa Rica	Maldives	Türkiye
Cuba	Marshall Islands	Turkmenistan
Dominica	Mauritius	Tuvalu
Dominican Republic	Mexico	
Equatorial Guinea	Moldova	
Ecuador	Montenegro	

Table: Economies with GNI between $4,256 and $13,205 per capita

High-income economies I

Andorra	Greece	Poland
Antigua and Barbuda	Greenland	Portugal
Aruba	Guam	Puerto Rico
Australia	Hong Kong SAR, China	Qatar
Austria	Hungary	Romania
Bahamas, The	Iceland	San Marino
Bahrain	Ireland	Saudi Arabia
Barbados	Isle of Man	Seychelles
Belgium	Israel	Singapore
Bermuda	Italy	Sint Maarten (Dutch part)

Table: Economies with GNI more than $13,205 per capita

High-income economies II

British Virgin Islands	Japan	Slovak Republic
Brunei Darussalam	Korea, Rep.	Slovenia
Canada	Kuwait	Spain
Cayman Islands	Latvia	St. Kitts and Nevis
Channel Islands	Liechtenstein	St. Martin (French part)
Chile	Lithuania	Sweden
Croatia	Luxembourg	Switzerland
Curaçao	Macao SAR, China	Taiwan, China
Cyprus	Malta	Trinidad and Tobago

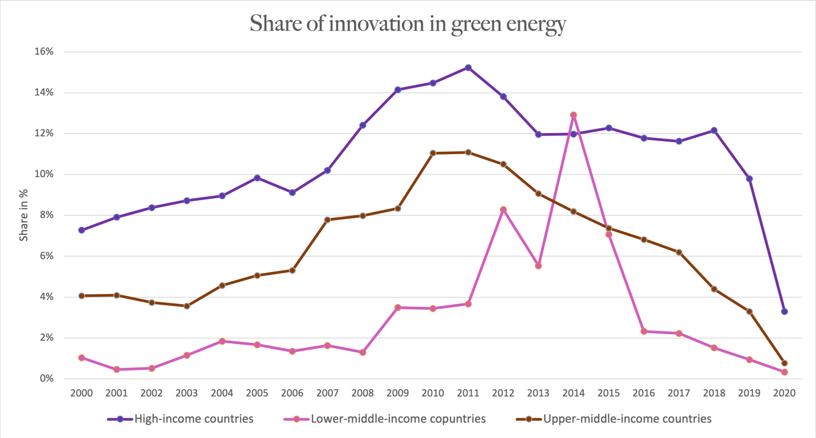
Table: Economies with GNI more than $13,205 per capita

High-income economies III

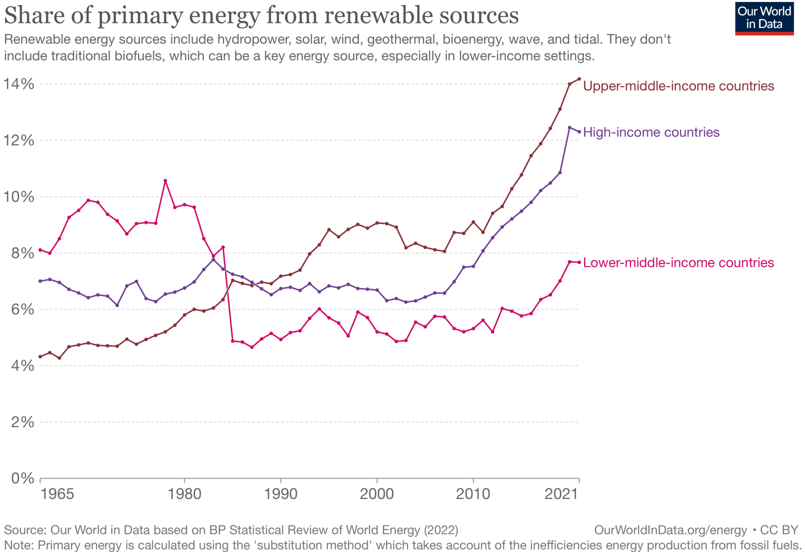
Czech Republic	Monaco	Turks and Caicos Islands
Denmark	Nauru	United Arab Emirates
Estonia	Netherlands	United Kingdom
Faroe Islands	New Caledonia	United States
Finland	New Zealand	Uruguay
France	Northern Mariana Islands	Virgin Islands (U.S.)
French Polynesia	Norway	
Germany	Oman	
Gibraltar	Panama	

Table: Economies with GNI more than $13,205 per capita

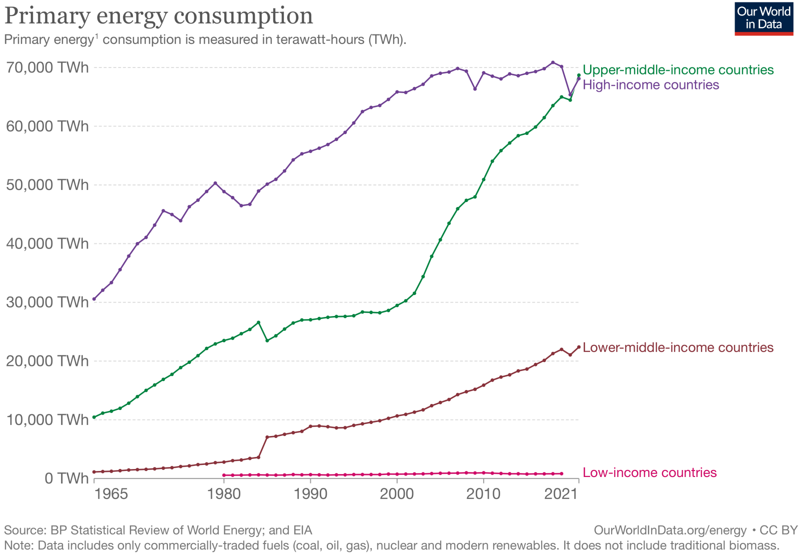
Share of green innovations among all the innovations



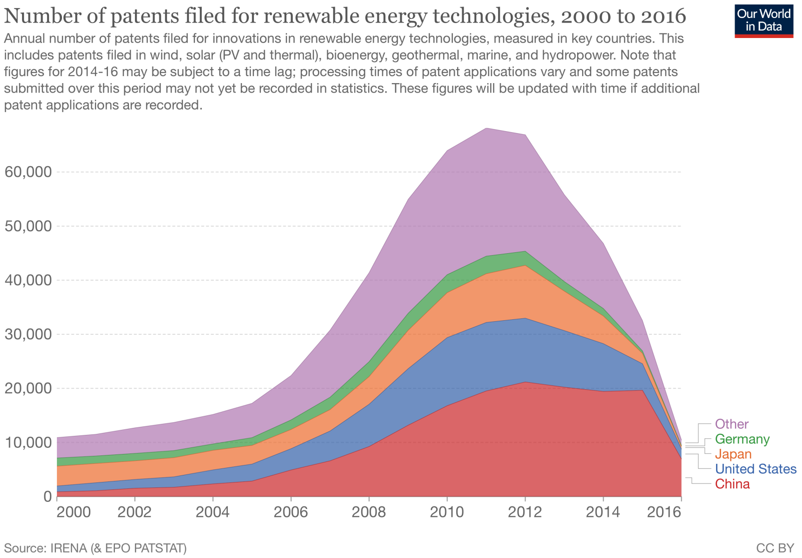
Green energy usage



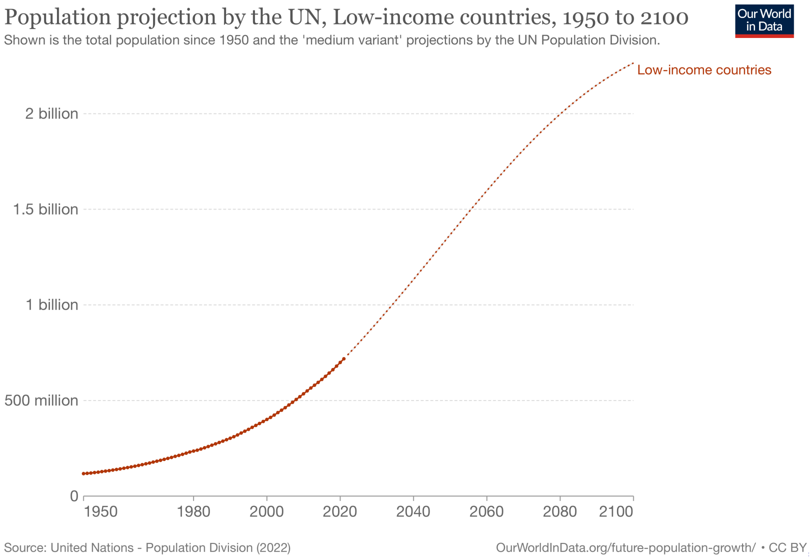
Energy consumption and economic well-being



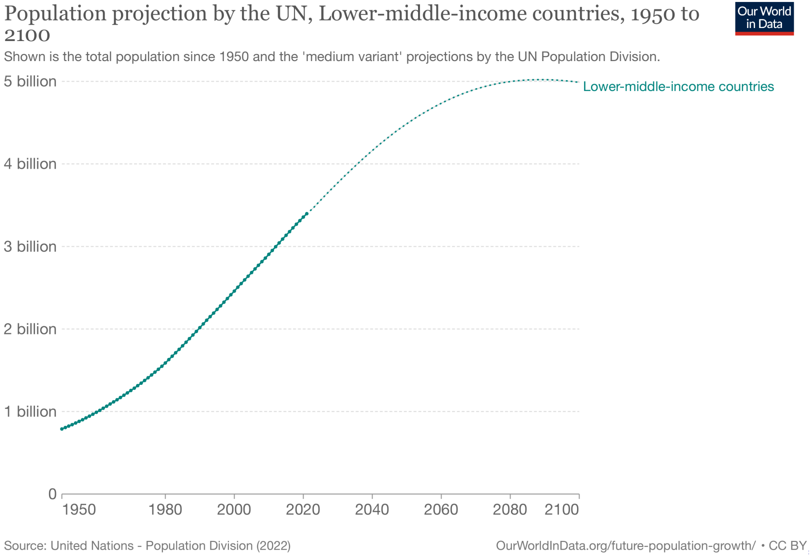
Geography of innovations in green technology



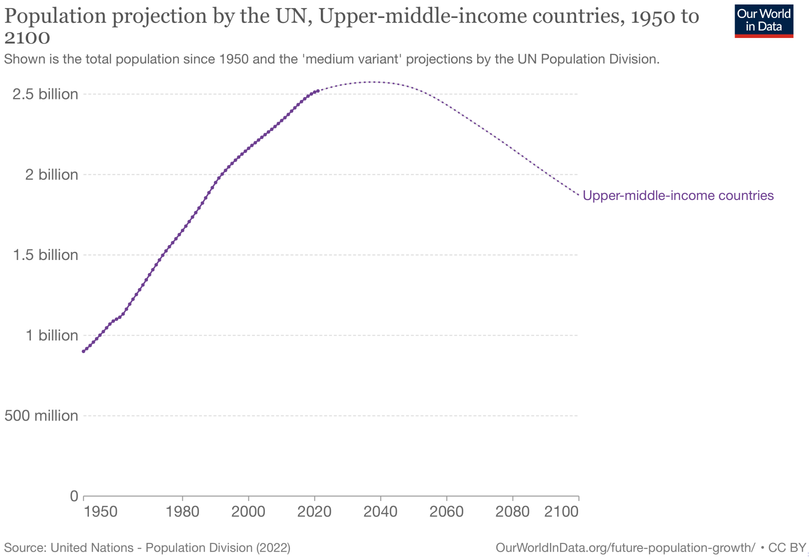
Population projections for low-income countries



Population projections for lower-middle-income countries



Population projections for upper-middle-income countries



Population projections for high-income countries