Sustainable Macroeconomics, Climate Risks and Energy Transitions

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Usual approaches: Market - or Growth-oriented

=> Market orientation:

- Providing the right market incentives for energy transition
- But there is some significant short-termism (Haldane, BoE)

=> Long-run growth orientation

- Rely on long-run growth models and policies
- But many of the IAM, DICE, DSGE, or NK models miss important components of the issues

=> Macroeconomic orientation:

- We bring the tradition of medium-run macroeconomics to the forefront to respond to the challenges of climate change
- And want to answer the question of what **Macroeconomics** is needed to address the challenges of climate risks?
- Test macro tools, instruments, and policies have proven useful, yet often multiple (conflicting) goals

⇒ Our new book "Sustainable Macroeconomics, Climate Risks, and Energy Transitions
Presents Dynamic Modeling, Empirics, and Policies

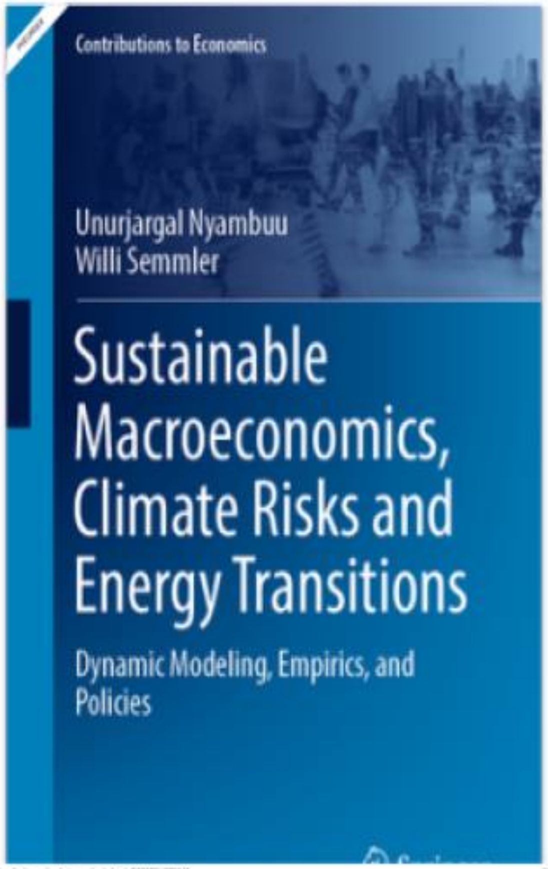


Figure: Recent Book, Springer Publishing House, July 20

I. Introduction; Outline/Motivation

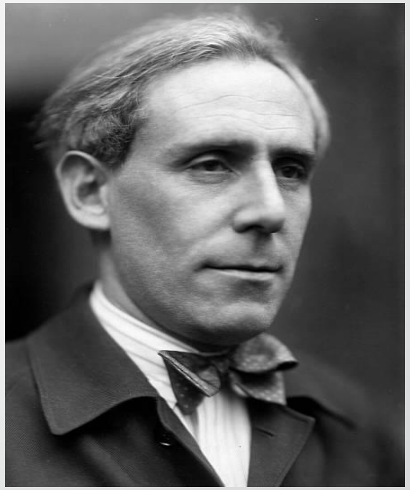
- I. Introduction: I leave aside chs. 1-5 of our Book; The fossil fuel resource-based growth, creating the challenges of Climate Change
- II. Causation– Long-run Growth, CO_2 Emission, Temperature?
- III. Mitigation efforts and decarbonization: How to flatten (reverse) the emission curve?
- IV. Driver 1 of decarbonization: Global economy
- V. Driver 2 of decarbonization: Private sector
- VI. Driver 3 of decarbonization: Financial sector
- VII. Driver 4 of decarbonization: Public sector
- VIII. Driver 5 of decarbonization: Multiple sectors
- IX. Conclusions

1. Introduction; From Climate Change to Climate Risks => Extreme Weather Events

I. Introduction; Research on Extreme Events: Emil Julius Gumbel

(New School Professor: 1940-1945, then 1953 Columbia)

Emil Julius Gumbel, Mathematician, statistician, economist, (1891-1966); Professor in Heidelberg, until 1932



=> (1935), Les valeurs extrêmes des distributions statistiques

⟹ (1958), Statistics of Extremes, CUP

⟹ **Extreme value theory: Extreme events in**

- Financial markets: Large financial crashes
- Climate economics: Extreme weather events

⟹ **IPCC 5 assessment** reports since 1988

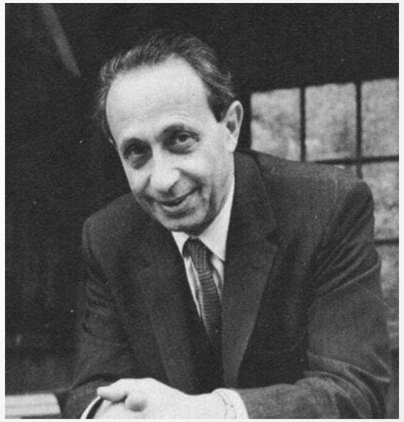
Gumbel: "It seems that the rivers know the theory.
It only remains to convince the engineers of the validity of this analysis"

I. Introduction; Research on Ethics of the Future; Intertemporal justice and fairness

(New School Philosophy Professor: Hans Jonas (1903–1993)

"Act so that the effects of your action are not destructive of the future possibility of life... the new imperative addresses itself to the public policy...Kant's categorical imperative was addressed to the individual..."

"The Imperative of Responsibility"



II. Causation – GDP, CO_2 Emission, and Temperature

=> Economic growth of advanced countries since 1850: GDP per capita increased annually by 2% and overall by a factor of 10 (GDP 15 times higher)

=> Use of fossil fuel resources for industrialization, rise of living standard per capita generating externalities and climate risks

=> Data: Need for Long-run data sets of economic growth...
=> Data: The externalities creating CO_2 emission and climate risks, measures...

World GDP dataset

- World GDP annual growth rates from 1871 to 2012
- Sources:
  - Angus Maddison (2009), Historical Statistics of the World Economy
  - World Bank (2013), World Development Indicators Online
- World GDP growth rates are derived from GDP country-level estimates expressed in 1990 International GK dollars

II. Causation – GDP, CO_2 Emission, and Temperature

Data: OWID-CO_2, => Country data, sectoral data;

=> Gallegati, Ramsey, and Semmler (2016)

=> Wavelet theory -- Filtering out different time scales

Global CO2 emissions dataset

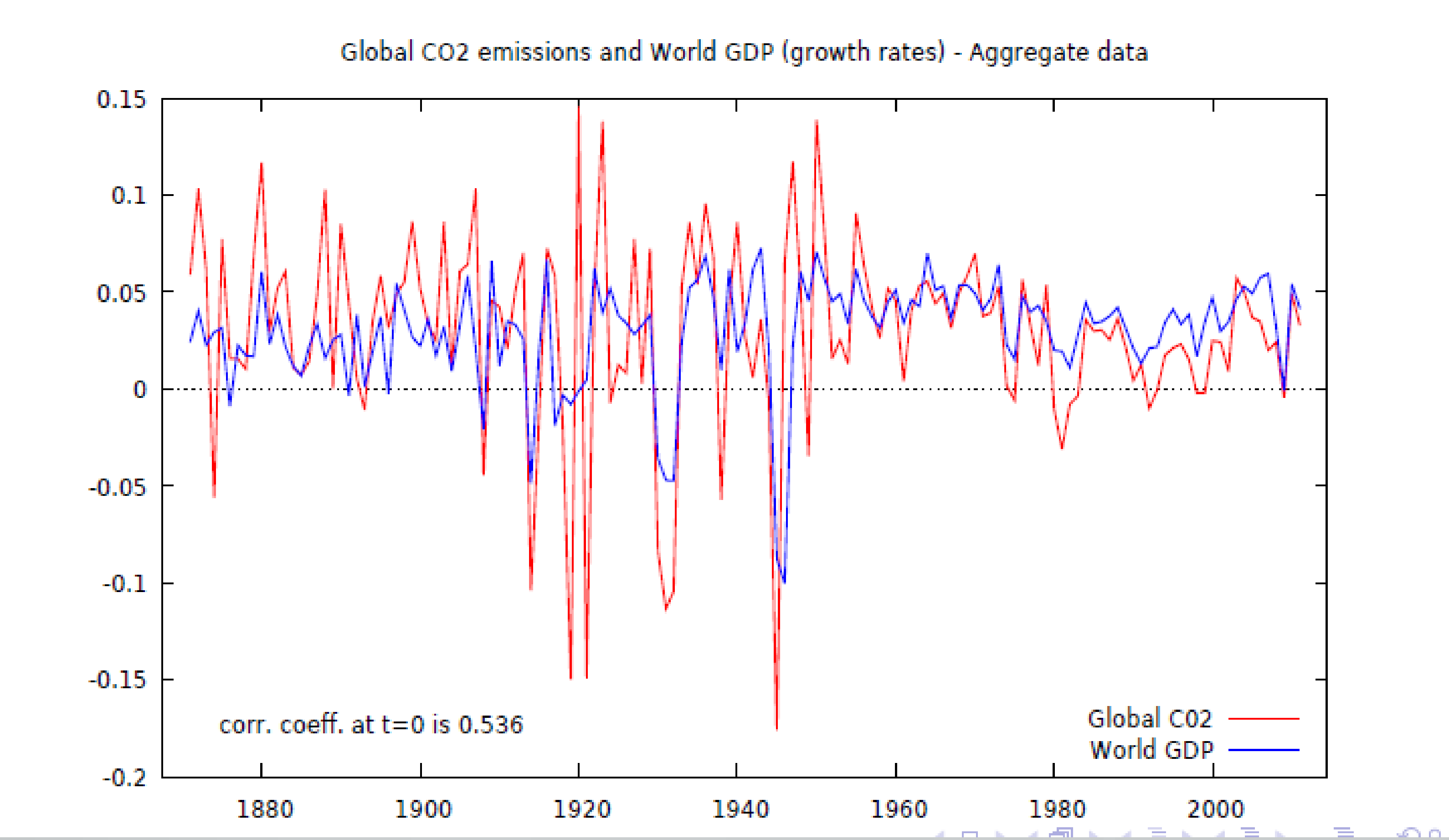
- Global CO2 Emissions from Fossil-Fuel Burning (Gas, Liquids, Solids): 1751-2011
- Sources:
  - Tom Boden and Bob Andres, Carbon Dioxide Information Analysis Center Oak Ridge National Laboratory, USA
  - Gregg Marland, Research Institute for Environment, Energy and Economics, Appalachian State University, USA
- All emission estimates are expressed in units of carbon dioxide (CO2)

II. Causation – GDP, CO_2 Emission, and Temperature

Frequency domain interpretation of different scale levels

Scale level J	Detail level D_j	Annual frequency resolution
1	D_1	2-4
2	D_2	4-8
3	D_3	8-16
4	D_4	16-32
5	S_4	greater than 32
5	D_5	32-64
6	S_5	greater than 64

II. Causation – GDP, CO_2 Emission, and Temperature



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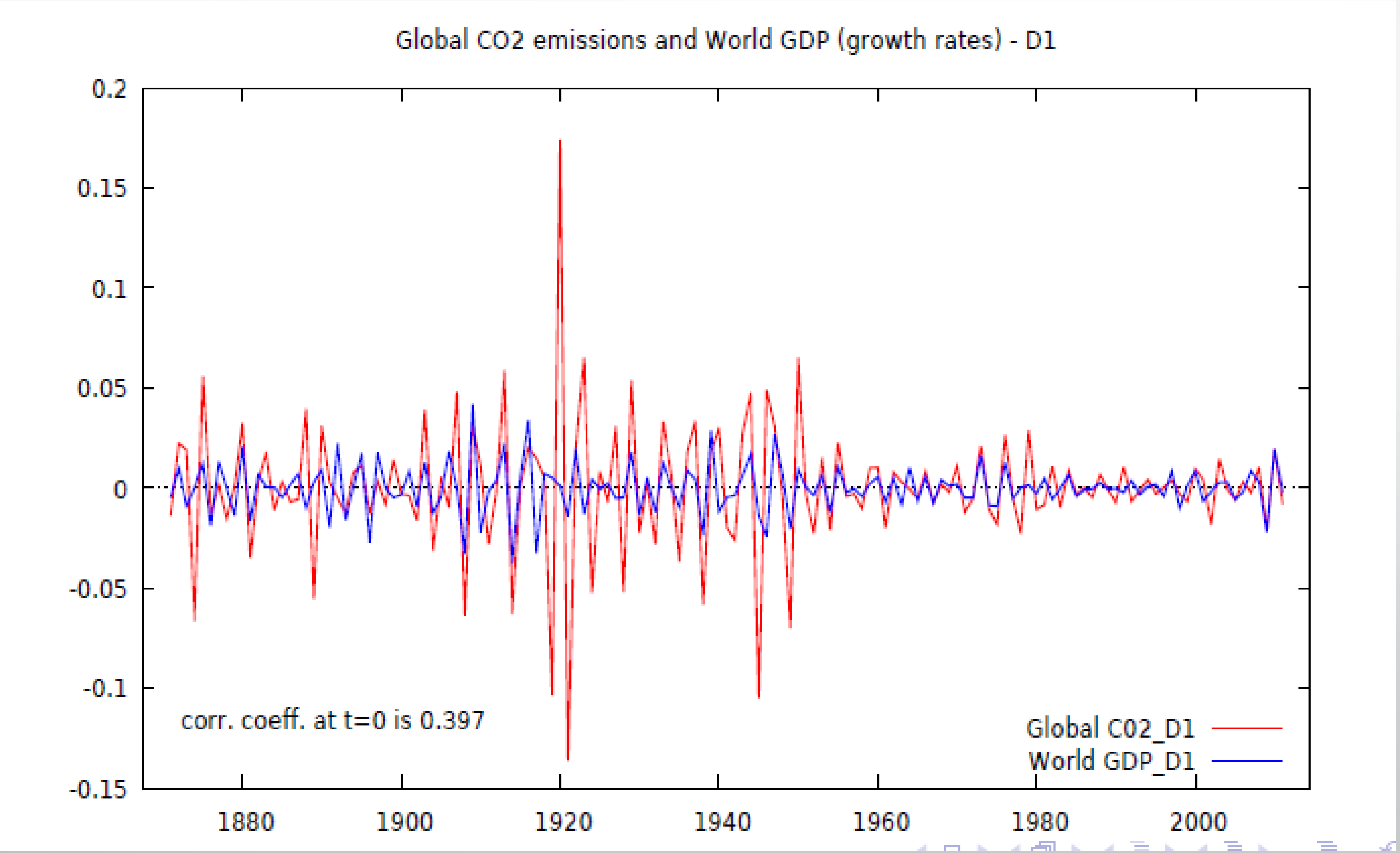

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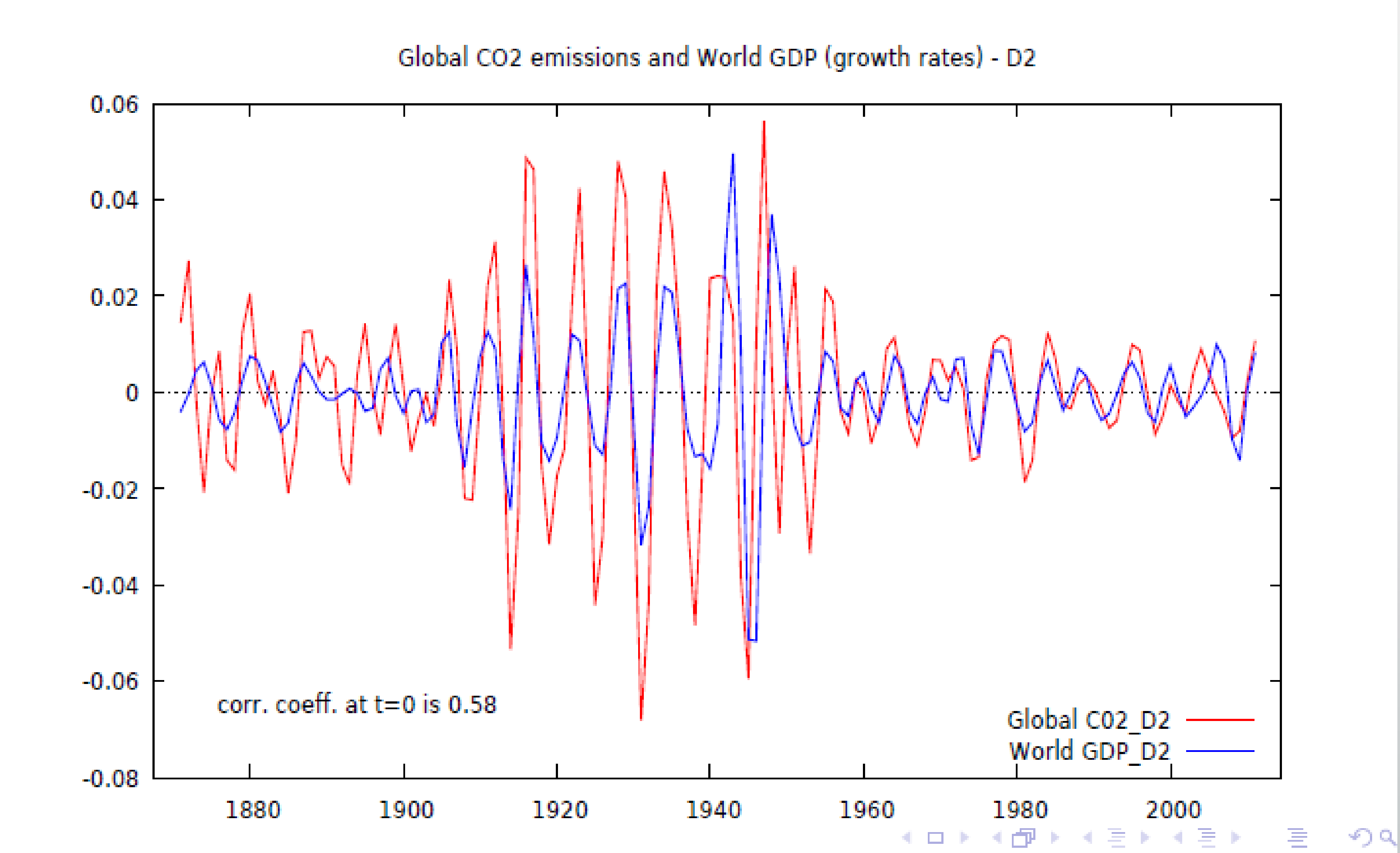

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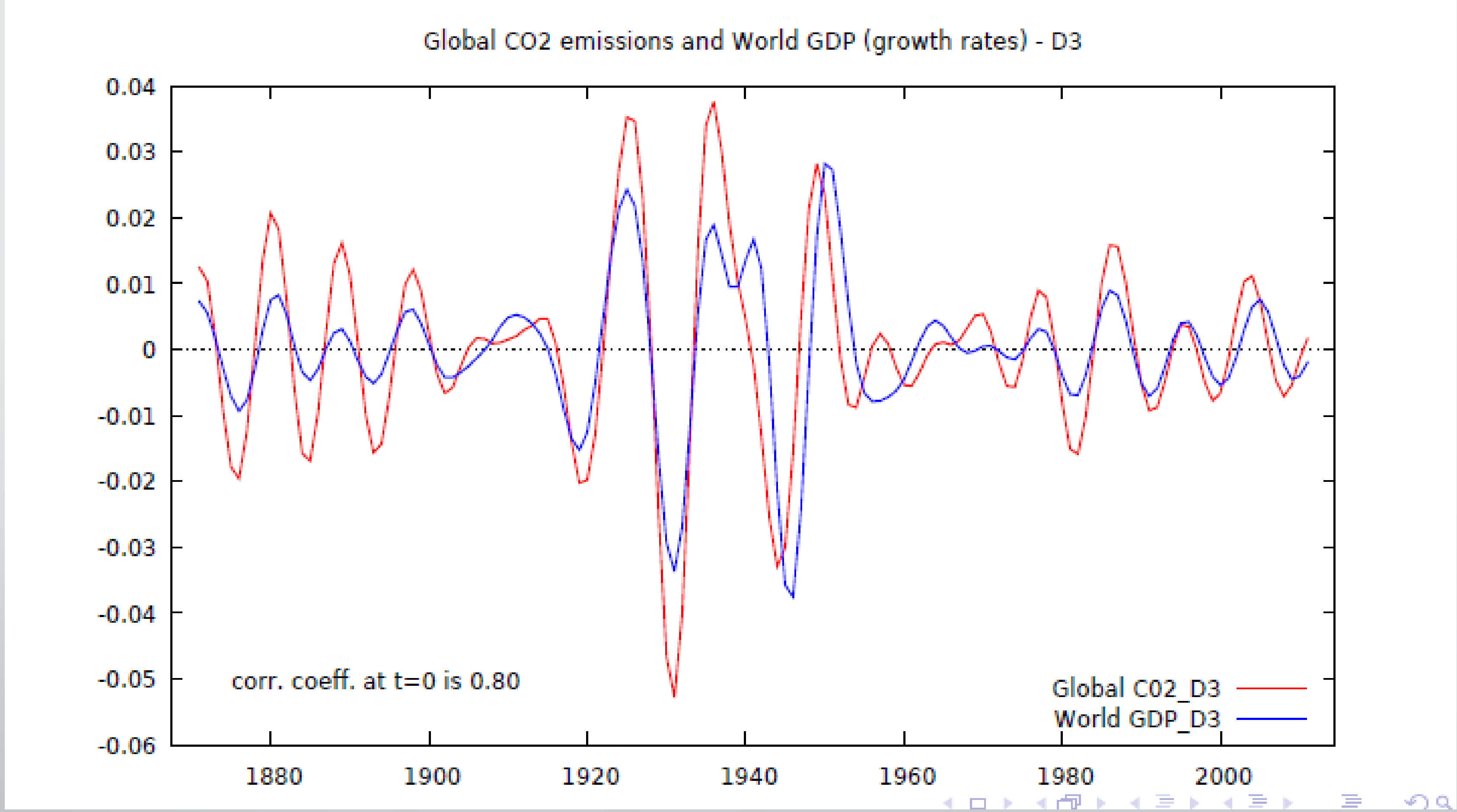

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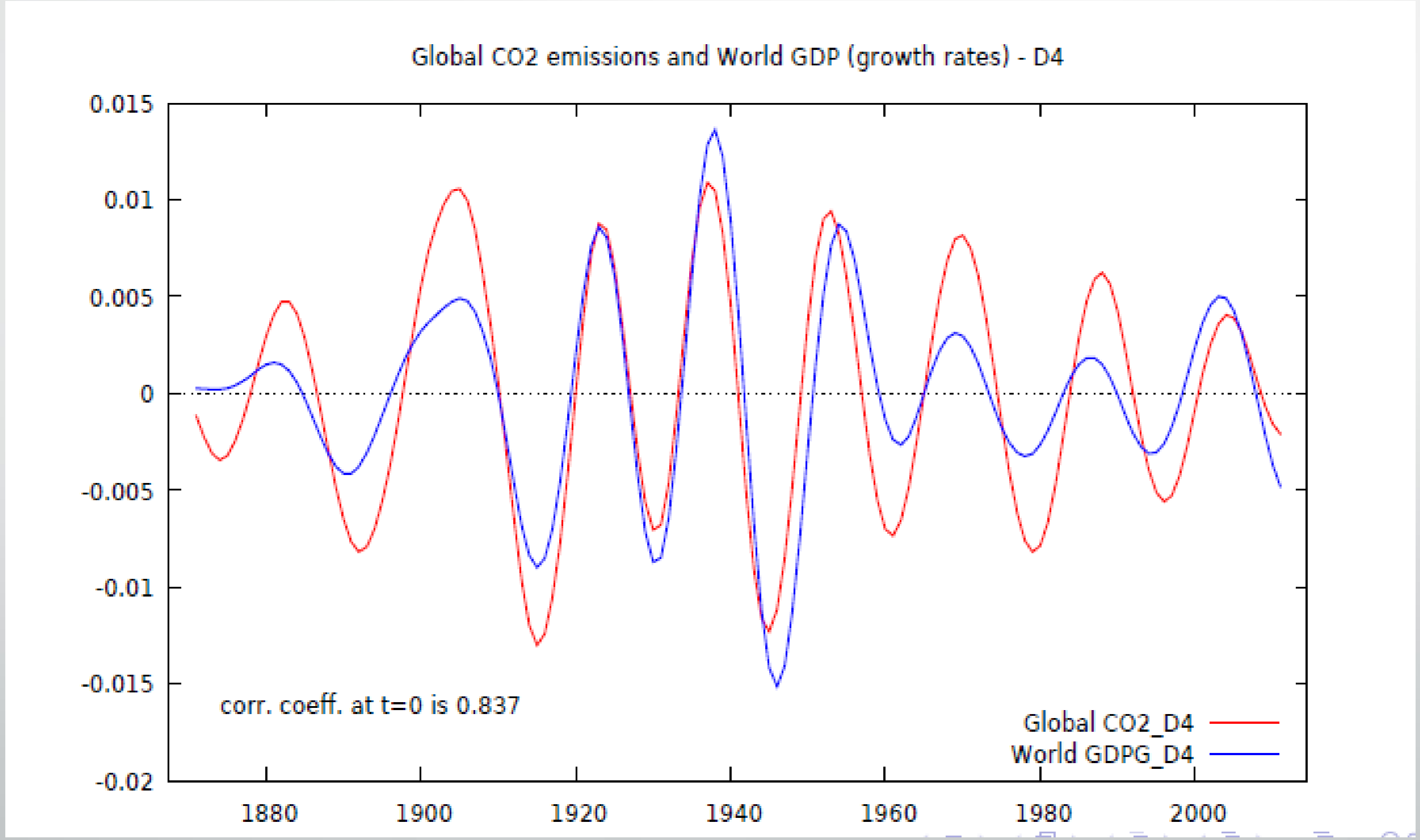

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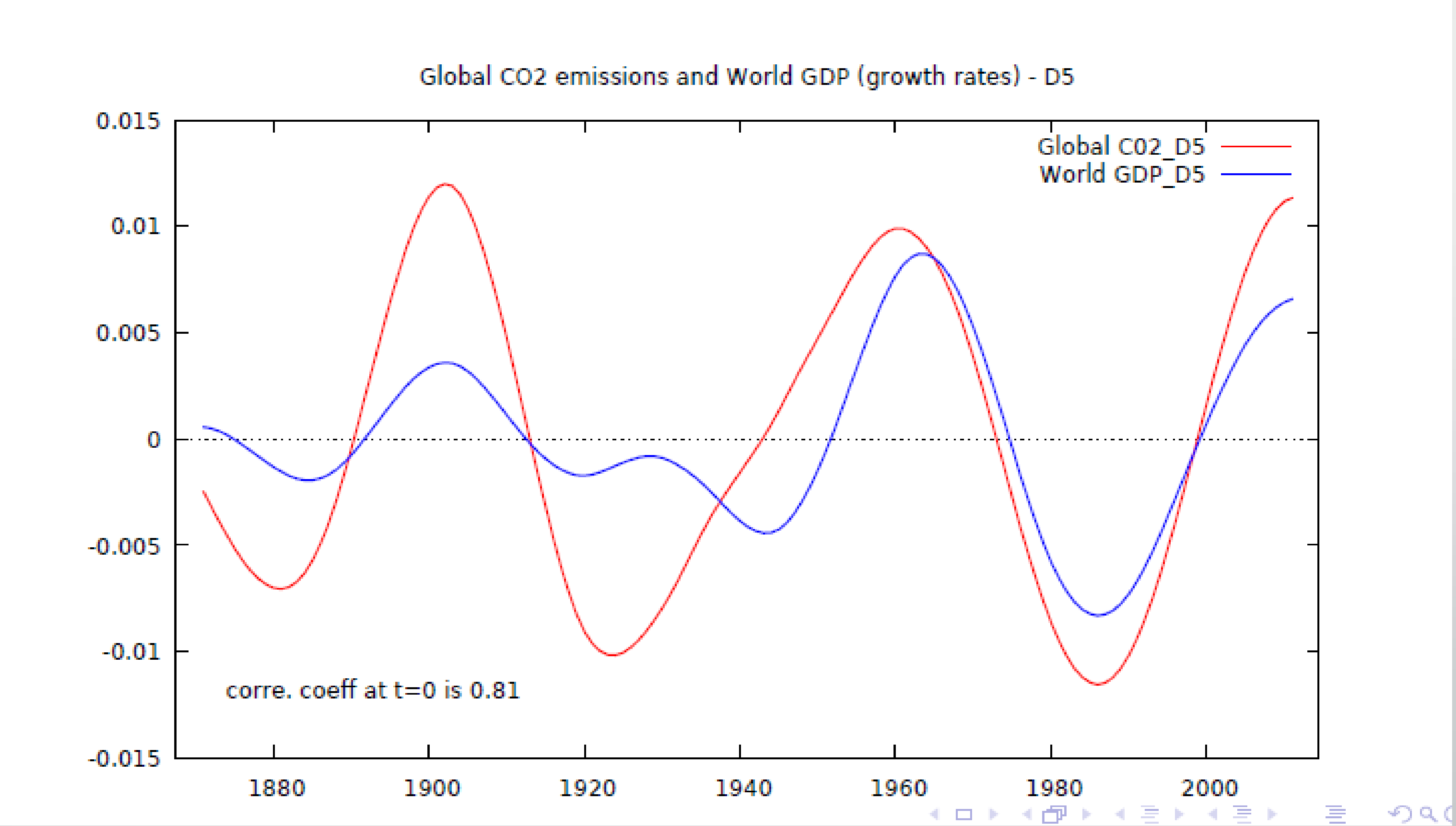
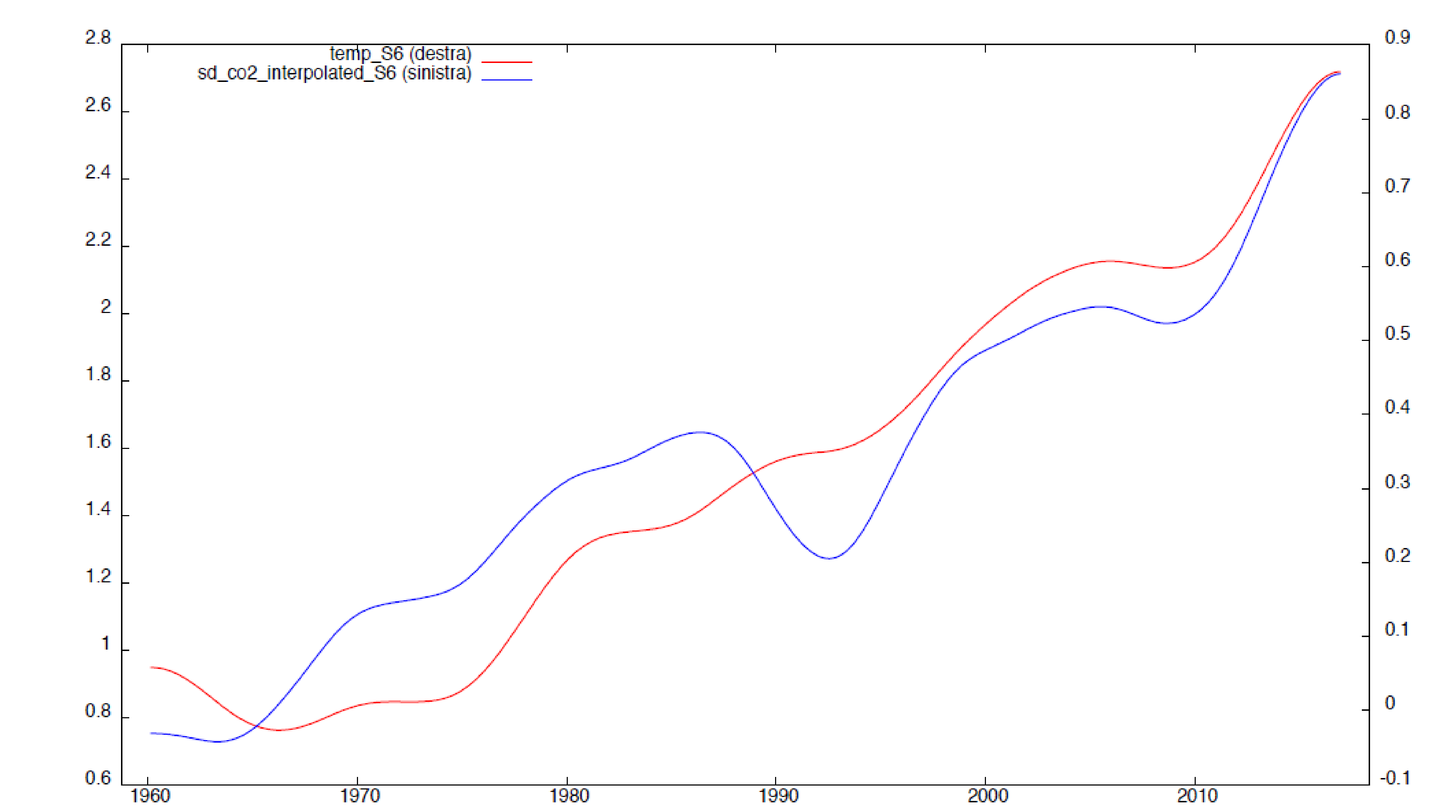


II. Causation – GDP, CO_2 Emission, and Temperature

Left scale: CO_2; Right scale: Temperature, using wavelets



II. Causation => Flattening (reversing) the emission curve?

GDP per capita increase from 1880: 12 times higher; Is there a Kuznets Environmental Curve? See IMF papers, with Loungani et al. (2018), Data Source: Owid-CO2

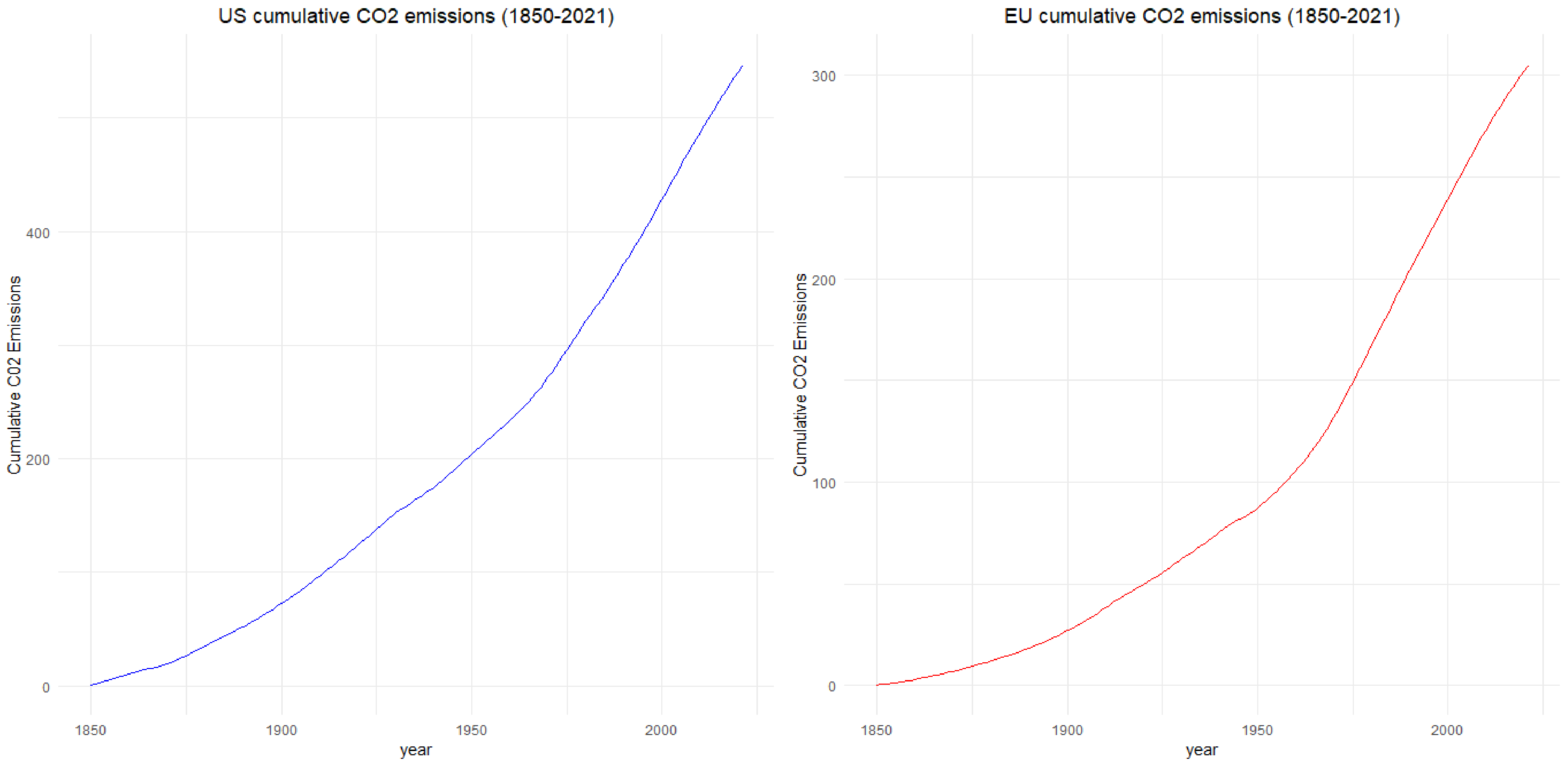
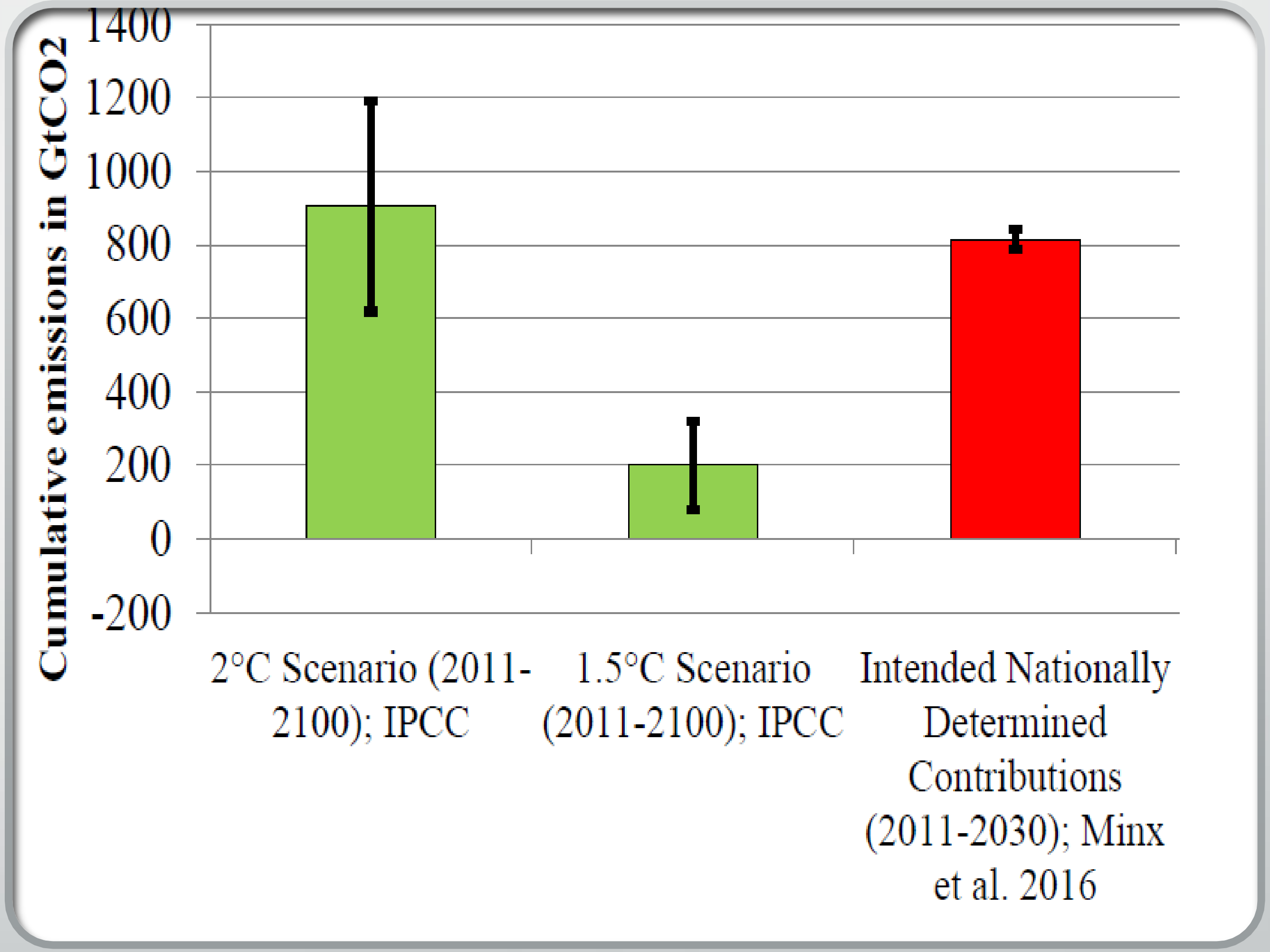


Figure 2: Cumulative Emissions in Giga Tones Plotted from 1850 to 2021, source: Owid-CO2

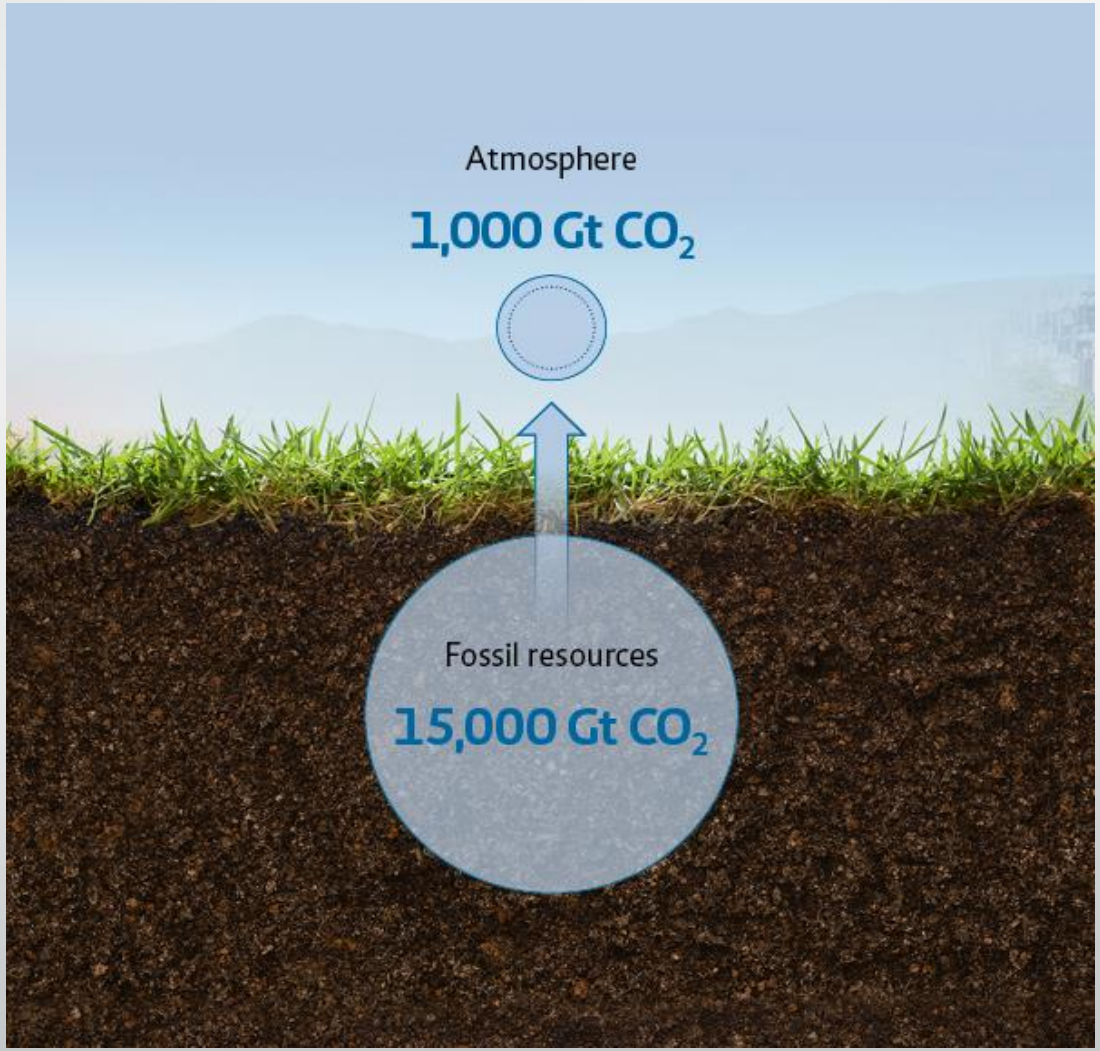
II. Causation – Carbon Budget? Paris (2015) policy targets, see Edenhofer et al. (2014), PIK research

=> Paris (2015) Target:

- Reduction of 50 % (65%) of net emissions until 2030
- Zero net emission by 2050
- Klimarat (May 2024)



II. Causation – Carbon Budget? ; Where are we now? At the upper constraint of 400 ppm Edenhofer et al. (2014), PIK research



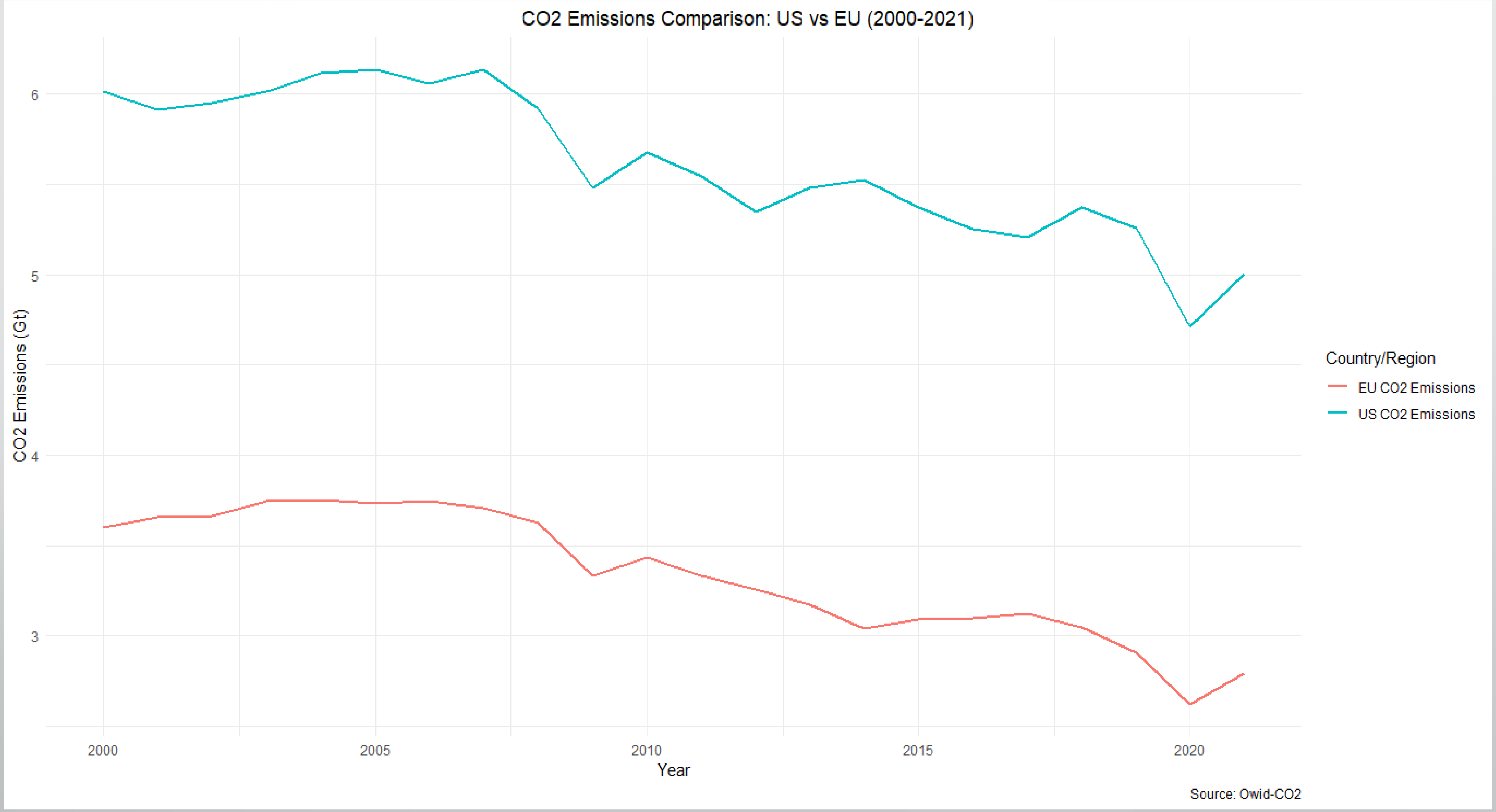
II. Causation, Carbon Budget and Tipping points? and long-term trends

(see Keller et al. 2015, and Hansen, Greiner et al. (2010), Tipping Surface, Haider et al. (2022)

- Probable **temperature** rise makes temperature rising (Hansen), by the end of the century 2-4 C
- **Arctic sea ice** is likely to disappear (next 10 years? probably sooner), and s**ea levels** are likely to rise by 28-43cm, up to 80 cm, 5- 6 meters? (depending on collapse of Greenland Ice shields)
- Permafrost (release of more CO2 and Methane), Russia this summer
- Collapse of Ocean circulations, see Keller et al (2015)
- It is very likely that parts of the world will see an increase in the frequency **of flooding, heat waves, desert formation, draughts, desert formation, forest fires, landslides)**
- Climate change is likely to lead to increased severity/intensity of **air turbulence**, **tropical storms, Hurricanes, Typhoons** since the 1990s already heavy
- Tipping points and a) **higher frequency**, and b) **long run changes**: impact on ecosystem, water supply, costal conditions, health, productivity of agriculture and food supply, labor working conditions

III. Mitigation Efforts and Energy Transition? - Can we achieve flattening (reversing) of the emission curve? Lower growth rates of emission

But: It requires lower and then near zero growth rates of net zero emission until 2050



III. Mitigation Efforts and Energy Transition?– The tasks are how to flatten (or reverse) the curve?

How to achieve lower growth rates and then net zero emissions for 2050

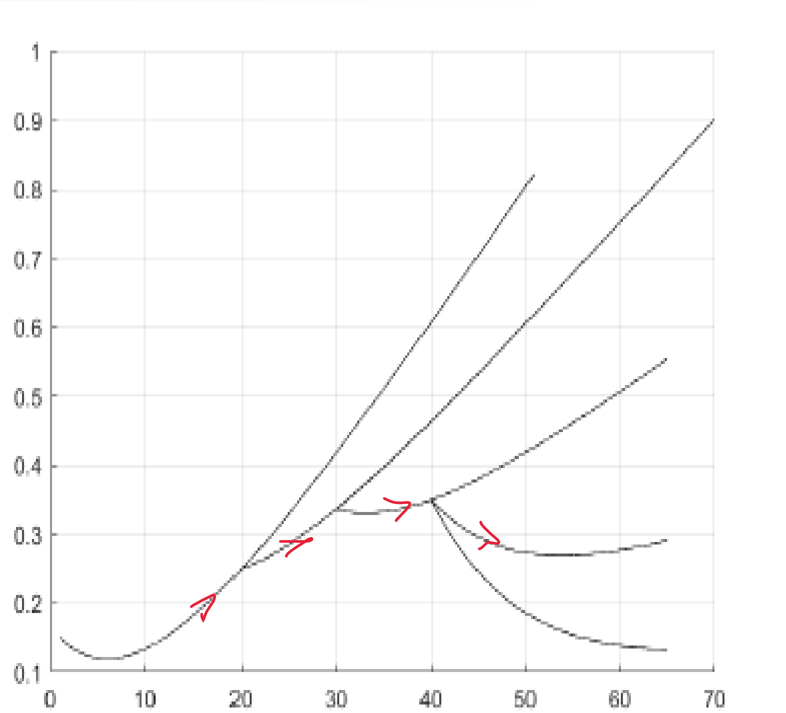
$$\dot{ce}(t) = -\alpha * ce(t) + log(e^{(g_{ce}t)})$$

=> mitigation measures

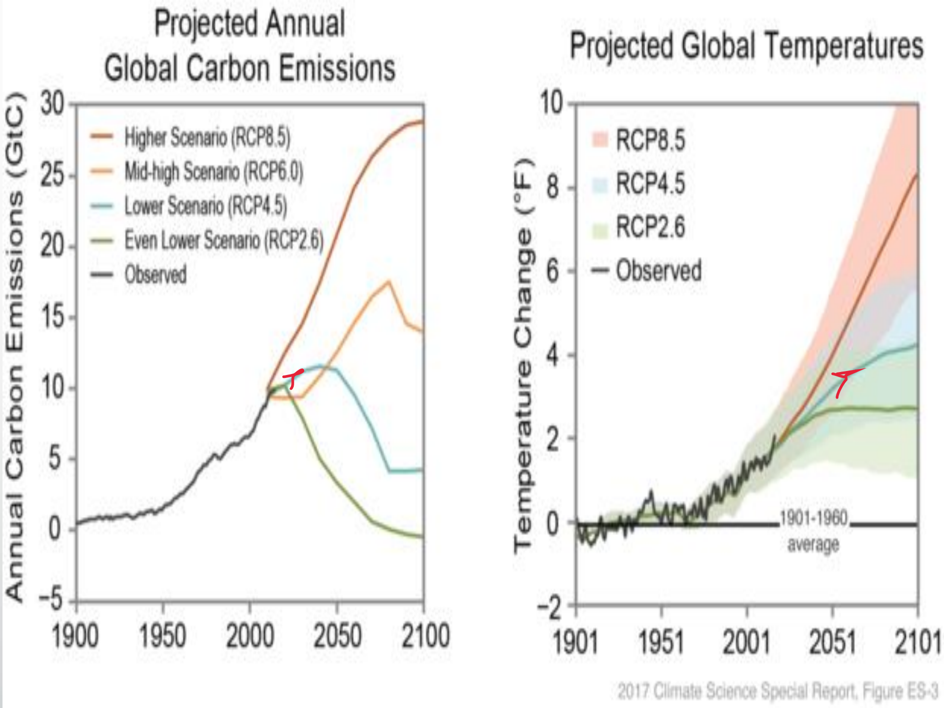
- Less output
- Standards, regulation
- Energy conservation
- Cap&trade
- Carbon tax-subsidies
- New energy technology
- Financial instruments
- Macro policies
- Sectoral policies

=> Drivers but also

Obstacles?



Non-stationary carbon emission simulated; starting from the upper curve: gce = 0.002, gce = 0.0015, gce = 0.001, gce = 0.0005, and gce =0.0001, only the lowest growth rate is not only flattening the curve but reversing it

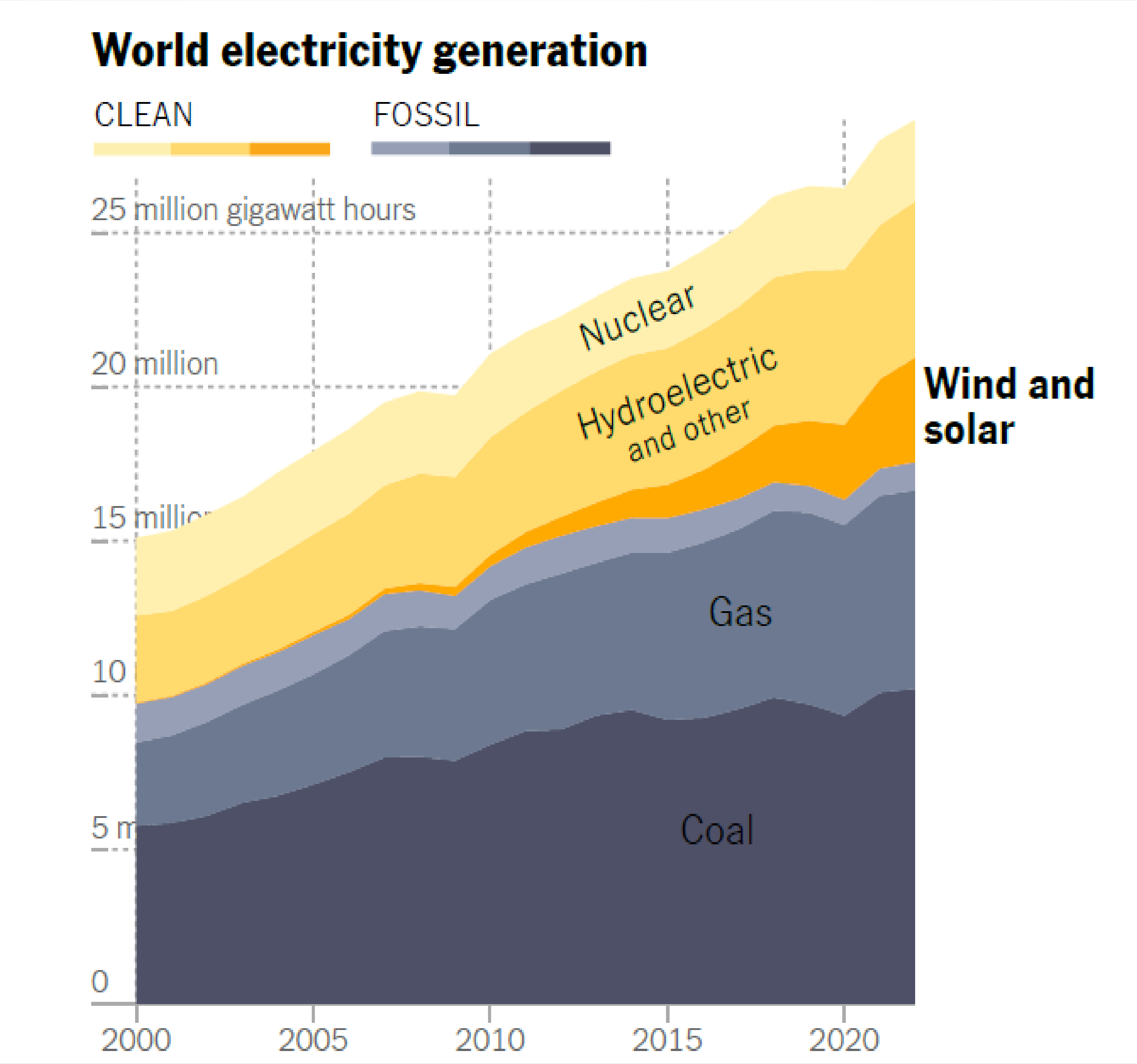


NOAA National Centers for environmental information, 2022

IV. Driver 1: Global economy and energy transition – Increase of global green electricity generation

⇒ Drivers: There are global negotiations (COP) and other drivers; UN, IMF WB, populist movements ..., but also

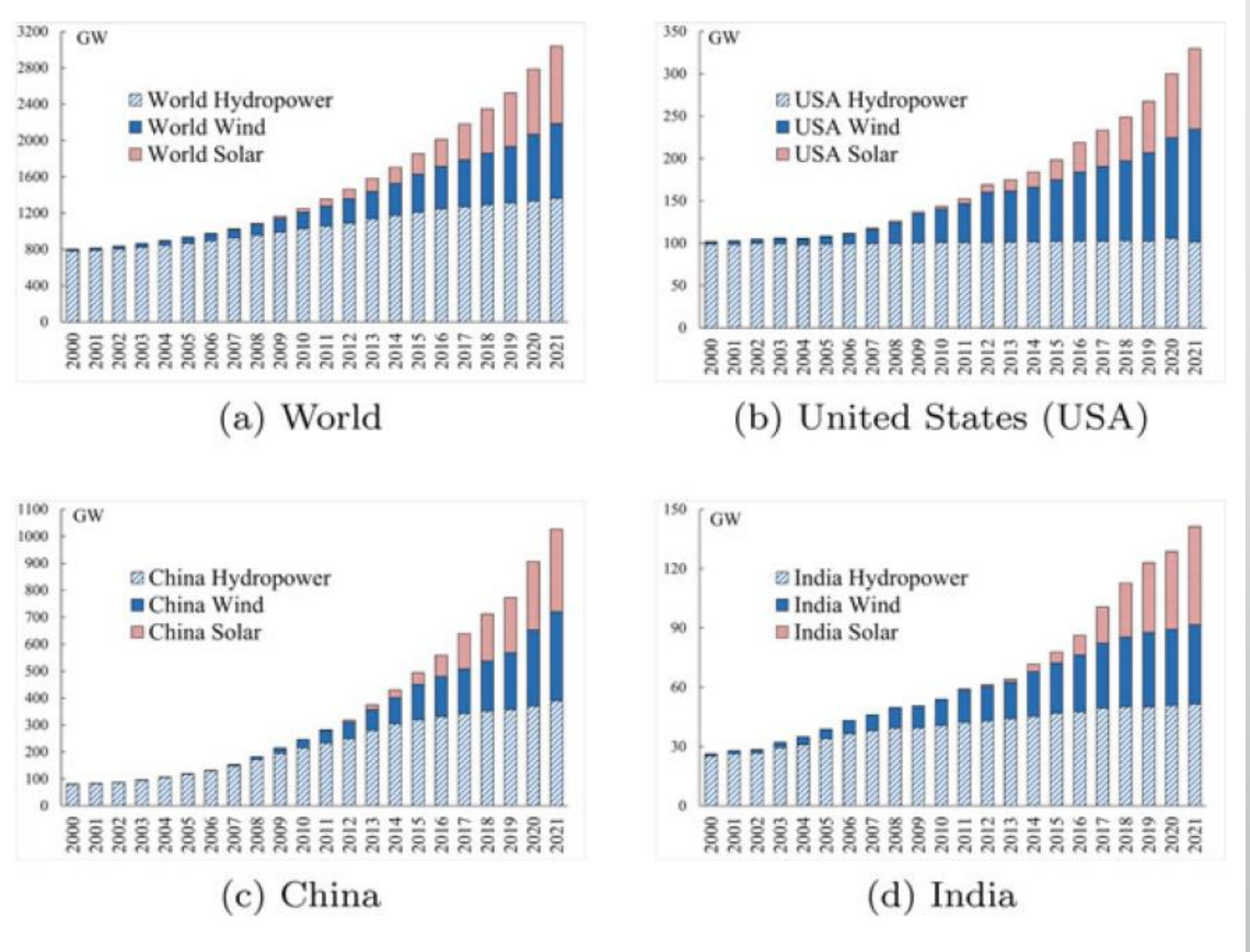
⇒ **Obstacles**: Public opinion dynamics; irreversibilities, lock-ins, leakages, Non-participation, policy games, and resistance from fossil fuel companies, Chs. 10



IV. Driver 1: Global economy and energy transition – Increase of global green energy investments

=> Major issues worldwide:

- If there are worldwide efforts of decarbonization
- Should all countries have the same targets and efforts for decarbonization?
- What should be the burden sharing; with financing flows to low-income and emerging market countries?



IV. Driver 1: Global economy and energy transition=> Burden sharing? Country group specific targets?

=> A model of **Fair Transition:**

- K=capital stock
- Y=output; $Y = Z(Z_K K + Z_S S)^{\omega}$
- C=consumption (or gap)
- R=Remaining fossil fuel resource
- S=extraction of fossil fuel
- m= stock of extracted fossil fuel
- E=emission
- λ = target relative to preindustrial emission (1880)

$$\max_{C,S} \int_0^T e^{-\theta t}\left(ln(C) - \tau(E - E^*)^2\right) dt$$

s.t.

$$\dot{K} = Y - C - \delta K - \varrho(R^0 - m)^{-2} S$$

$$\dot{R} = \varphi(R^0 - m - R - R^b) - S$$

$$\dot{E} = \vartheta S - \varsigma(E - \lambda E^*)$$

$$\dot{m} = S$$

IV. Driver 1: Global economy and energy transition=>Burden sharing? Country-group specific targets?

Groups of countries:

=> targets

λ = target relative to

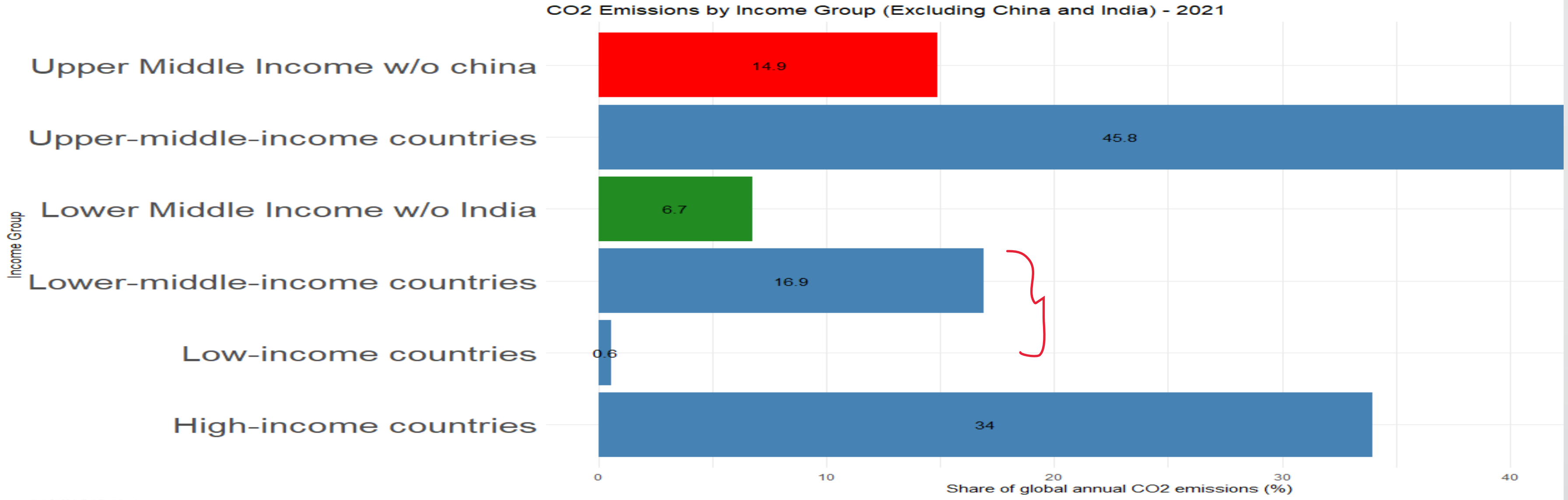
pre-industrial emission (1880)

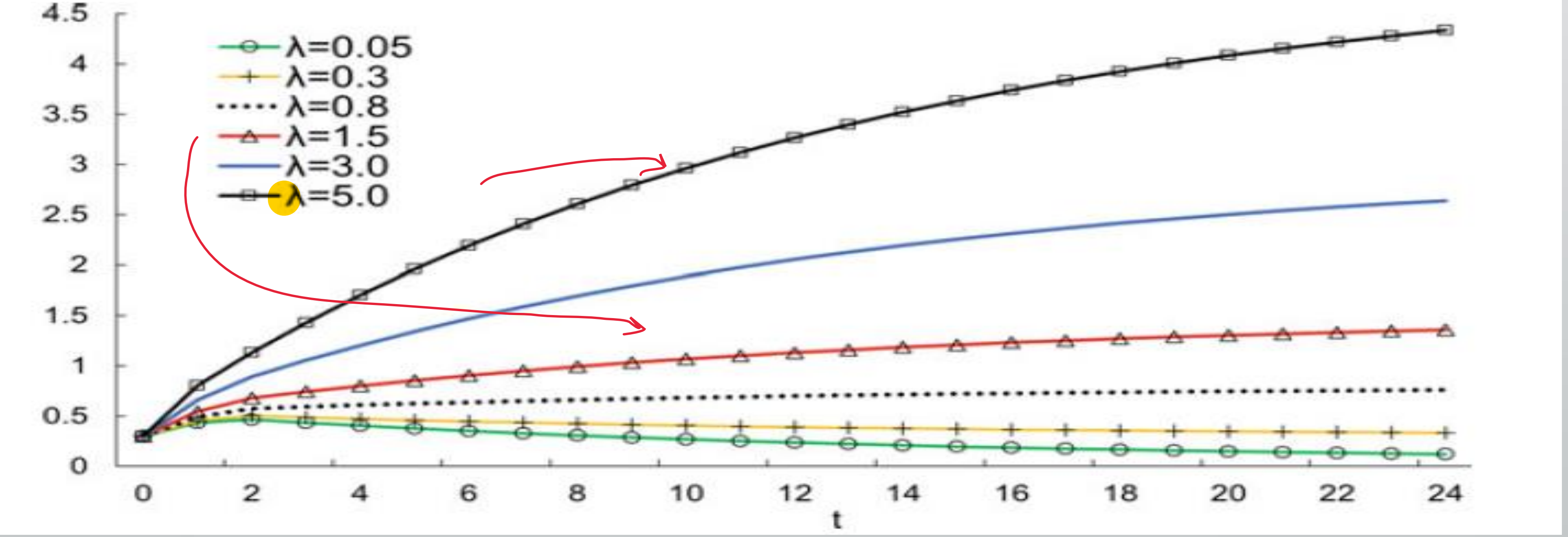
Higher carbon emission path of EMC, but a much lower share in world emission

=>Burden sharing

- Flow of finance,
- Technology transfer

=> Obstacles: Not sufficient support





V. Driver 2: Private sector=>Phasing out fossil fuel, phasing in renewable energy, but there are barriers to entry (Ch. 8 of the book)

Can renewable energy firms enter the energy market? => Entry and competition barriers

- There are dominant fossil firms (subsidized oligopolies) dominating the energy markets
- They set up entry barriers and undertake entry deterrent investments
- A limit pricing model of model of Gaskins and Judd et al. can be used, see also Semmler et al.
- There are new entrants, success or failure of new entrants can be explained in 3 model versions

Oil companies	Fracking companies
China Petroleum & Chemical Corp. (SNP)	Chevron Corp. (CVX)
PetroChina Co. Ltd. (PTR)	Exxon Mobil Corp. (XOM)
Saudi Arabian Oil Co. (Saudi Aramco)	ConocoPhillips Co. (COP)
Royal Dutch Shell PLC (RDS. A)	Halliburton (HAL)
BP PLC (BP)	
Exxon Mobil Corp. (XOM)	
Total SE (TOT)	
Chevron Corp. (CVX)	

V. Driver 2: Private sector => Inventions, innovations, and risks of failure: Death Valley

=> Nordhaus; Climate Casino..ch. 23, There is technological, market and financial risks ; Acemoglu et al, (2012), Agion et al. (2022

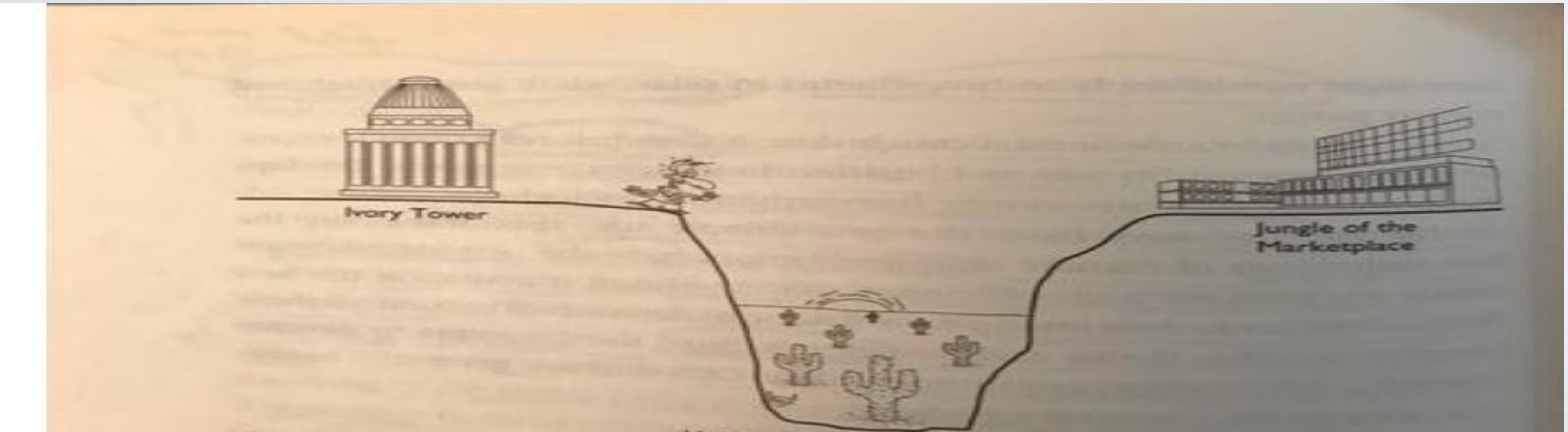


Figure 40. Few innovations survive the transition from scientific laboratories to the marketplace.

- ⟹ Innovation and diffusion dynamics (of CO_2 reducing technologies) need to be supported by de-risking by public innovation policies (Arrow) (but there could be an issue of lock-in, B. Arthur)
- ⟹ But when it is developed and ready to be phased in, there are usually entry barriers
- ⟹ Entry barriers/barriers to competition:
- ⟹ Lock-ins (Brian Arthur)

Model versions: I. defensive incumbents, II. evolutionary models and III.game theoretic models

V. Driver 2: Private sector => Entrants and Incumbents- Entry/Competition Barriers

Brock (1980s), Gevorkyan/Semmler (2016)

Model Version I: Defensive Incumbents; Entry and competition deterring barriers 1) **Entry** barriers (IO literature, see Bain): capital requirements, credit cost, economies of scale, advertisement, customer loyalty; 2) **Competition** barriers (lawyers, political lobbying, patents ..)

$$\max_{x} \int_0^T e^{-rt} [pq - C(q) - x - \varphi(x)] \, dt$$

$$\dot{E} = x - \delta_E E$$

where E is the competition-deterring capital,[3] x is the investment in it, and δ_E is the depreciation rate of that capital. In Eq. (2), competition-deterring capital can be represented by the dominant energy firms' efforts to restrict competition, for example, by political lobbying, investment into entry deterring capital, protection of innovations through patents, advertising efforts, and coalition formation.[4] We conveniently assume that the price is a function of the market share of the dominant firms:

$p = p(s)$ for $0 \leq s \leq$

$q = sd(p).$

$C(q)$ is the cost of production

$R(s) = p(s)sd(p)$

$$p(s) = p^c + (p^m - p^c)$$

$$d = b - ap$$

V. Driver 2: Private sector=> Entrants and Incumbents- - Entry Barriers

Gevorkyan/Semmler (2016)

multiple equilibria

Table 1
Parameters and steady states.

	SS1 (attractor)	SS2 (repellor)	SS3 (attractor)
Entry-deterring capital $E(0)(p^m = 8)$	0	30.05	37.4
Entry-deterring capital $E(0)(p^m = 7)$	0	32.5	35.5
Entry-deterring capital $E(0)(p^m = 6)$	0	0	0

Example: $r = .02, \delta_E = .15, \rho = 5, \chi = 10, c = .001, \alpha = .5, p^m = 8,7,6 p^c = 2, b = 10, a = .5$.

V. Driver 2: Private sector=> Entrants and Incumbents: Market Dynamics; Thresholds – entry barriers; but can be reduced through policies

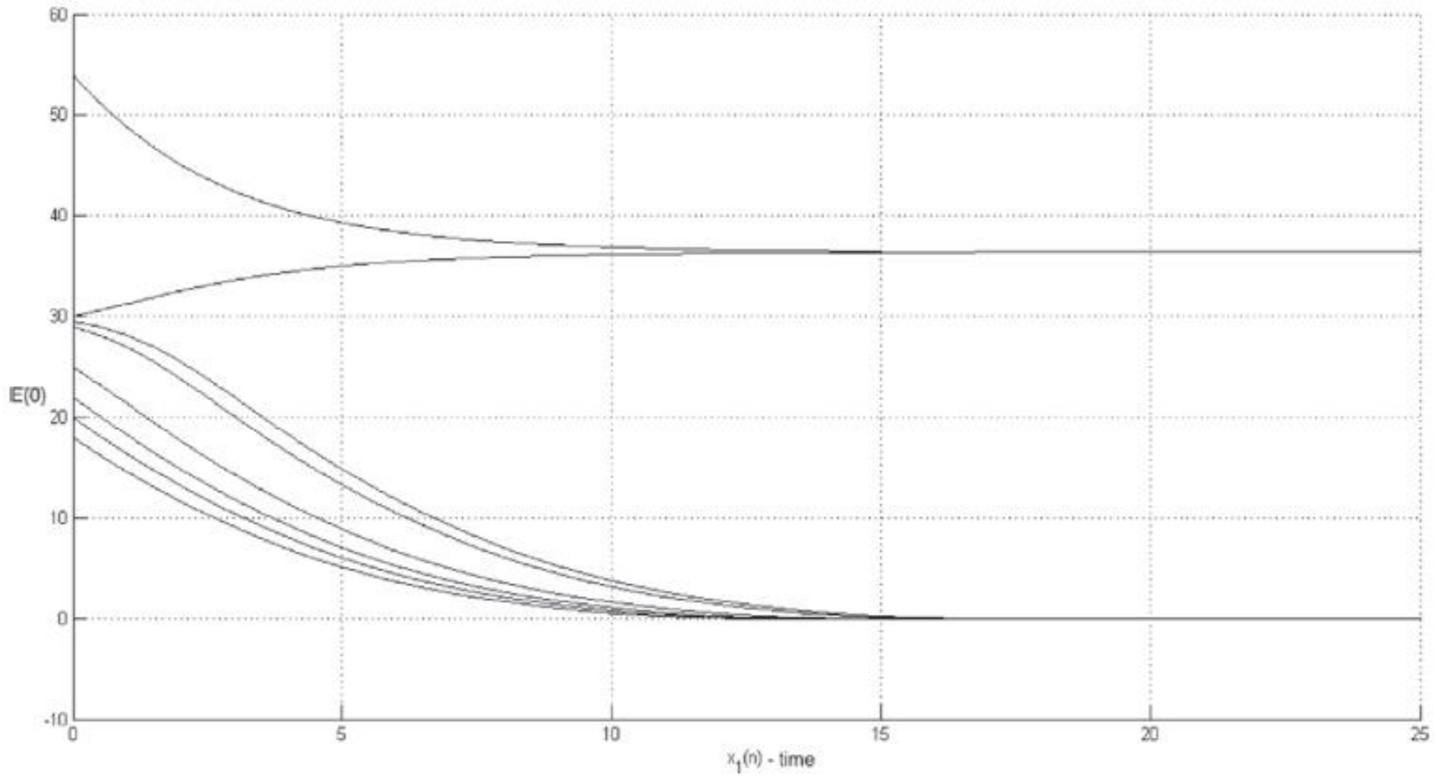


Fig. 1. Multiple equilibria; upper two trajectories, convergence to dominant firms' market share, higher markup, high attracting market share, reached from initial condition E(0)=30.05; declining trajectories represent declining market share due to competition below threshold E(0)=30.05, $p^m = 8$.

V. Driver 2: Private sector=> Entrants and Incumbents; Phasing in of new energy firms

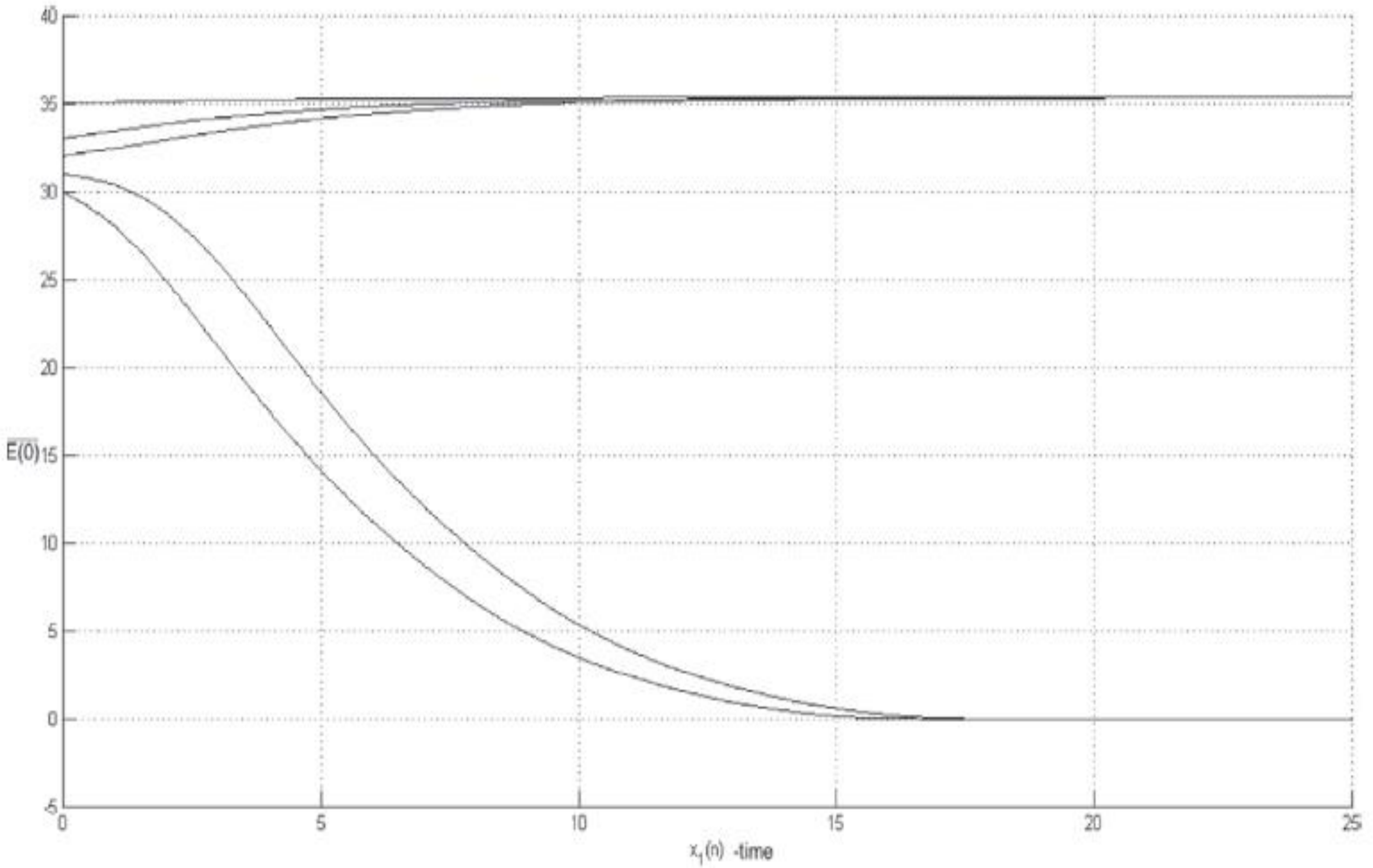


Fig. 2. Loss of dominance, market share shrinking, even with large initial capital and market share, loss of dominance due to lower markup, E(0)=32.5, p = 7.

V. Driver 2: Private sector => Evolutionary models, see ch. 8 of the book

=> **Model version II**: non-innovating (incumbents) and innovating firms (active entrants): u= numbers of engineers, x_2:Innovators (active), x_1: Incumbents (passive); x_3 debt evolution

- Dynamic evolutionary models, see Brian Arthur (1989), see Braga, Semmler, and Grass (JEDC 2022)

- Technology (Pistorius & Utterback, 1996) - *entrants and incumbents:* simultaneously compete, cooperate, and have a predator-prey relationship, see also Utterback et al. (2018)

- Lotka-Volterra system, such as those applied to the bioeconomic literature (e.g.: fishery model in Clark (1976) and Semmler & Sieveking (1994)

- Heterogeneous Firm Model but with dynamic limit pricing - Judd & Petersen (1985), Gaskins (1971), Kato & Semmler (2011) with:

✓ Entrants (Innovator – Renewable Energy), with pay-off function

✓ Incumbents (Fossil Fuel Energy), but passively responding

✓ Competition among them

✓ Evolution of debt

- For conventional climate models, see also Kotlikoff et al. (2019); Acemoglu et al. (2012);

IV. Driver 2: Private sector => Evolutionary models; market dynamics with Entrants and Incumbents,

Semmler (1994), Kato/Semmler (2011), Arthur (1989), Nordhaus, Climate Casino, ch 23, Braga and Semmler (2020); evolutionary model of Lotka-Volterra type

Model version II: non-innovating (incumbents) and innovating firms: u= numbers of engineers, x_1=incumbents, x_2=entrants, x_3 debt of x_2

Multi-period Payoff function of the Entrant; Model solved through

$$\max_u V = \int_0^T e^{-\gamma t} g(x_2, x_3, u)dt$$

s.t.

$$\dot{x}_1 = k - a x_1 x_2^2 + b x_2 - x_1 e/\mu \quad (1)$$

$$\dot{x}_2 = x_2(a x_1 x_2 + v g(x_2, x_3, u) - \beta) \quad (2)$$

$$\dot{x}_3 = -g(x_2, x_3, u) - \tau x_3^2 \quad (3)$$

$$g(x_2, u) = \mu(x_2, u) x_2 u - cu - c_0 x_2 - r x_3$$

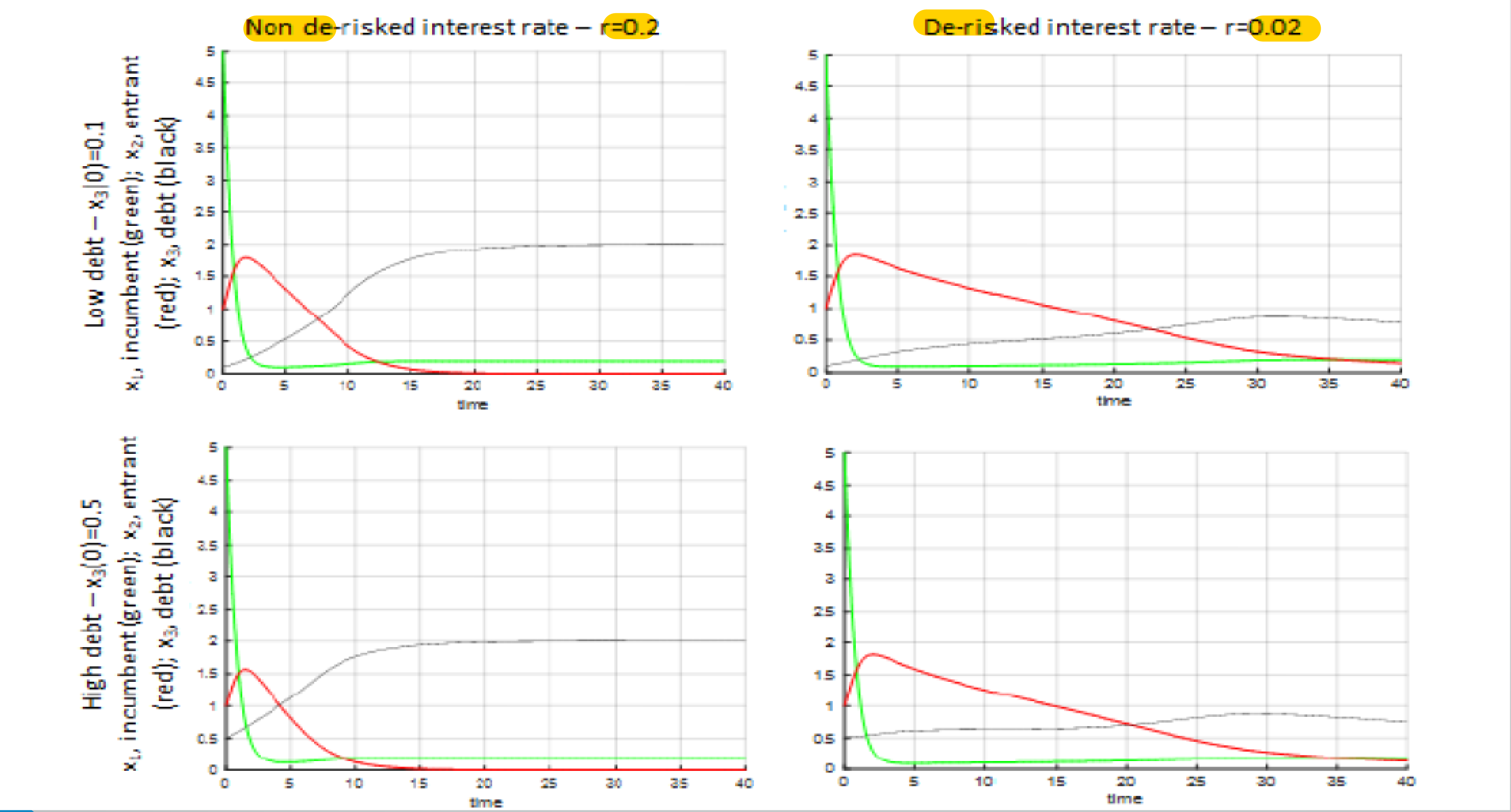
$$\mu = \alpha/(\Phi + x_2 u)$$

- x1: number of incumbent firms
- x2: number of innovator firms
- x3: external finance
- u: cooperative innovative effort
- Mu: Mark-up

V. Driver 2: Private sector => => Evolutionary models; Phasing in Renewable Energy:

Entrants, Incumbents, and Debt; Braga and Semmler, JEDC (2020); evolutionary model;

Model version II: non-innovating (incumbents) and innovating firms (entrants)



V. Driver 2: Private sector => Game theoretical models with limit pricing

Model Version III: Limit pricing and renewable energy firms into the energy sector: Game theoretical model: Semmler et al. (2022, SCED), Cournot oligopoly model and entrants; strategic interactions

Driver: => Renewable energy technology is key, but how to phase it in?

Model of entry game, with

entry barriers and limit pricing

- Dominant firms (incumbents)

  (fossil fuel firms)

$$\max_{p_t} \int_t^{t+N} e^{\gamma t}(f(p_t) - w_t)(p_t - c_d)e^{-rt}dt$$

$$\text{s.t.} \quad \dot{w}_t = (p_t - c_f) \cdot w_t u_t J - \gamma w_t$$

- Fringe Firms (entrants)

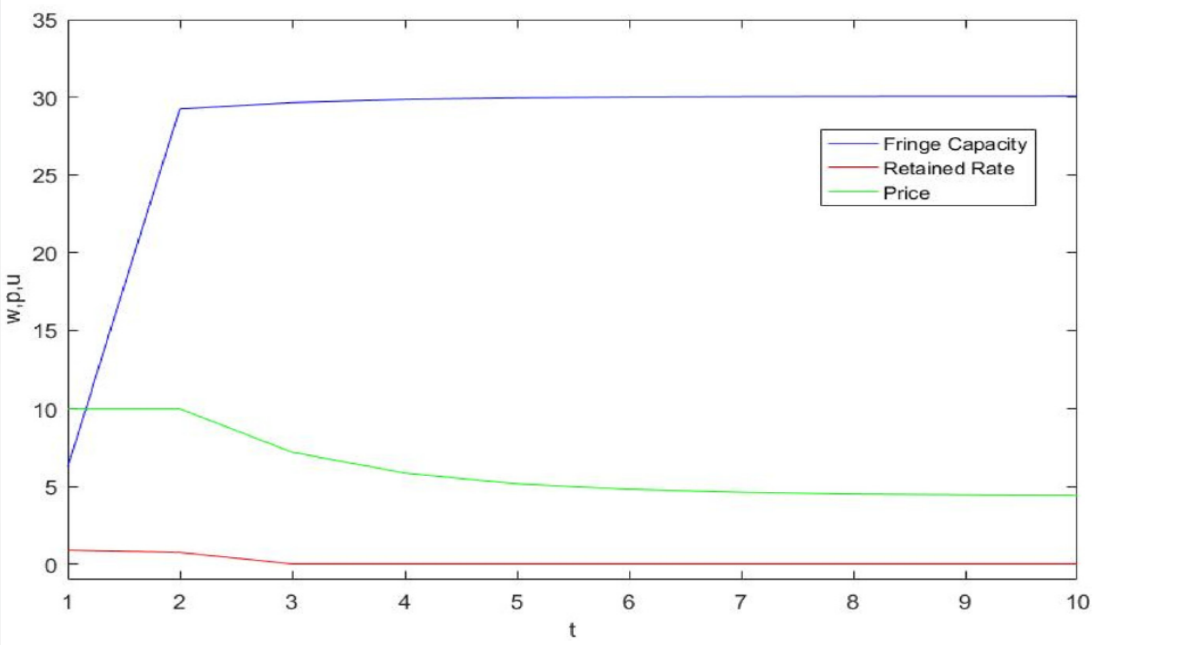
  (renewable energy entrants)

$$\max_{u_t} \int_t^{t+N} e^{\gamma t}(p_t - c_f)w_t(1 - u_t)e^{-rt}dt$$

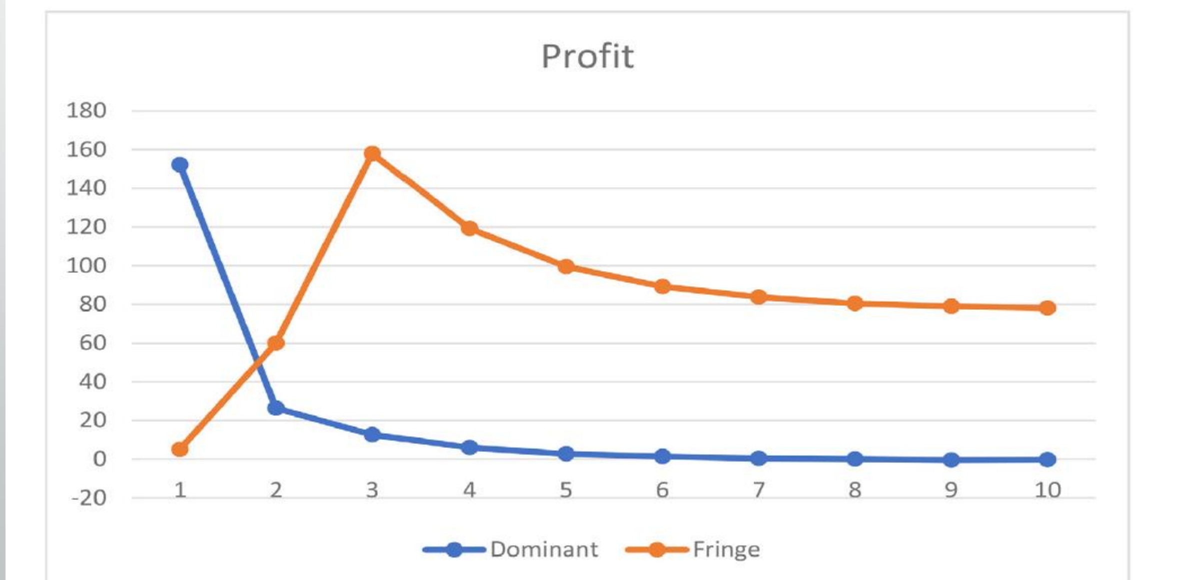
$$\text{s.t.} \, \dot{w}_t = (p_t - c_f)w_t u_t J - \gamma w_t$$

V. Driver 2: Private sector; Game theoretical models; Who wins in the energy supply–demand game?

- Fringe firms (entrants)



- Dominant and
- fringe firms' profits



V. Driver 2: Private Sector=> Overall: Cost advantage on the supply side, we see declining electricity cost

=>Inspite of Obstacles

=> Eventually

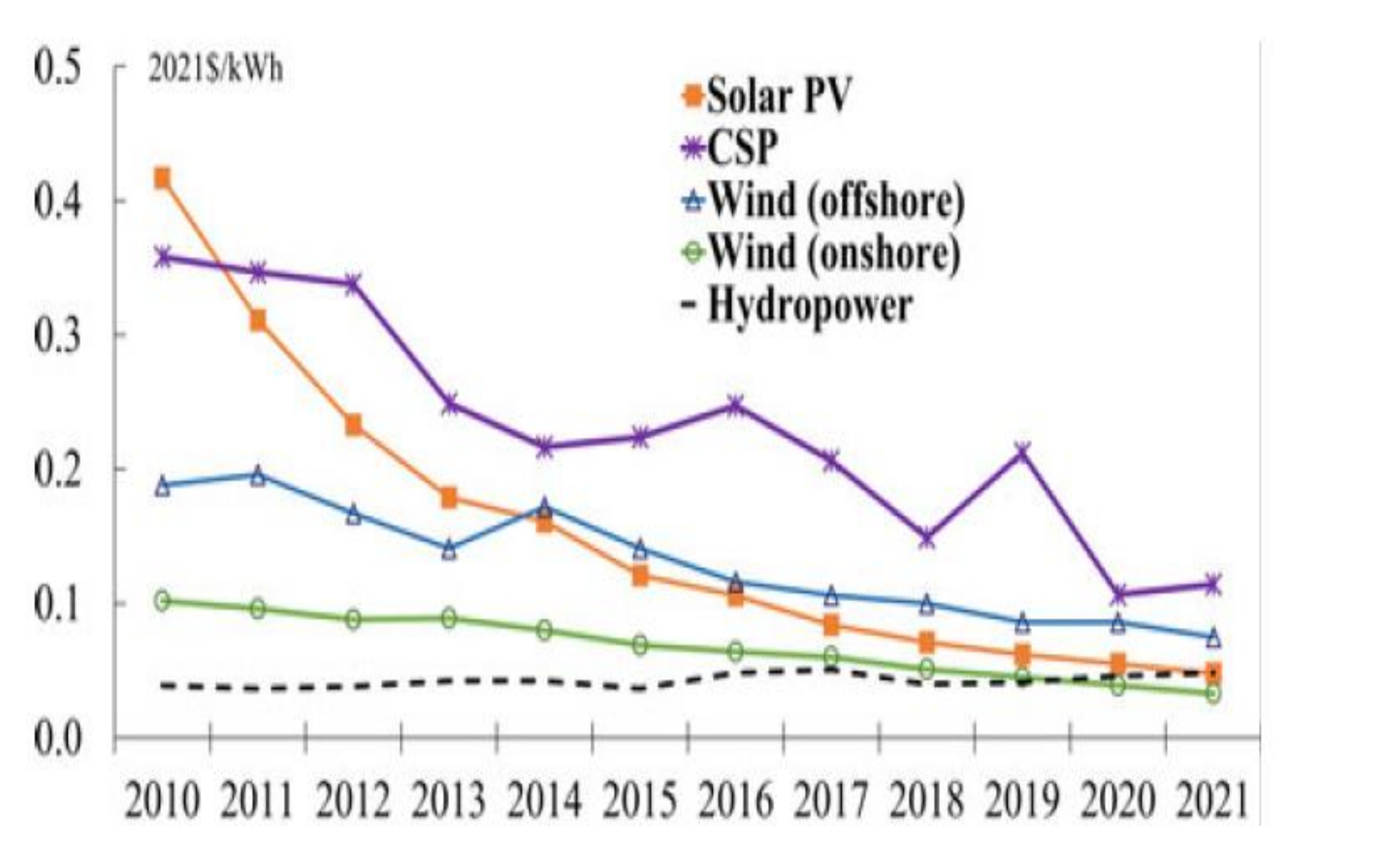
declining

cost of

renewable

energy

(electricity cost)

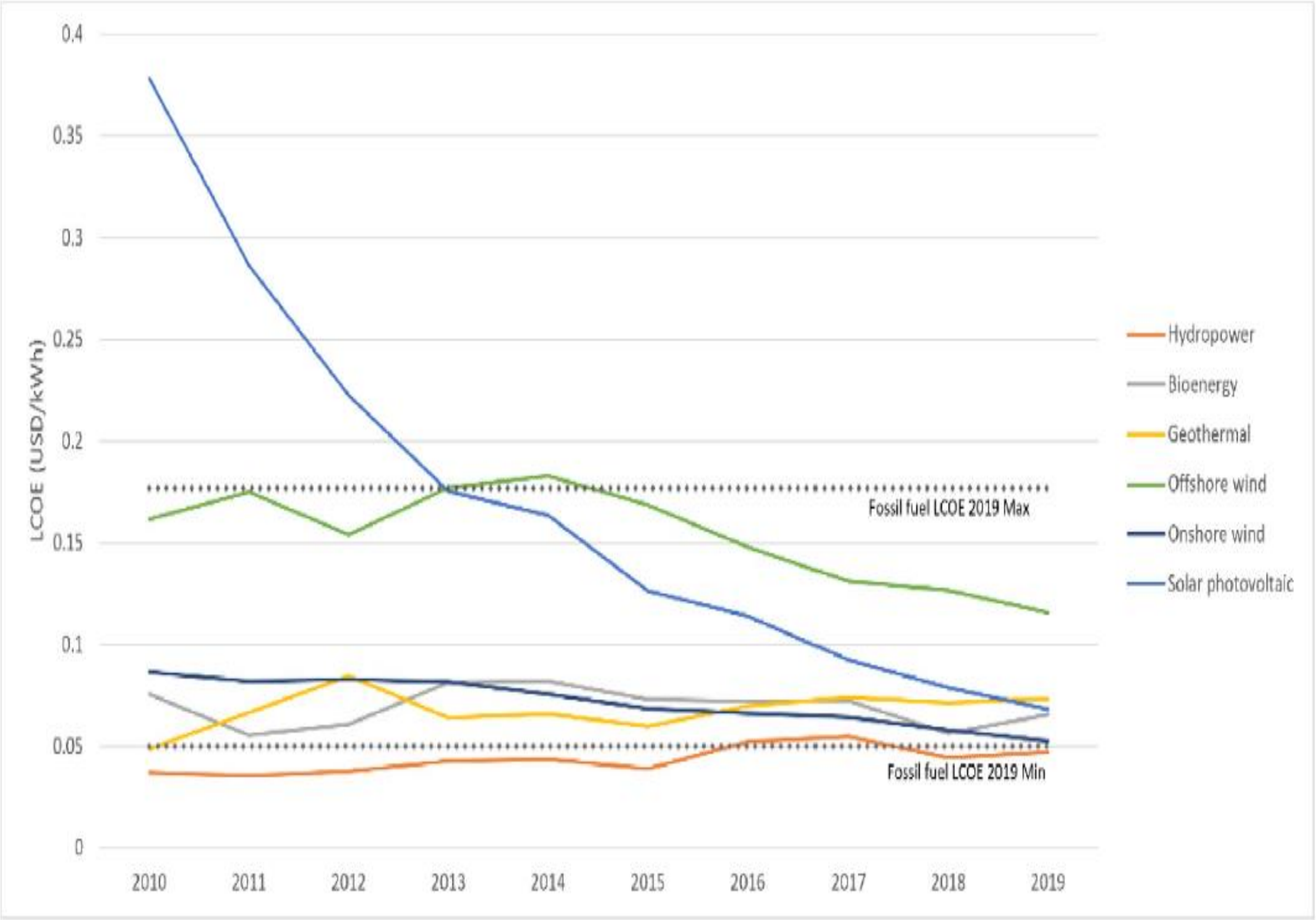


V. Driver 2: Private sector=>Cost advantage? Declining energy costs?-- but who wins the game in the future?

=>Future conflict expected:

- Fossil fuel countries can can reduce supply and increase the price: Backstop technology,
- Renewable energy, can enter, reducing the demand for fossil fuel, see our book ch. 6.

=> Conclusion: R&D, innovations and market entry of renewables should be subsidized



Obstacles: Fossil fuel price-setting oligopolies and entry game

VI. Driver 3: Financial Sector; Acceleration of decarbonization?

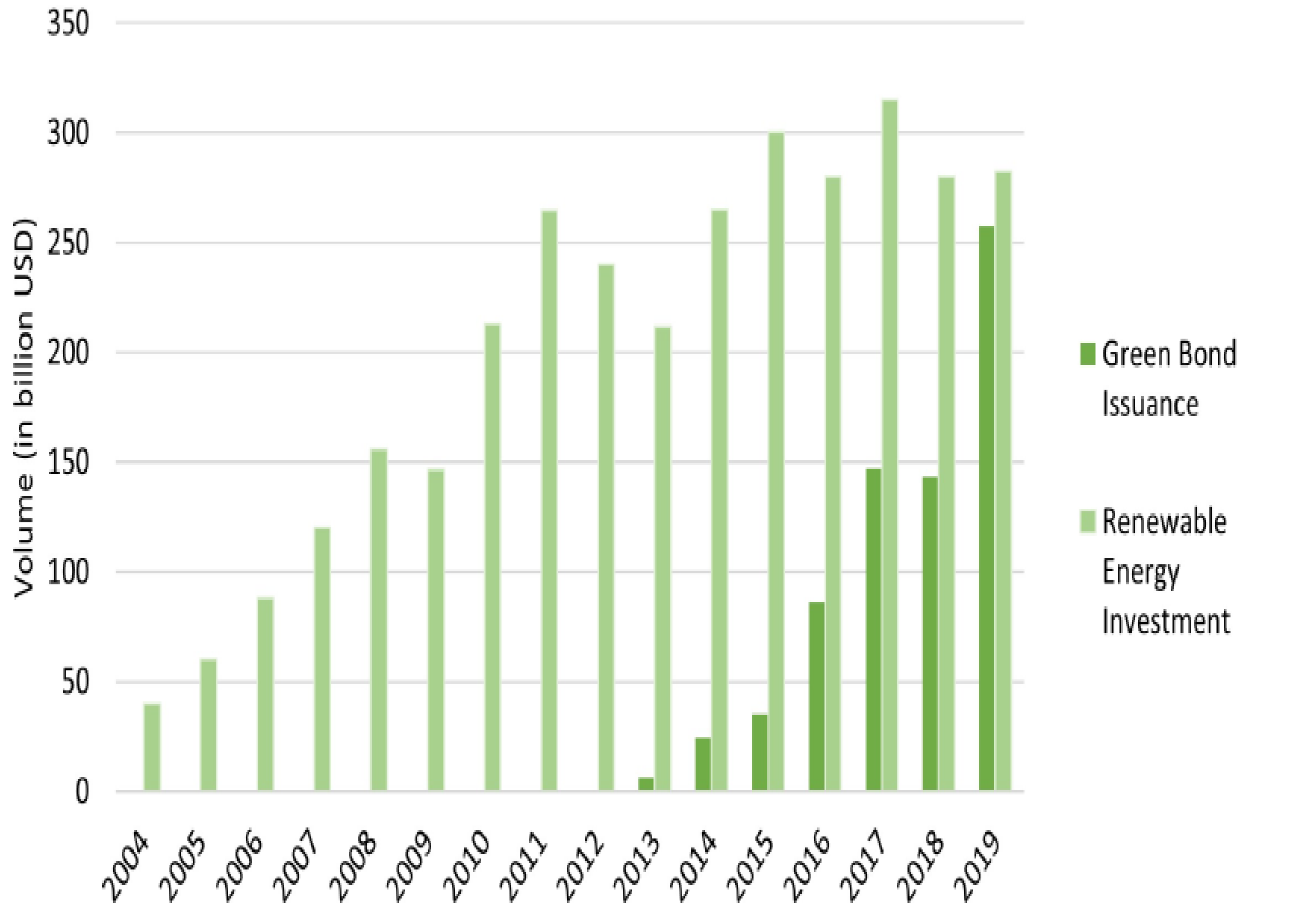
Climate (sustainable) finance (See ch. 8 of the book)

=> Financial market:

Can it be a **driver** of Decarbonization?

=> Generic finance:

- Self-financing
- Equity finance
- Bond finance
- Bank credit
- Crowd finance
- Portfolio shifts



Source: Bloomberg and Bloomberg New Energy Finance.

VI. Driver 3: Financial Sector; Decarbonization faster with asset pricing and asset holding

1. Price of an asset as Driver:

- Discount rate δ
- Future cash flows

=> Typical cases

- CAPM and CCAPM)

$$p_t = \underbrace{E_t \left[\sum_{i=1}^{k} \left(\frac{1}{1+\delta} \right)^i d_{t+i} \right]}_{p_t \,=\, \text{fundamental value}} + E_t$$

Obstacles:

=> Short-termism of financial markets, a roadblock:

- Green project evaluation
- See Haldane et al.
- and

=> High risk premia

Decision horizon, N, iterations T, discount rate, δ, and present value, PV

[1.5pt] N = 6	T = 40	T = 40	T = 40	T = 40	T = 40
δ	0.01	0.015	0.03	0.07	0.15
PV	$138.1 \geq Inv$	$133.3 \geq Inv$	$126.1 \geq Inv$	$109.5 \geq Inv$	$85 \leq Inv$

For example:

=> For green assets: lower δ

- 1. If de-risking by the state, see Braga et al)
- 2. Preference of asset holders
- Then green assets held

VI. Driver 3: Financial Sector; Decarbonization faster with static portfolio;

Reallocation from brown to green assets? (Markowitz Portfolio, return and risks, better Sharpe ratio?)
See Lichtenberger et al. (2022), in "Econometrics "

2. Static portfolio: benefits

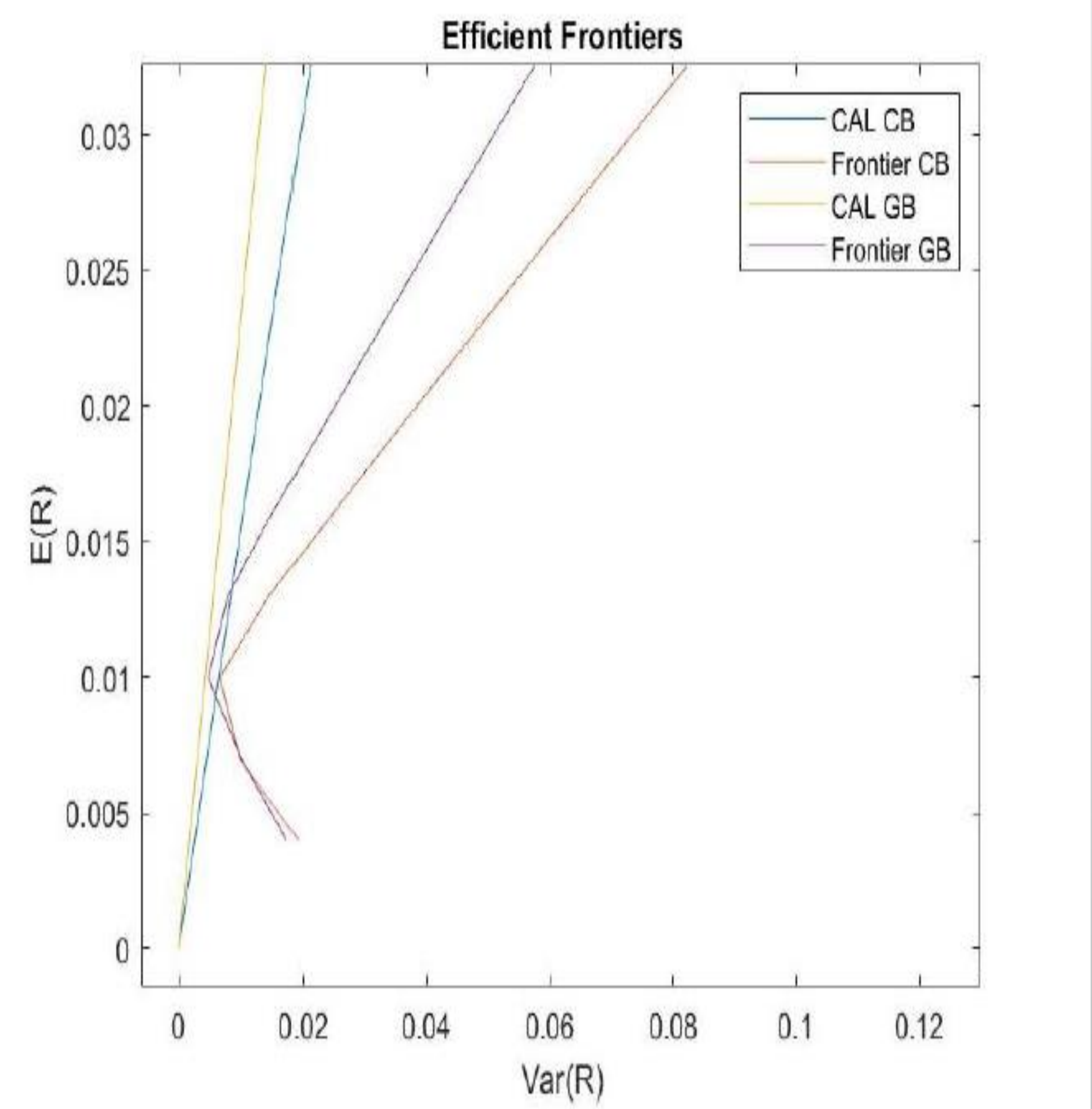
=> Performance of green and brown assets (in static portfolio)

- Green assets have lower returns (greenium), but a higher Sharpe Ratio, since **volatility is lower**
- Green assets as a larger fraction of portfolios, have lower volatility, higher SR, stabilize portfolios
- Green assets holdings lead to lower capital costs (WACC)

=> Markowitz efficient frontier:

- Efficient frontiers of the green bond (GB); corporate energy bonds (CB)
- Efficient frontiers and Markowitz efficient weights computed

=> Conclusion: Shifting financial asset holdings can help accelerate the transition



VI. Driver 3: Financial Sector; Decarbonization faster with dynamic portfolio

Reallocation from brown to green assets? (Merton Portfolio)

3. Dynamic portfolio performance (Merton):

- One or two risky assets in a Merton portfolio
- Difference between performance with negative and positive externalities?
- See the model with one risky asset (fluctuating) and one risky-free asset
- Merton's model with negative and positive externalities

$$\max_{v,c,\xi} \int_0^T e^{-\theta t}(\beta_1 log(v_t W_t) + (1-\beta_1) log(c_t W_t))dt$$

$$\text{s.t.} \quad \dot{W}_t = \xi_t R^e_{i,t} W_t + (1-\xi_t)\, R^f_t W_t - (v_t + c_t) W_t$$

$$R^f_t = constant$$

$$R^e_{i,t}(x_t) = (\xi_2\, sin(\xi_4 x_t) + \xi_5)(1 \pm \delta(v_t W_t))$$

VI. Driver 3: Financial Sector; Dynamic portfolio model (Merton)

Dynamic portfolio: benefits and costs

=> Positive externality:

upper graphs $\delta(\cdot) > 0$

=> Negative externality:

lower graph with $\delta(\cdot) < 0$

=> Faster transition if financial market does better discriminate between the two cases and is not driven driven by short-termism

=> $\delta(\cdot) > 0$: Incentivized by some de-risking, subsidies, or green investors except lower returns,

=> $\delta(\cdot) < 0$: tax on brown assets, or disclosure requirements

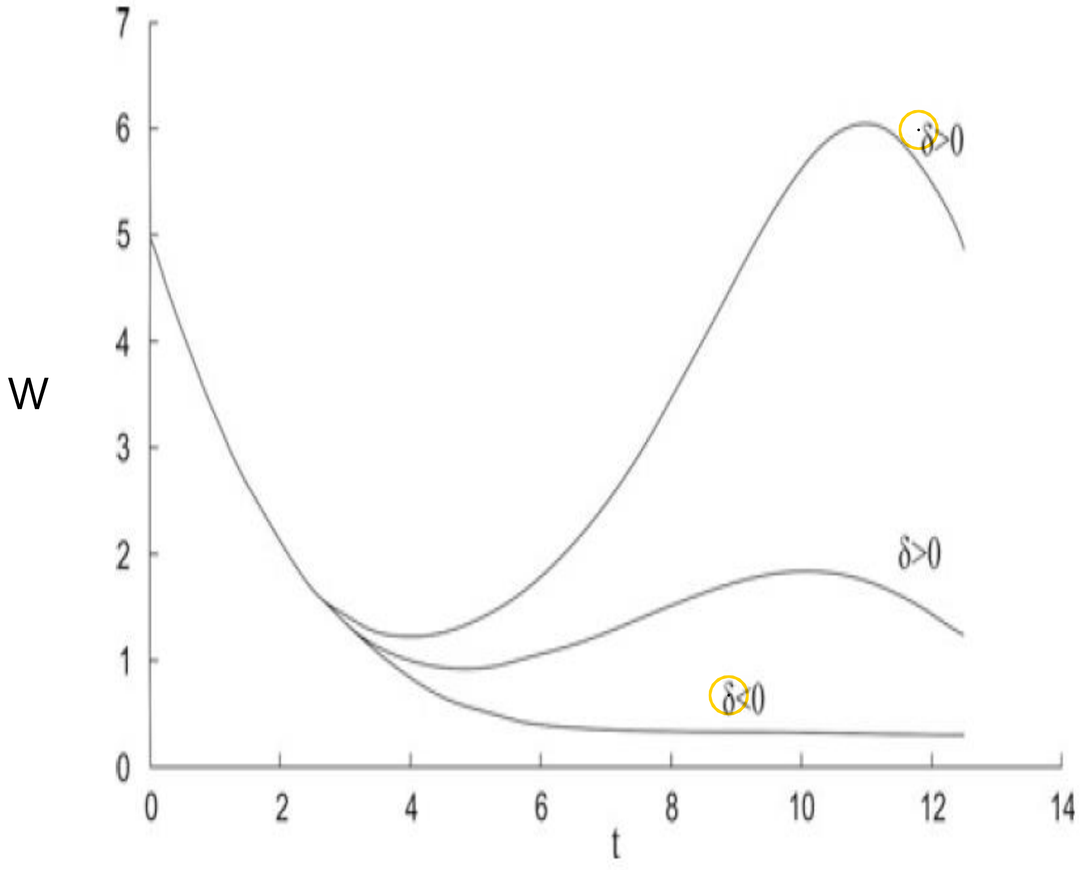
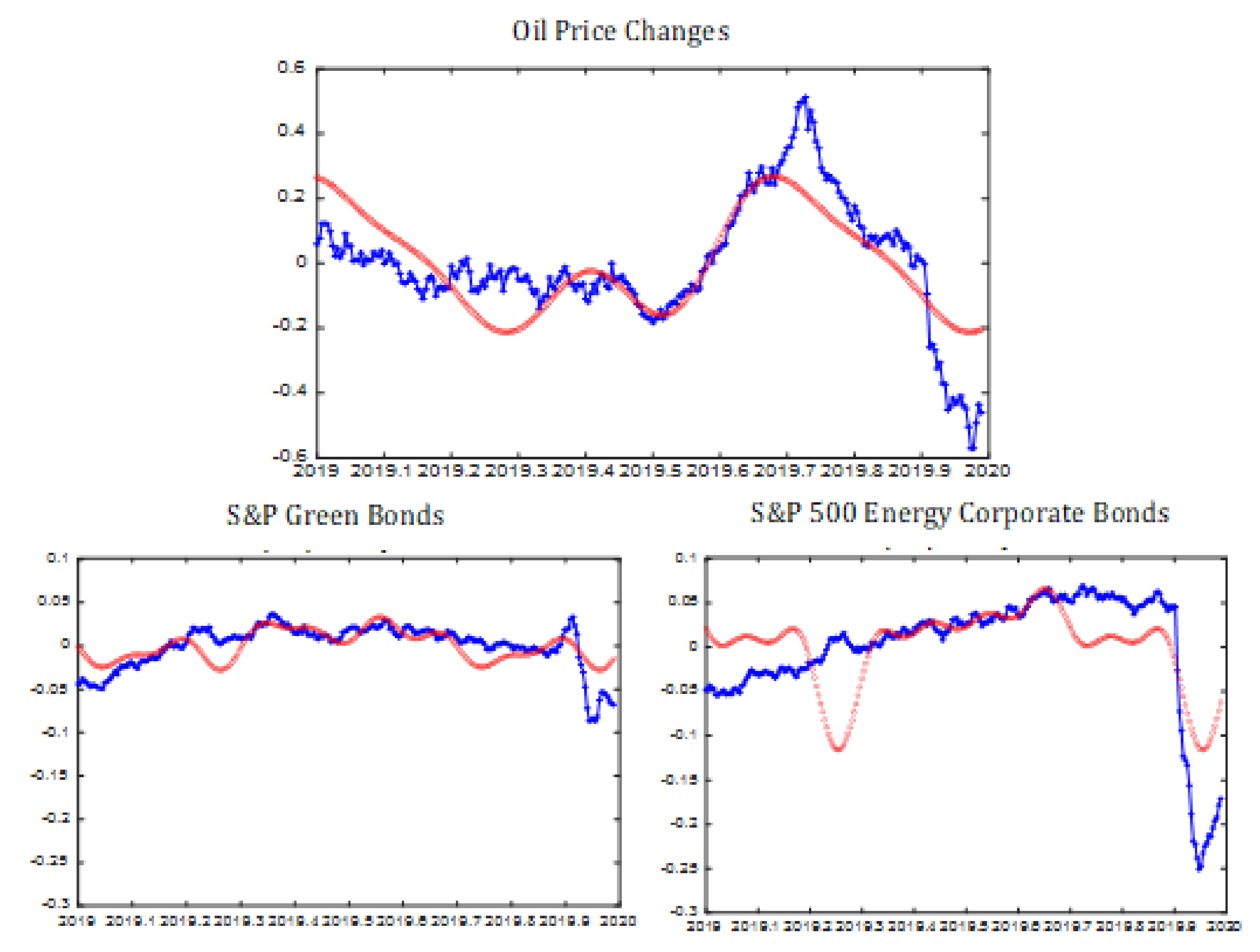


Fig. 8.10 Solution path for wealth for different types of externalities for different values of $\delta(\cdot)$, Figure: $T = 25$. This figure shows trajectories of wealth for different types of externalities, two upper graphs $\delta(\cdot) > 0$, lower graph with $\delta(\cdot) < 0$. It is assumed that $N = 6$ and $T = 25$

VI. Driver 3: Financial Sector; Green bonds, Oil Prices, brown and green bonds

- Oil price is extremely volatile. **Fossil fuel securities strongly co-move with oil price** while green bond and equity returns are less impacted by oil price volatility. We visually observe this by running harmonic estimations



VI. Driver 3: Financial Sector; Green bonds; Higer Sharpe ratio

- Green bonds (vs conventional bonds) have lower yields, lower volatility and on average higher Sharpe ratios. (Semmler et al., 2020)

- **Bond yields**: Green bonds show negative premium, see Kapraun and Scheins (2019),
  - Very heterogeneous market, but mostly…
  - Not in all sectors,,,,

- **Sharpe Ratio** roughly the same as fossil fuel assets, but for green bonds
  - yield lower (yield at issue, yield to maturity, current yield)
  - volatility lower
  - Sharpe Ratio:

$$Sharpe\ Ratio = \frac{R_p - R_f}{\sigma_p}$$

- **Green equity** (Internationally traded):
  - Stock prices (ishare, brown and green ETS trading)
  - Green equity higher Sharpe ratio….

=> **Obstacle: Dominance of short-termism, arbitrage, oil price dominance, and risk premia**

VII. Driver 4: Public sector and macroeconomic policies; Can macroeconomics and macro policies be good drivers for decarbonization? (ch.9)

- As compared to Nordhaus' long-run growth-oriented models; IAM (DICE), DSGE, and others
- Our medium-run (large-scale) dynamic macro models with **macro policies** include:

-- source of CO_2 emission

-- innovative technology

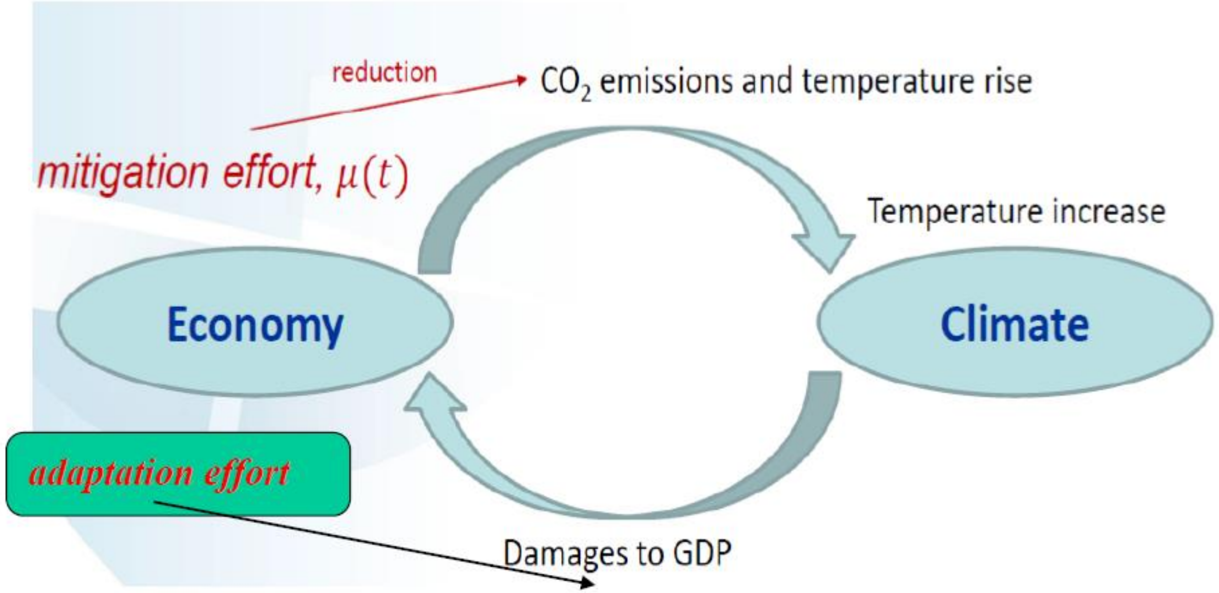
-- mitigation policies

-- adaptation policies

-- tipping points, disruptions and regime changes

-- multiple vulnerabilities, disasters and disruptions

Starting with a growth model, a high dim macro model with extensive public sector; IMF Working paper no **WP/19/145**, see also and Bonen et al. (2016), Maurer et al. (2016, 2018)



⇒ **Model** should include:

- **Capital accumulation** and growth
- **Causes:** Should include **fossil energy** extraction (coal, oil, gas), producing pollution and externalities, generating
- **Disaster** vulnerability, with **damage effects on production and households**
- **Mitigation** policy, i.e. generation of **renewable energy**
- **Adaptation** policies; (carbon tax and climate investments; climate infrastructure, adaptation to disaster risk)
- **Options** of other policy decisions

VII. Driver 4: Public Sector; Large scale dynamic macro models – IMF models; Generic large scale macro dynamics, with regime changes, see our work for the IMF

State variables, IAM only K, T, M:

K : private capital per capita,
g : public capital per capita,
b : country's level of debt,
R : non-renewable resource ,
M : GHG (Green House Gas) concentration in the atmosphere.

Control variables:

C : per capita consumption,
ep : government's net tax revenue,
u : extraction rate from the non-renewable resource,

The stock of public capital g is allocated among three uses:

ν_1 : standard infrastructure,
ν_2 : climate change adaptation,
ν_3 : climate change mitigation (IAM; μ),

$$\nu_1, \nu_2, \nu_3 \geq 0, \quad \nu_1 + \nu_2 + \nu_3 = 1.$$

$$W(T, X, U) = \int_0^T e^{-(\rho-n)t} \frac{\left(C\,(\alpha_2 ep)^{\eta} \left(M - \tilde{M}\right)^{-\epsilon} (\nu_2 g)^{\omega} \right)^{1-\sigma} - 1}{1-\sigma} \, dt$$

s.t. $\quad Y(K, u) = A(A_K K + A_u u)^{\alpha} \quad$ and

$$\dot{K} = Y \cdot (\nu_1 g)^{\beta} - C - ep - (\delta_K + n)K - u\,\psi R^{-\zeta},$$
$$\dot{R} = -u,$$
$$\dot{M} = \gamma\, u - \mu(M - \kappa \tilde{M}) - \theta(\nu_3 \cdot g)^{\phi},$$
$$\dot{b} = (\bar{r} - n)b - (1 - \alpha_1 - \alpha_2 - \alpha_3) \cdot ep,$$
$$\dot{g} = \alpha_1 ep + i_F - (\delta_g + n)g.$$

VII. Driver 4: Public Sector; Large scale dynamic macro models, Macro policies

=> Models of the Climate-macro links with many components

=> Conclusion: Extensive policy tools available

Model type	Individual models	Model features							
		Extended welfare function	Mitigation policy	Adaptation policy	Renewable and nonrenewable energy sources	Nonlinearities and tipping points	Carbon tax	Green bonds	Multiphase
(1) DICE 2008	Nordhaus (2008)		✓				✓		
(2) Extended IAMs	Bonen et al. (2016)	✓	✓	✓	✓	✓			
	Semmler et al. (2018)	✓	✓	✓	✓	✓[a]			
	Atolia et al. (2018)	✓	✓	✓	✓[b]	✓			
(3) Macro policy augmented models	Kato et al. (2015)		✓[c]		✓		✓		
	Flaherty et al. (2016)		✓[c]					✓	✓
	Heine et al. (2019)		✓[c]				✓	✓	✓
	Orlov et al. (2018)		✓					✓	✓[d]
(4) Synthesis models	Semmler et al. (2019)	✓	✓	✓	✓	✓		✓	✓
	Mittnik et al. (2020)	✓	✓	✓	✓	✓[e]		✓	✓

VII. Driver 4: Public Sector; Progress of Drivers; Sovereign debt, inflation rates, and distributional issues as obstacles?

⟹Are there "good" and "bad" **sovereign debt** dynamics (Blanchard, 1987, 2019); **Inflation** (fossilflation and greenflation?)

=>1. **Fiscal Policies** (Semmler and Proano, 2018)

- Primary balance (surplus), T>G , but: perils of contractionary budget consolidation
- Delay of interest and principal repayments
- Changing the maturity structure of debt (from short to long)
- Debt reduction through new financial tools,

=> 2. **Monetary** Policies (Faulwasser et al 2020, Braga et al 2014)

- Decrease of interest rate, UMP, QE, and macroprudential policies
- Monetary policy with climate concerns (disruptions, climate finance, climate mandate?)
- Operational tools of CBs on climate risks exist

=> 3. **Financial** Policies

- Issuing of convertible debt
- Windfall profit tax (on winners of the rise of fossil fuel prices)
- Tax on carbon-intensive wealth (Bastos and Semmler, 2023)
- Inflation-adjusted green bonds (Tahri 2023)

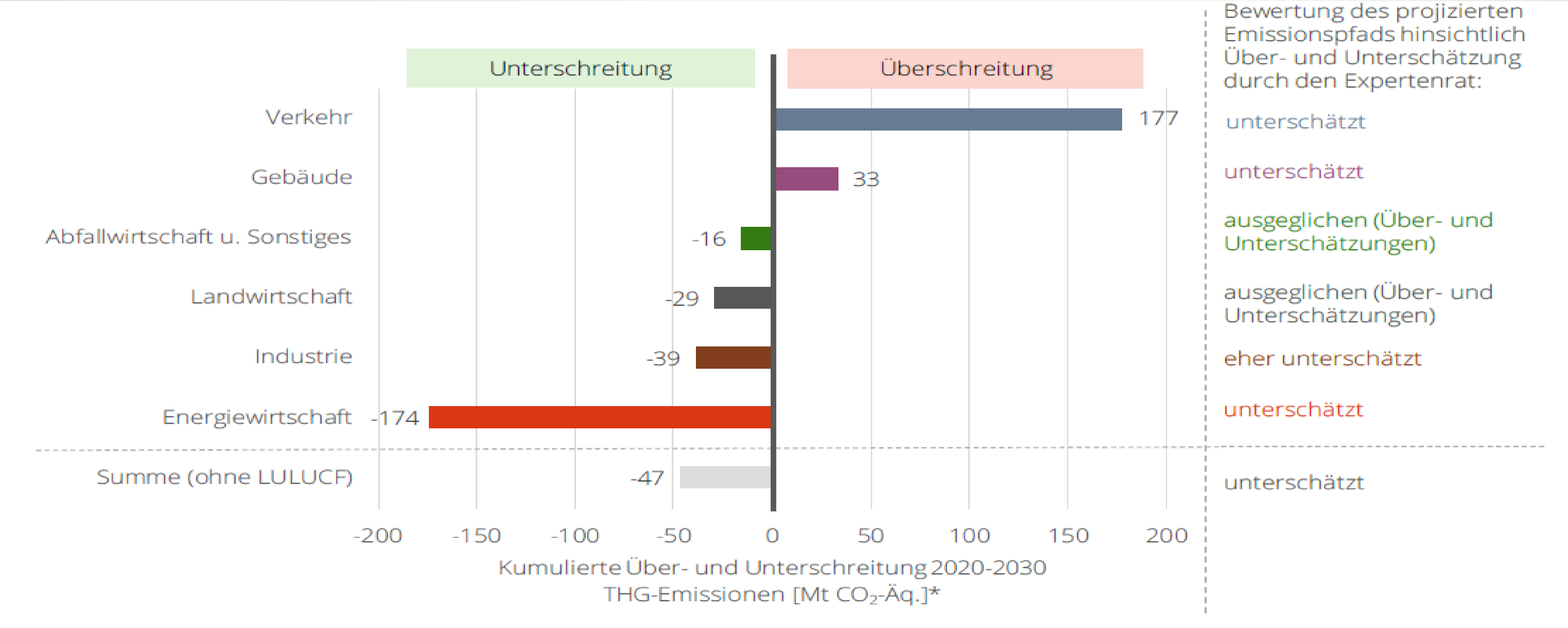
=> Obstacles in macroeconomics: Other macro goals: Sovereign debt, Inflation, Distribution

VIII. Driver 5: Multisectoral decarbonization

Stefan Mittnik and Willi Semmler

In: Oxford University Handbook, The Macroeconomics of Global Warming 2015; DIW Berlin, VJH 2023, OWID

=> **Broad sectors that Governments have focused on:** see OWID-CO2: **energy production, housing, transport, manufacturing; and agriculture,** see sectoral data at OWID, Klima Expertenrat (2024)



=> **Multisectoral models of decarbonization**: based on Input-Output analysis (71 sectors)

- Multisector macro model with preferences: input-output system with energy coefficients

  Data: German I-O tables (1995), 71 sectors with energy intensity, Co2 intensity aggregated into 2 sectors (LCI, HCI), using EU Klemps data for output and employment of those sectors, for 8 countries

  Results: **Employment** and **output** dynamics for 8 countries

VIII. Driver 5: Multisectoral model (see Kaldor's 3 sector model)

$$U_t = \int_0^T e^{-\rho t} \frac{\left[H_t^{\beta} L_t^{\theta}\right]^{1-\sigma} - 1}{1-\sigma} dt,$$

$$\begin{aligned} \dot{K}_t + \delta K_t &= B_K N_t^K F(K_t, X_t) \\ &= B_K \left(1 - N_t^H - N_t^L\right) F(K_t, X_t) \\ &= B_K F(K_t, X_t) - P_H H_t - P_L L_t, \end{aligned}$$

- K: Capital stock
- H: Hi carbon intensity consumption goods
- L: Low carbon intensity consumption goods
- X: Technical progress
- The effects of all four policies can be explored in this model
- T: Model with finite time horizon

VIII. Driver 5: Multisectoral model=> Data Description

- We use German (energy) Input-Output Tables (1995) to disaggregate the economy into an H and an L sectors
- Calculation of direct and total CO_2 intensities for 71 sectors
- Median as cut-off value
- Approx. 90% of CO_2 in the production process HCIS is emitted in (HCSI:High Carbon Intensity Sectors)
- We use for the same sectors the Klemps data for employment and output for the same sectors

#	Sector	Dir.	Tot.	Sector	Sector
1	Supply of Electricity and Heat	5.652	6.145	H	H
2	Electricity and Gas	5.652	6.276	H	H
3	Other Air transport	0.867	1.309	H	H
4	Coke, refined petroleum and nuclear fuel	0.842	1.887	H	H
5	Basic metals	0.557	2.229	H	H
6	Fabricated metal	0.557	1.722	H	H
7	Foundry products	0.557	1.264	H	H
8	Glass and glass products	0.467	1.073	H	H
9	Other non-metallic minerals	0.467	1.082	H	H
10	Other mining and quarrying	0.340	0.915	H	H
...	(...)				
54	Electrical machinery and apparatus, nec	0.028	0.357	L	L
55	Medical, precision and optical instruments	0.025	0.272	L	L
56	Recreational, cultural and sporting activities	0.025	0.120	L	L
57	Other business activities	0.022	0.095	L	L
58	Computer and related activities	0.022	0.087	L	L
59	Post and telecommunications	0.021	0.127	L	L
60	Other service activities	0.019	0.137	L	L
61	Insurance and pension funding, except compulsory soc	0.017	0.113	L	L
62	Financial intermediation, except insurance and pensio	0.015	0.082	L	L
63	Leather, leather and footwear	0.013	0.410	L	L
64	Office, accounting and computing machinery	0.010	0.259	L	L
65	Wearing Apparel, Dressing And Dying Of Fur	0.010	0.426	L	H
66	Renting of machinery and equipment	0.009	0.031	L	L
67	Activities related to financial intermediation	0.009	0.082	L	L
68	Real estate activities	0.002	0.053	L	L
...	(...)				

VIII. Driver 5: Multisectoral model=> Definitions of CO_2 Ratios

(Using I-O tables)

- **Direct CO_2 (Output) Intensity [kt/mill. EUR]:**

$$c^{*}_{\mathrm{dir}} = X^{-1}c$$

- **Total CO_2 Output Intensity [kt/mill. EUR]:**

$$c^{*T}_{\mathrm{tot}} = c^{*T}_{dir} (I - A)^{-1}$$

- **Direct CO_2 (Labor) Intensity [kt/1000 workers]:**

$$c^{*T}_{\mathrm{e,\,dir}} = E^{-1}c$$

- **Total CO_2 (Labor) Intensity [kt/1000 workers]**

VIII. Driver 5: Multisectoral model=> Decarbonization policies

- **Policies:**
- Preferences
- Carbon Tax only
- Carbon tax and wage subsidies
- Carbon tax and subsidy

- Germany, 1992 - 2005
- USA, 1970 - 2005
- Japan, 1973 - 2005
- United Kingdom, 1970 - 2005
- Sweden, 1970 -2005
- South Korea, 1970 – 2005
- Australia, 1989 – 2005
- Hungary, 1992 -2005

VIII. Driver 5: Multisectoral model=> Double-sided (composite) VAR and IRs

The first–order VAR is of the form

$$y_t = c + Ay_{t-1} + \varepsilon_t,$$

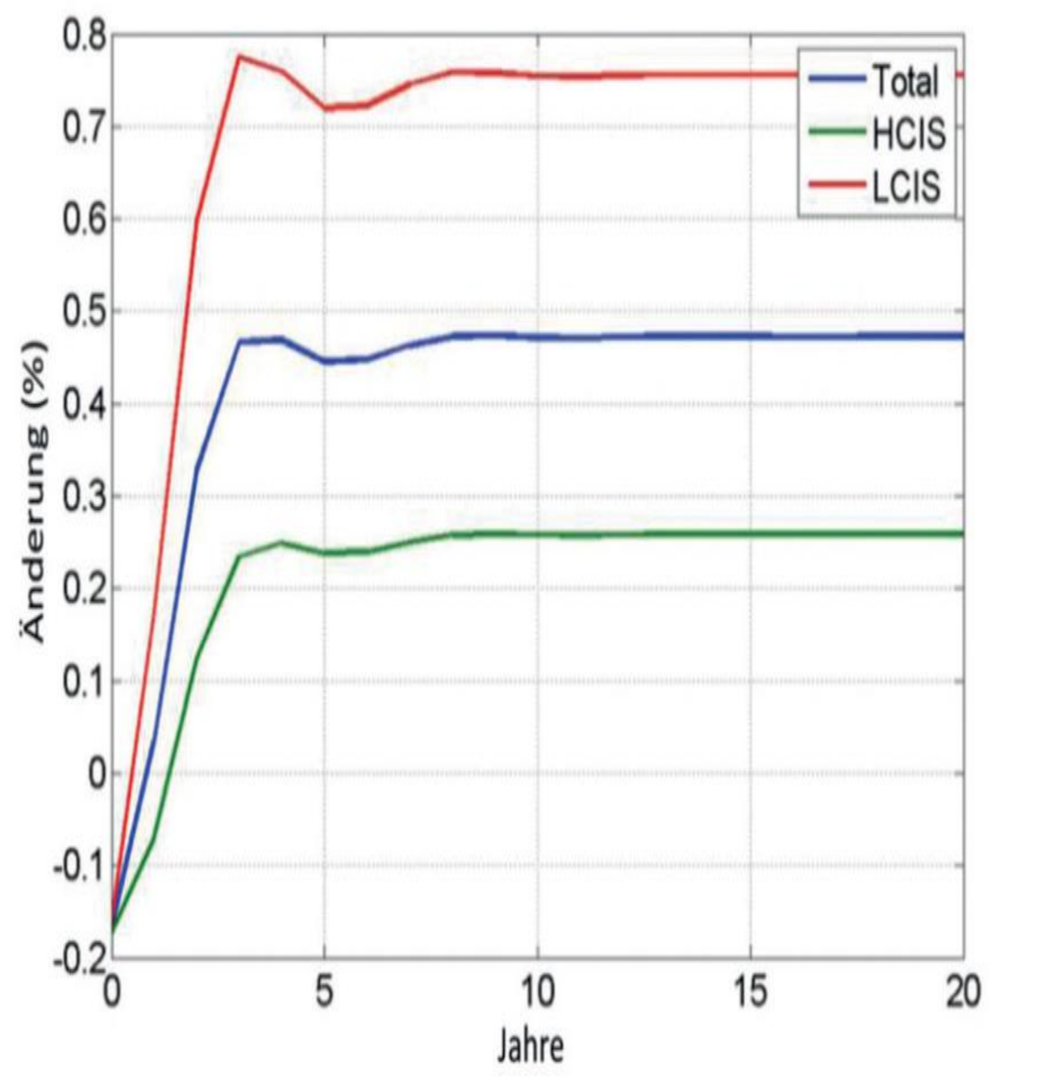
$$y_t = \begin{pmatrix} out_{hi,t} \\ out_{lo,t} \\ emp_{hi,t} \\ emp_{lo,t} \end{pmatrix}$$

Analysis consists of 4 steps:

1. For each country we estimate the joint dynamic process of output and employment both in HCIS and LCIS for each country.
2. Impulse response analysis (IRA): Investigate how the variables of the system respond to individual shocks.
3. Specify policy measures in terms of composite shocks.
4. Analyze responses to policy measures over time.

VIII. Driver 5: Multisectoral model=> Results: After 10 years, for tax and **HCI** and subsidies for **LCI;** effects on sectoral **employment** and **outputs**

For US: **Employment** (left), Employment and Output (right)



Output and Employment Effects after 10 years

	EMPLOYMENT					*OUTPUT*		
	HCIS Relative Employm Effects	LCIS Relative Employm Effects	HCIS Absolute Employm Effects	LCIS Absolute Employm Effects	TOT Employm Growth Effects	HCIS Output Growth Effects	LCIS Output Growth Effects	TOT Output Growth Effects
Germany	0.51%	0.49%	108,984	90,806	199,790	-0.98%	0.74%	-0.02%
USA	0.27%	0.71%	233,624	475,082	708,707	-2.58%	-0.08%	-1.32%
Japan	0.27%	1.18%	98,106	344,981	443,087	0.81%	3.18%	2.02%
United Kingdom	0.15%	0.59%	22,570	86,385	108,955	-1.80%	0.19%	-0.81%
Sweden	-0.13%	0.00%	-3,331	-3	-3,334	-0.39%	0.94%	0.28%
South Korea	0.06%	0.82%	8,581	69,704	78,284	-1.18%	0.32%	-0.50%
France	0.37%	1.53%	51,249	177,598	228,847	-3.69%	-1.60%	-2.64%
Australia	-1.56%	-0.59%	-94,070	-17,832	-111,902	-2.69%	1.69%	-0.99%
Hungary	0.51%	1.22%	11,733	21,202	32,935	-0.79%	1.43%	0.32%

VIII. Driver 5: Multisectoral models allow for the study of transition

- Driver:
- Allows for studies of policies of greater (fossil fuel) energy independence: The use of I-O tables can also be used for GDP growth loss estimation due to the recent energy crisis; Russian embargo of Germany computed: see Mittnik/Semmler in DIW, VJH 2022, German Energy crisis

- **Obstacles**
- Lack of human capital; approach also needs compensatory, adjustment policies for structural change and reallocation of labor and capital (see our paper in Rodrick, ed., Industrial policies)

- Disadvantage: Sectors are not actors. Actors are companies, households and their preferences, policymakers. So public policies such as regulations, standards, taxes, and subsidies are needed to provide incentives

IX. Conclusions—Major Challenges

- Flattening and reversing of the emission curve by policies-- is **not sufficiently** achieved, Klimarat
- Faster reversing of the emission curve is needed – but also better **burden sharing** (within and across countries) and fair transitions are needed
- For mitigation **multiple policies** are required to facilitate transition-- market-oriented policies, innovative technology, green finance, macroeconomic (fiscal, monetary), and sectorial policies, to flatten (or reverse) the curve
- For adaptation -- **Multiple vulnerabilities** are interacting, producing not only **more frequent** but **more severe** extreme events; a better forecast, early warning systems, and preparation for future extreme events is needed
- Great perils are the **tipping points** -- They result from complex dynamics, which need to be studied more (regime shift models and more data-intensive research)
- Conflicting policy goals or **multiple worries**? between **growth** and **climate protection**? But **macroeconomic** worries and conflicting multiple goals; **macro goals** (such as unemployment, inflation, financial stability, income distribution) and **climate protection**
- **Summary: There are already major drivers but also major obstacles**

General Literature

- Nordhaus, DICE model solution package, Yale website
- Nordhaus, The Question of Balance (2007), Climate Casino (2013), IAM (DICE)
- Greiner and Semmler: Global Environment, Natural Resources and Growth, OUP (2008)
- Bernard and Semmler (eds): OUP Handbook, The Macroeconomics of Global Warming (2015)
- Gruene, Greiner, and Semmler, Economic Growth and the Transition from Non-renewable to Renewable Energy (2013)
- Bonen, Loungani, Semmler, and Koch, Investigating to Mitigate and to Adapt, IMF paper, 2016
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- Flaherty et al: Climate Financing through Climate Bonds, (2016), RIBF
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- Braga, Semmler, De-risking….JEDC paper (2022);
- Semmler, Lessmann, Tahri, and Braga, Green transition, investment horizon, and dynamic portfolio

  Decisions, Annals of Operations Research, 2022
- Semmler, Di Bartolomeo, and Fard, Game-theoretical papers on limit pricing (SCED, 2022)
- Mittnik and Semmler, Sectoral decarbonization
- Mittnik, Semmler, and Haider, (2020) Climate disaster risks—empirics and multi-phase dynamic model.
- Econometrics 8(3):1–27

  Lichtenberger et al..(2022), Climate Finance, in „Econometrics" ; Bastos and Semmler (2023)

Literature on computational and econometric works

Important recent methods for more advanced students:

Computational methods:

L. Gruene, M. Stieler, and W. Semmler (2015): "**Using NMPC** for Solving Dynamic Decision Problems in Economics, NSSR, http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2242339, published in JEDC, 60: 112-133,

H. Maurer and W. Semmler (2015): Expediting the Transition from Non-Renewable to Renewable Energy", Discrete and Continuous Dynamic Systems, vol 35, no 9, September, 2015.

Atalio M., P. Loungani, H. Maurer and W. Semmler "Optimal Control of a Global Model of Climate Change with Adaptation and Mitigation" (2022), Journal of the American Institute of Mathematical Sciences (AIMS), Doi: 10.3934/mcrf.2022009.

in AIMS This paper is using the computational methods AMPL, software packages for NMPC and AMPL exist.

E. Saltari and G., Di Bartolomeo,, and W. Semmler (2021). "A Nash Equilibrium for Differential Games with Moving-Horizon Strategies." (with 2021. Computational Economics. https://doi.org/10.1007/s10614-021-10177-8.

L. Gruene, M. Kato and W. Semmler (2005), "Solving Ecological Management Problems Using Dynamic Programming" (), Journal of Economic Behavior and Organization, vol. 57, no. 4: 430-448, 2005.

L. Gruene and W. Semmler (2004): "Using Dynamic Programming with Adaptive Grid Scheme for Optimal Control Problems in Economics", Journal of Economic Dynamics and Control, vol. 28:2427-2456, 2004

Data and econometric work:

Data: on CO2 emission and economics, for countries regions and sectors: Owid-CO2; on renewable energy: International Energy Agency, ECB data, Fed St. Louis.

P. Chen, H. Maurer, and W. Semmler (2022) "Delayed Monetary Policy Effects in a Multi-Regime Cointegrated VAR (MRCIVAR)", in: Econometrics and Statistics, available online: https://doi.org/10.1016/j.ecosta.2022.03.004,

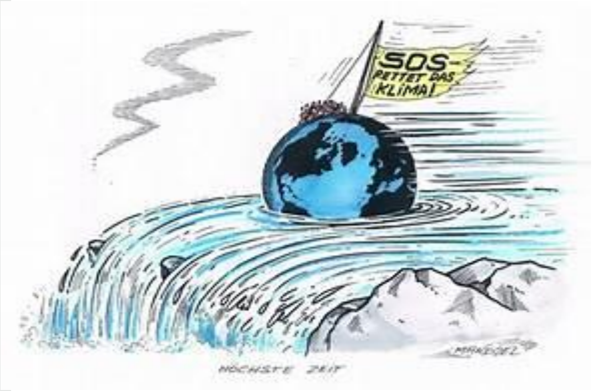
A. Lichtenberger, J. P. Braga, and W. Semmler, (2022) "Green Bonds for the Transition to a Low-Carbon Economy" (with, 2022, Published in Econometrics, DOI:10.3390/econometrics10010011Corpus ID: 247342223

Braga, J., Chen, P., and Semmler, W. (2024), Central Banks, Climate Risks, and Energy Transition – A Dynamic Macro Model and Econometric Evidence, Extended Version, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4794049

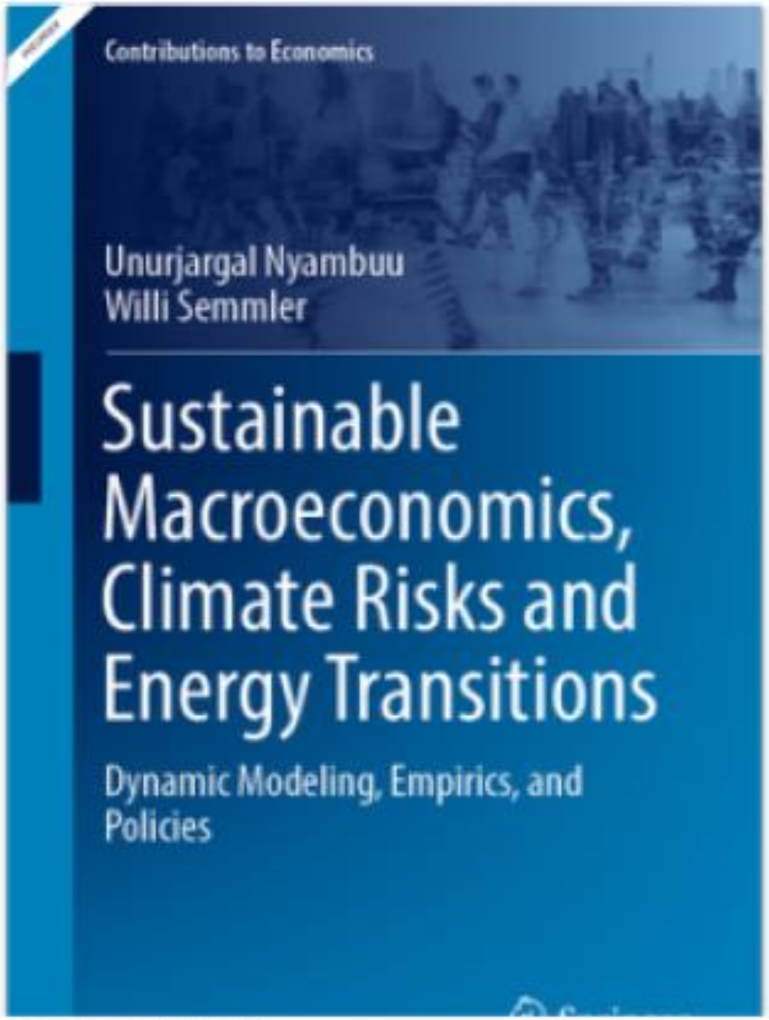
Roy, A., P. Chen and W. Semmler (2024) Carbon Tax versus Renewable Energy Innovation — Dynamic Modeling and a Regime Switching CO-Integration VAR SSRN, forthcoming.

THANK YOU

Willi Semmler, The New School, NY, and IIASA, Laxenburg



Book:
- What kind of sustainable macroeconomics is needed for the climate challenges?
- Textbook for macro courses, researchers, and policymakers



=>USA: Trumps Klimapolitik

=>Europa Klimapolitik

=> Recent Book, Springer Publishing House, July 2023

Appendix: CBs, Climate risks monetary policy, see Braga, Chen Semmler (2023)

We presume in a finite horizon decision model a quadratic objective function given by eq. (2).

$$Min_{i(.)} \int_0^T e^{-\rho t}[w_\pi(\pi(t) - \pi_s)^2 + w_y(y(t) - y_s)^2 + w_l(l(t) - l_s)^2 + w_i i(t)^2]dt \qquad (2)$$

The CB exogenously sets the policy targets given by π_s, y_s, and l_s. Eq. (2) assigns a quadratic penalty to the deviation of each variable from their target value, and defines weights for each target. The weights are given by w_π, w_y, w_l, and w_i.[12] Furthermore, the objective functional faces constraints given by the macro behavior of each variable. The state variables are represented by the following dynamic state equations:

$$\dot{\pi}(t) = -\alpha_1\pi(t) + \alpha_2 y(t), \quad with \quad \pi(0) = \pi_0 \qquad (3)$$

$$\dot{y}(t) = -\beta_1 y(t) - \beta_2(i(t) + \sigma(y(t)) - \pi(t) - r) \quad with \quad y(0) = y_0 \qquad (4)$$

$$\dot{l}(t) = \gamma_1 l(t) + \gamma_2(y(t)) - \gamma_3(i(t) + \sigma(y(t))) - \gamma_4\pi(t), \quad with \quad l(0) = l_0 \qquad (5)$$

$$\dot{m}(t) = -\sigma_1(m(t) - m_s) + \frac{\sigma_2(y(t) + d(t))}{g_r(s)(\sigma_3 l(t) + \sigma_4 d(t)) + \sigma_5}, \quad with \quad m(0) = m_0 \qquad (6)$$

Appendix: Climate risks and monetary policies

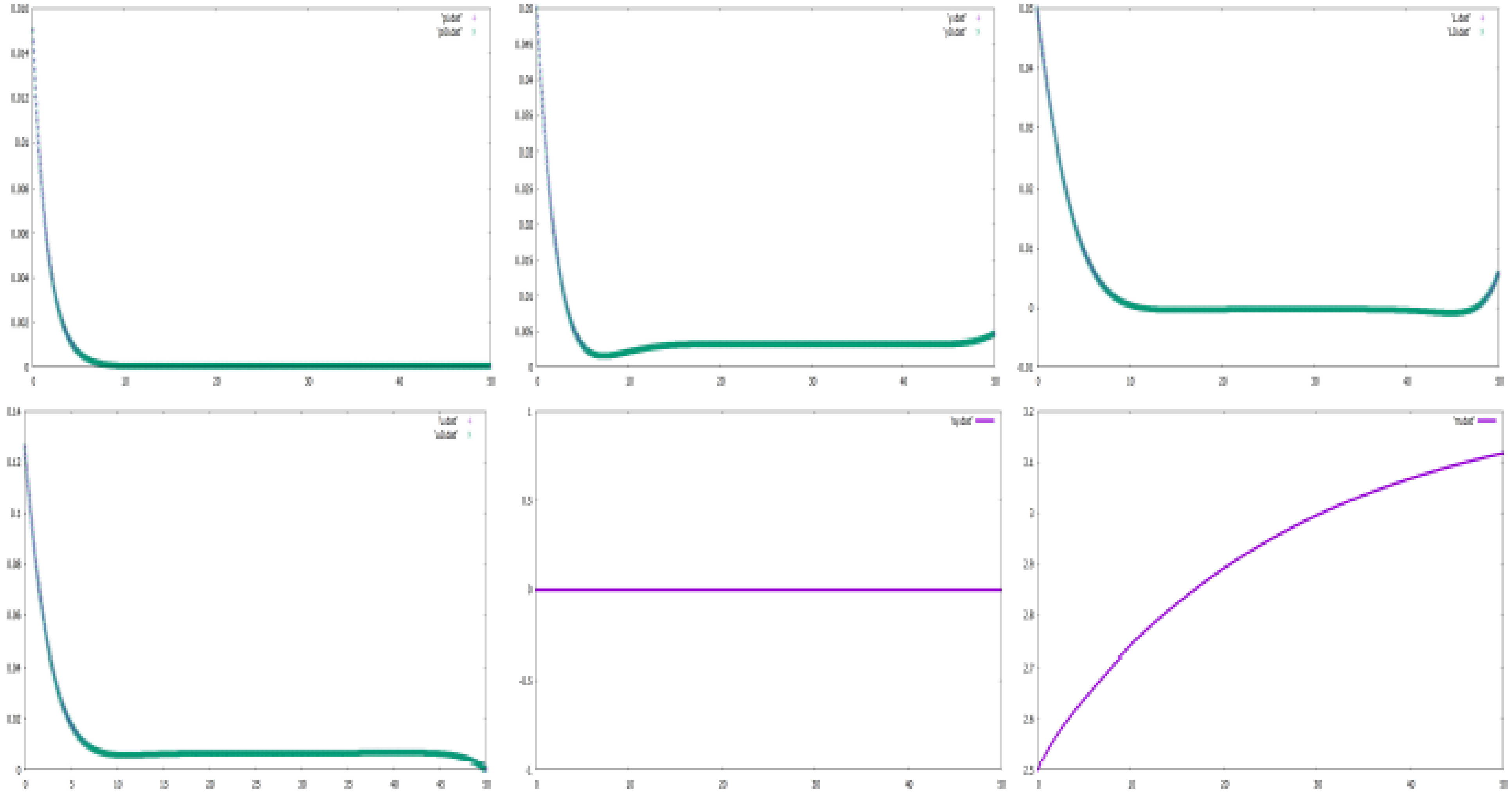


Figure 3: Model Simulation 1: Above: Inflation rate, positive output gap and credit flow; Below: interest rate (u), risk premium (sy), and emission (m) (when $g_r(s) = 0$or 1); emission control implicitly through $g_r(s)$ with time depending switches, as soon as interest rate moves down to 2%

Appendix: Climate risks and monetary policies

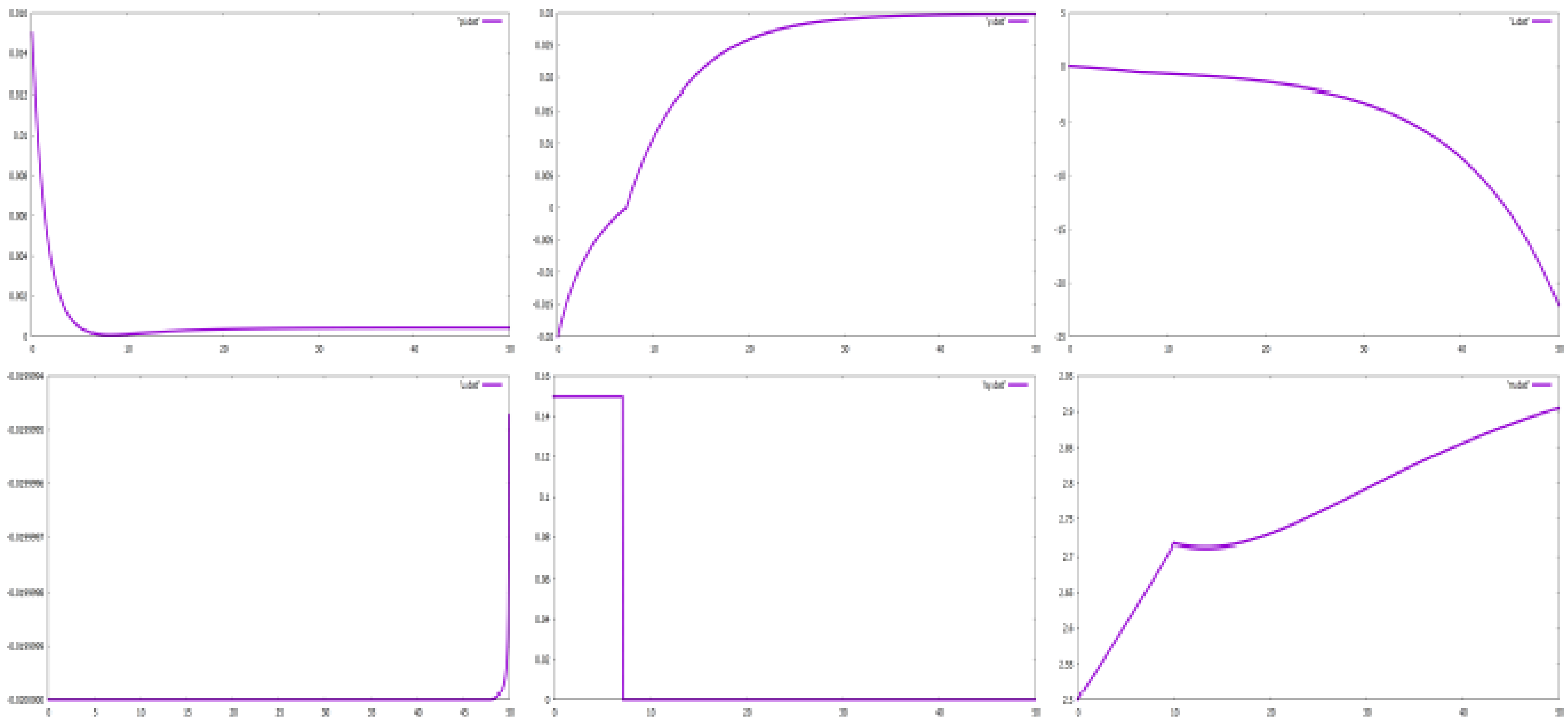


Figure 4: Simulation 2: Above: Inflation rate, negative output gap, and credit flow; Below: interest rate, risk premium and emission (when $g_r(s) = 0$ up to period 10 then $g_r(s) = 1$); time depending regime change, risk premium stays high as long as the output gap is negative; emission curve first increasing then flattening when credit flow for decarbonization is phased in.

Appendix: Climate risks and monetary policies;

with decision and transmission delays (see Aghion et al. on cost of delays)

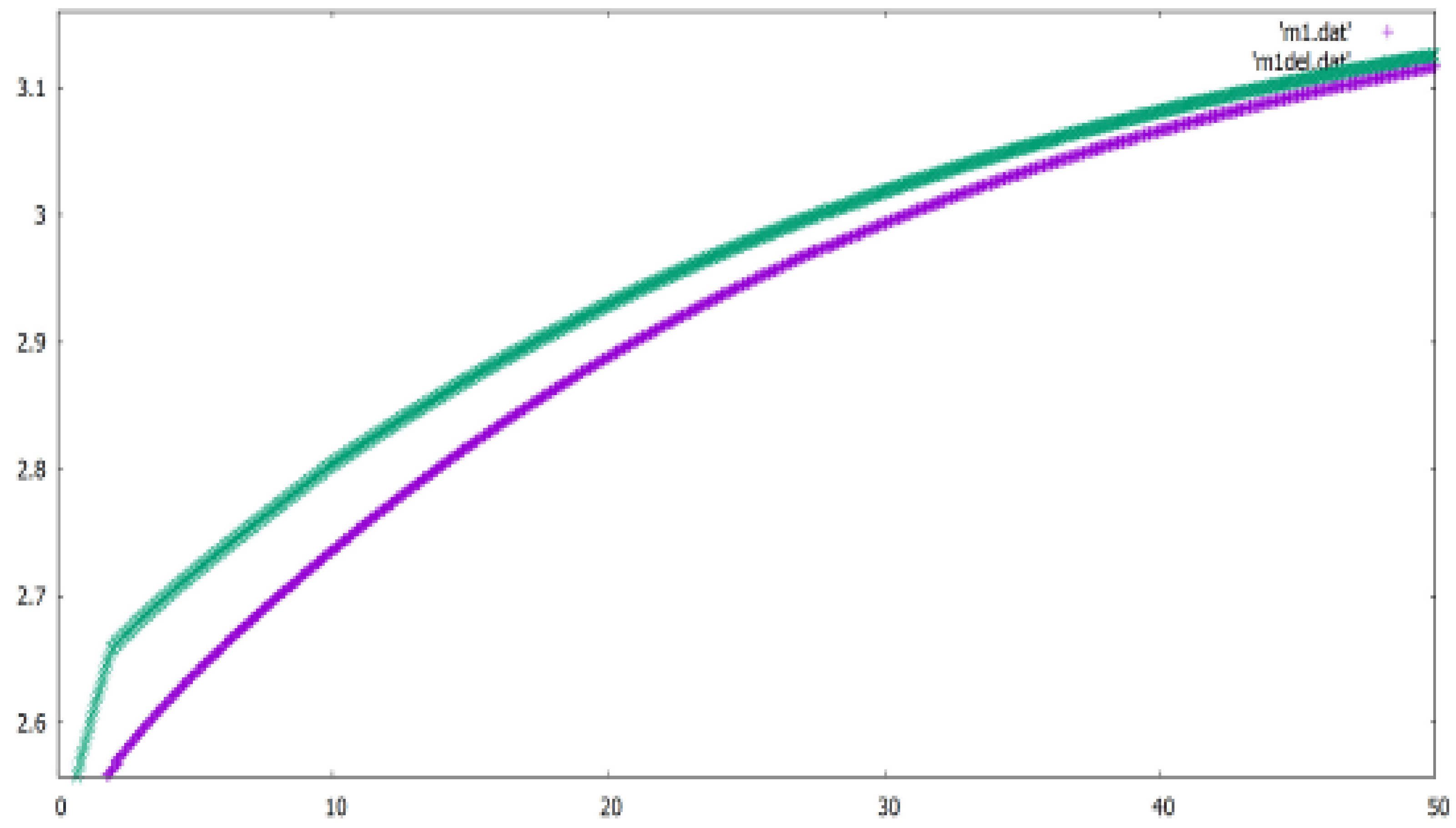


Figure 5: Upper graph: Model solution with delay, Lower graph: no delay; both graphs with regime switching $g_r(s)$ of credit flows

Appendix: Cost trends