XXVI Annual Conference of the Central Bank of Chile

Implications of Climate Change and Ecosystem Services Degradation For Macroeconomic and Financial Stability

The Macroeconomics of Climate Change and the Energy Transition

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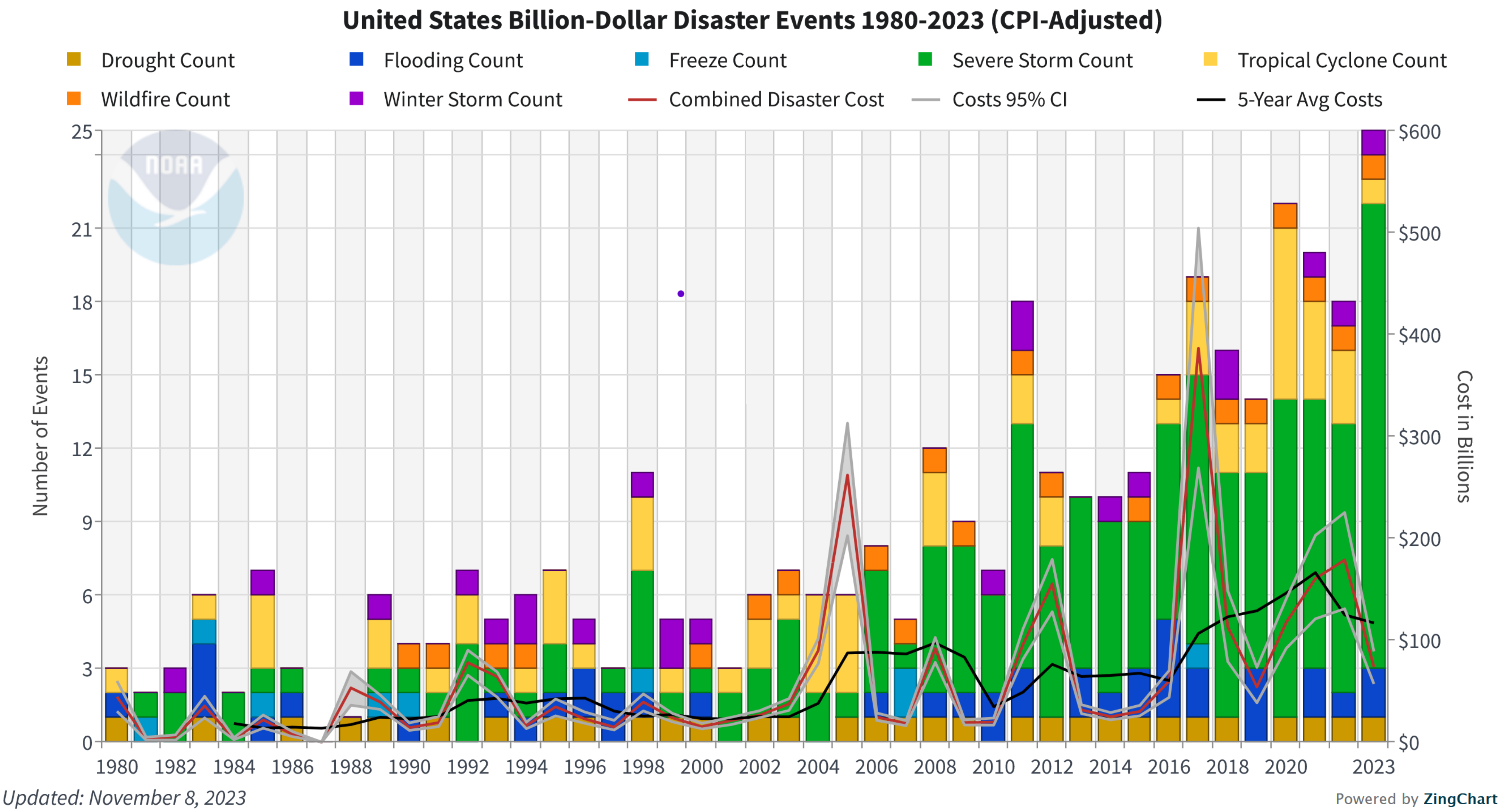
Climate and macro: physical risks,



Transition risks in energy markets


FINANCIAL TIMES

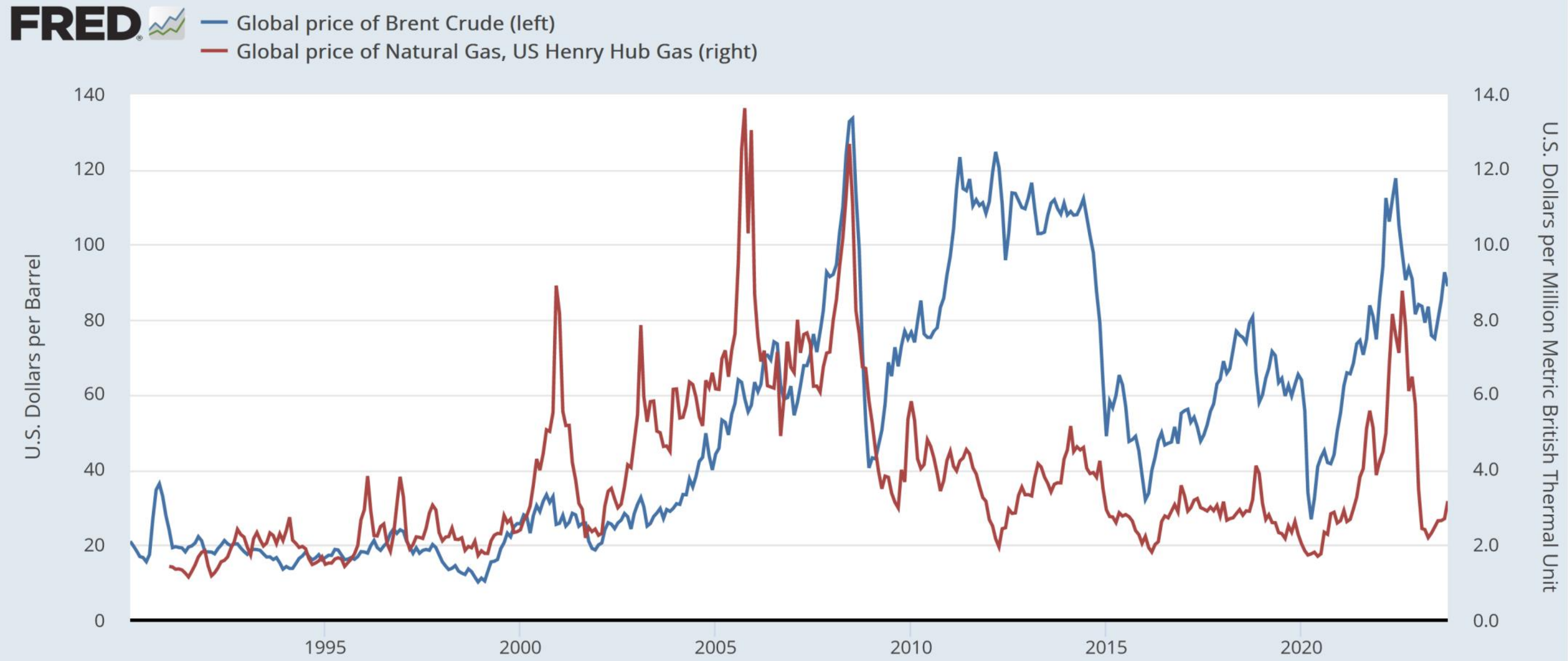
US COMPANIES TECH MARKETS CLIMATE OPINION WORK & CAREERS LIFE & ARTS HTSI

Opinion **Oil & Gas industry** + Add to myFT

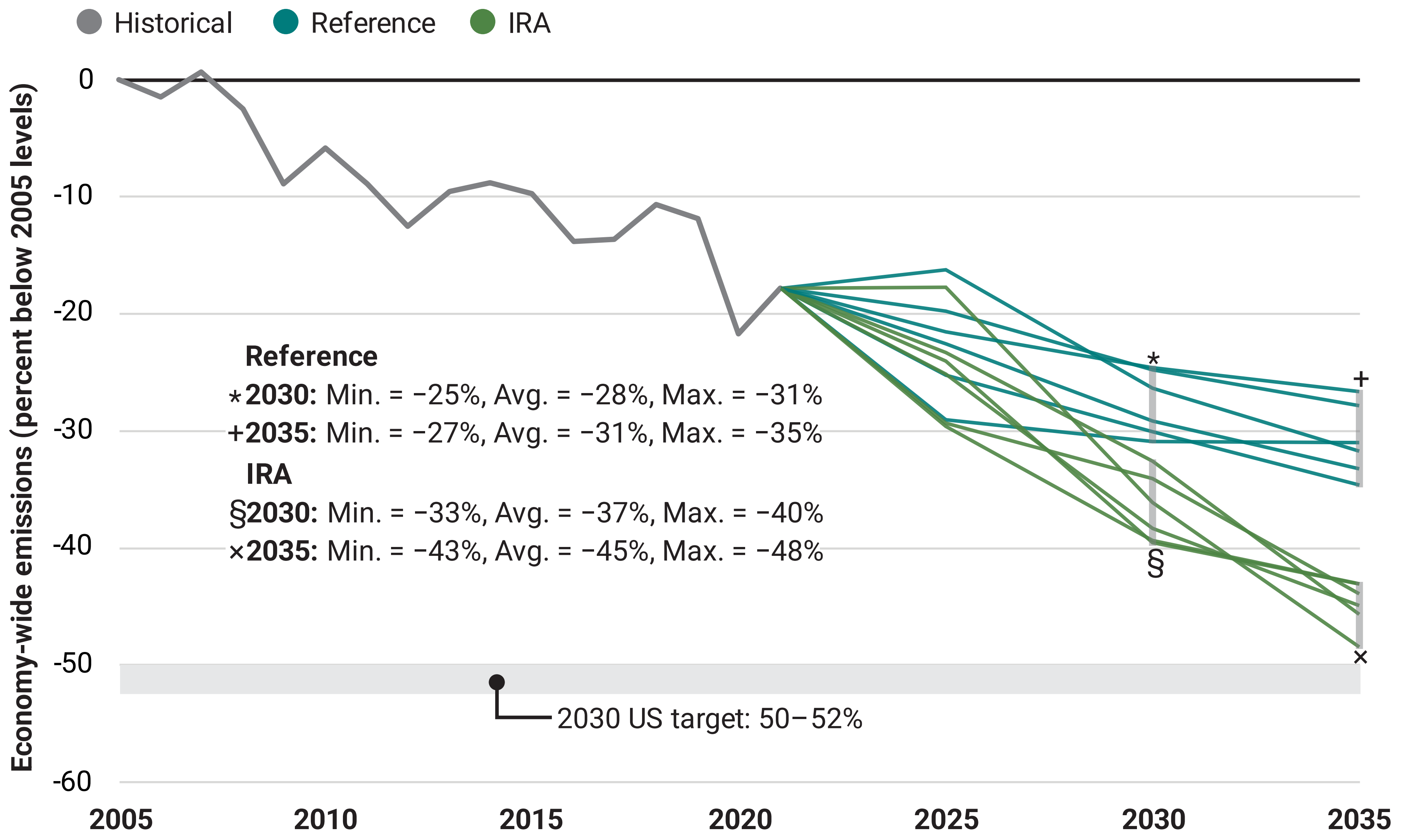
Peak fossil fuel demand will happen this decade

But the decline in oil, gas and coal will not be steep enough to limit global warming to 1.5C

FATIH BIROL + Add to myFT



Transition risks in climate policy



The IRA contributes approx. 10 pp to emissions reductions in 2030, relative to 2005

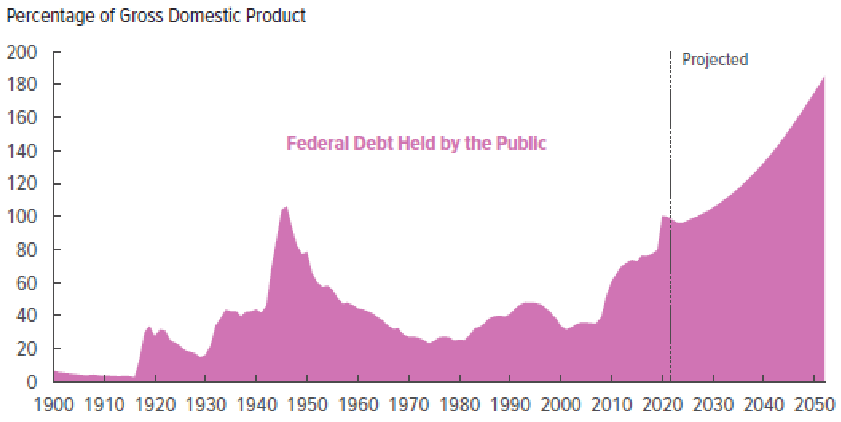
- No IRA: 25% - 31%
- With IRA: 33% - 40%

Different trajectories are from different models evaluated under same exogenous drivers

Source: Bistline et al (Science, July 2023)

Transition risks in fiscal policy

CBO long-term fiscal outlook (May 2023)



IRA cost factors

- The main tax credits are uncapped
- EPA tailpipe rule & power plant rules proposed post-IRA, not yet finalized
- Hard to model CCS (45Q) and H2 (45V) take-up

Fiscal impacts of IRA climate provisions

Source/date	Date	Components	Amount ('22-'31)
CBO/JCT (final)	Sept. 2023	All*	**$392B**
CBO/JCT (final)	Sept. 2022	LDV tax credits	$8B
CBO/JCT (final)	Sept. 2022	H2 (45V)	$13B
Cole et al	Aug 2022	LDV tax credits	$440B
Credit Suisse	Nov 2022	All*	$800B
Bistline, Mehrotra, Wolfram (BPEA)	March 2023	All*	$800B
JCT	May 2023	All*	$660B
JCT	May 2023	LDV tax credits	$99B (23-33)
Bistline & Blandford	Nov 2023	H2 (45V)	$390-$750B (lifetime)
Bistline et al (2024)	Nov 2023	All*	**$1.6T (23-33)**

* "All" includes power sector and transportation tax credits, capped manufacturing credits, clean fuel credits, and 45Q and 45V credits, however in early estimates 45Q and 45V modeling was limited.

Economists have a key role to play in guiding climate-related policy: climate fiscal policy, & monetary

This paper: a survey of climate & macro

Where can scarce commodity - economic research – be allocated for greatest impact?

Multiple dimensions of the growing macro-climate literaturer

1. Micro -> macro
2. Risks: physical/transitional (Carney 2015)
3. Positive-normative: Economic impacts of CC -> policy design
4. Policy perspective: climate policy/fiscal policy/monetary policy
5. Horizon: <10 years/10-50 years/>50 years
6. Trends -> volatility -> uncertainty -> deep uncertainty/tail risks

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Organizing framework

- Physical and transition risks (Carney (2015))
- capacious definition of transition risks to incorporate human/economic/institutional aspects of the energy transition (beyond narrow policy risk interpretation)

Physical risks:

1. Physical risks: Economic damages and macro impacts of climate change

Transition risks:

2. Mitigation risk: Macroeconomics of mitigation policy and the energy transition
3. Adaptation risk: Macroeconomics of climate adaptation
4. Implications for fiscal and monetary policy

High-level takeaways

1. Declare victory (truce?) on the SCC, Carbon Price of Warming, and Target-Consistent Price

High-level takeaways

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Key tensions

1. Quality of IAMs as policy guides
    - Pindyck 2013, Stern (2016), Stern-Stiglitz-Taylor (2022)…
    a. Limitations of damage functions
        - Top-down: focuses on GDP
        - Bottom-up: excludes many damages
    b. Structure doesn’t capture uncertainty (Barnett et al (2022))
    c. Discounting debate
2. Challenge premise: warming in perpetuity v. temperature ceiling (=> uncertain carbon budget)
    - Carbon price = Hotelling with modifications
    - Cost-benefit v. cost-effectiveness approach
3. Historically low SCC’s (DICE) rejected by climate science community
    - Rising et al (2022), Bastien-Olvera & Moore (2022)

High-level takeaways

1. Declare victory (truce?) on the SCC, Carbon Price of Warming, and Target-Consistent Price

Key tensions

1. Long-term emissions path: warming in perpetuity v. temperature ceiling (=> carbon budget)?
    - SCC consistent with long-term warming path
    - What about +2C ceiling? (Olijslagers et al (2023) etc)
    - Cost-benefit v. cost-effectiveness approach
    - With cap: Carbon price = Hotelling with modifications
2. Quality of IAMs as policy guides
    - Pindyck 2013, Stern (2016), Stern-Stiglitz-Taylor (2022)…

    a. Limitations of damage functions
        - Top-down: focuses on GDP
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    c. Discounting debate
3. Historically low SCC's (DICE) rejected by climate science community
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In practice, at this point these debates don't matter (at least for now)

- **EPA (2022) SCC and near-term Ramsey discount rate**

Emission Year	SC-CO_2 (2020 dollars per metric ton of CO_2) 2.5%	2.0%	1.5%
2020	120	190	340
2030	140	230	380
2040	170	270	430
2050	200	310	480

- **RFF team (Science 2022): $185/ton**
- **Moore et al. (2023) SCC meta-study: $467/ton**

2. Remember, GPD ≠ Welfare

EPA SCC damage function is bottom up and includes mortality, energy, labor productivity, agriculture, & coastal SLR

What about:

- Morbidity
- Migration
- Conflict
- Ecosystem services
- Biodiversity
- Natural capital (Dasgupta Review)
- Rights of nature

High-level takeaways

3. Policy design: Beyond carbon pricing

- Multiple externalities, multiple tools
- Meet the political process where it is – or risk irrelevance

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Mitigation policies

i. Carbon pricing
ii. Innovation policy
iii. Mixed policies & sectoral/targeted policies
    - Acemoglu et al (2012), Stern-Stiglitz (2017), Cole et. al (2023)
iv. Supply-side subsidies & industrial policy (IRA)
v. International coordination
    - Climate clubs – Nordhaus (2015)
vi. Carbon dioxide removal and nature-based solutions
    - Overshoot commission (2023);
    - Will we/what if we spend 2-3% of GDP on CDR?
vii. Corporate targets and voluntary measures
    - Kaplan and Ramanna (2021), Bolton and Kacperczyk (2022, 2023)
viii. Degrowth

High-level takeaways

4. We know little about the economic implications of the energy transition

- Economic fluctuations from policy implementation & policy uncertainty
- Energy security & global energy markets of the future
- Long run effects on: r*, TFP growth, growth rate of (productive) capital

Example: short-term macro effects of a carbon tax (Metcalf-Stock 2023) v. cap & trade (Känzig 2023)

Data
- EU+ (31 countries in EU-ETS)
- 15 have carbon taxes, imposed mainly on transport sector, at different levels, starting at different dates

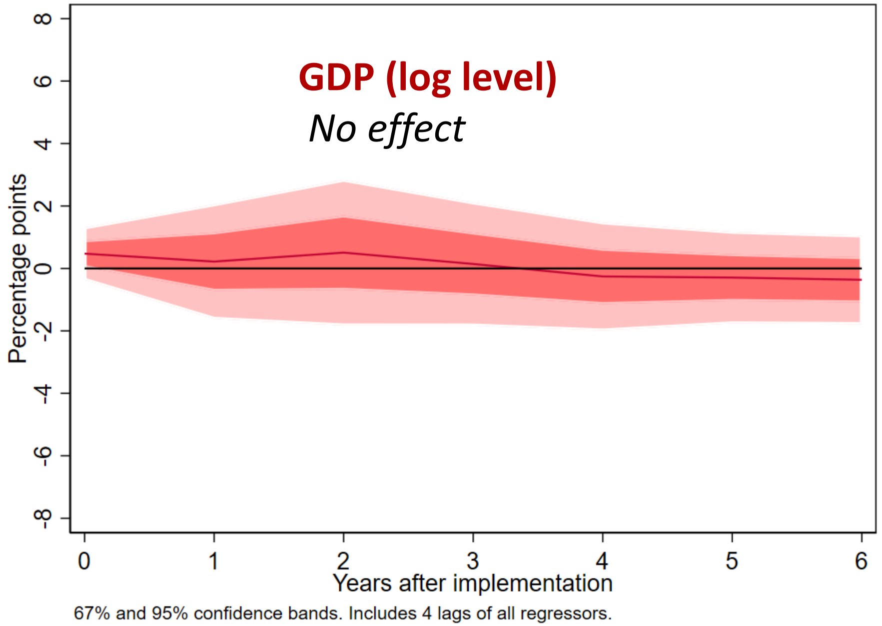
Method:
- Panel local projections, identified by tax timing

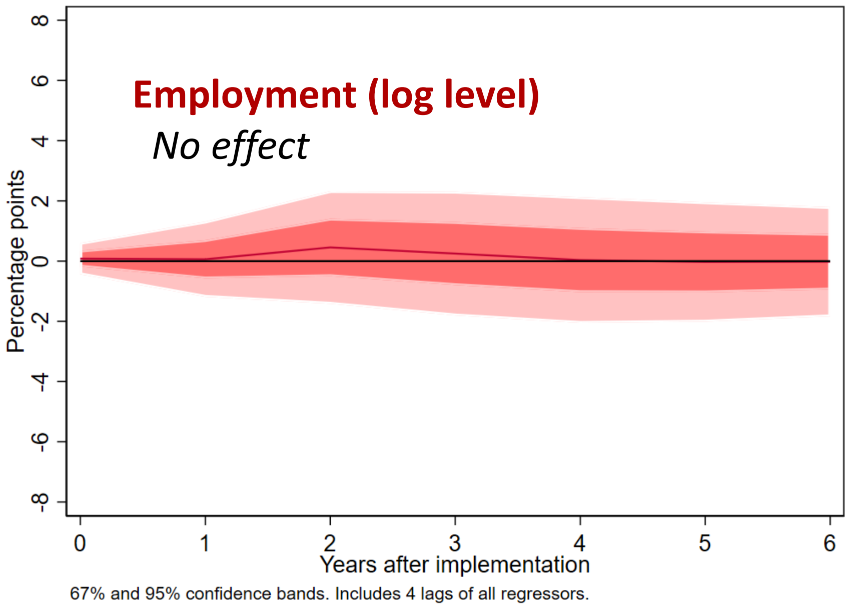
Findings:
- Negligible effect on GDP or employment
- Modest effect on emissions
  - In line with elasticity of demand for petroleum

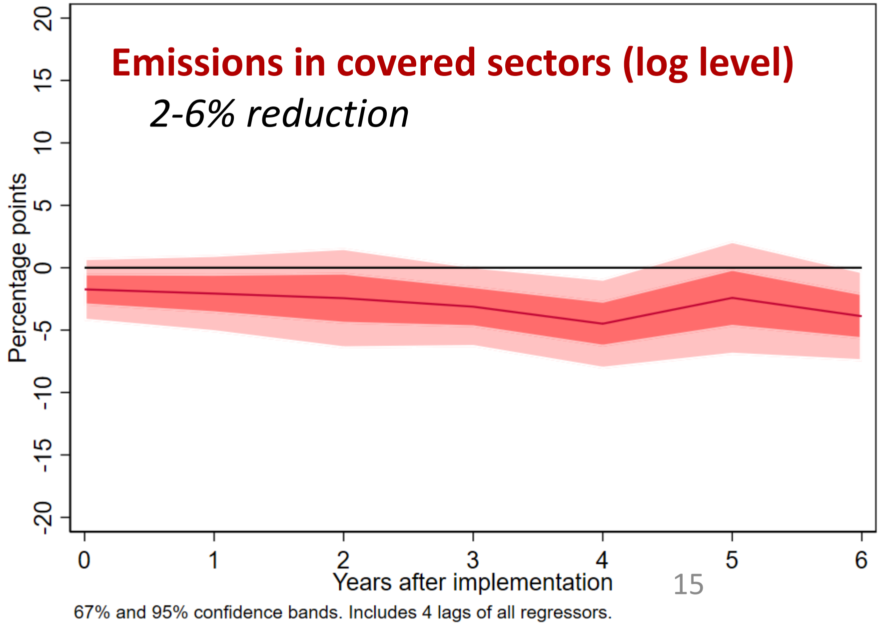
Caveats:
- Aggregate effect masks sectoral & regional reallocation & job loss/gain
- Possibly greater macro costs from cap & trade system (EU ETS – Känzig 2023), perhaps b/c of price volatility, perhaps sectoral coverage

CARBON TAX: Metcalf-Stock (2023)

Impulse responses: effect of a \$40 carbon tax on 30% of emissions







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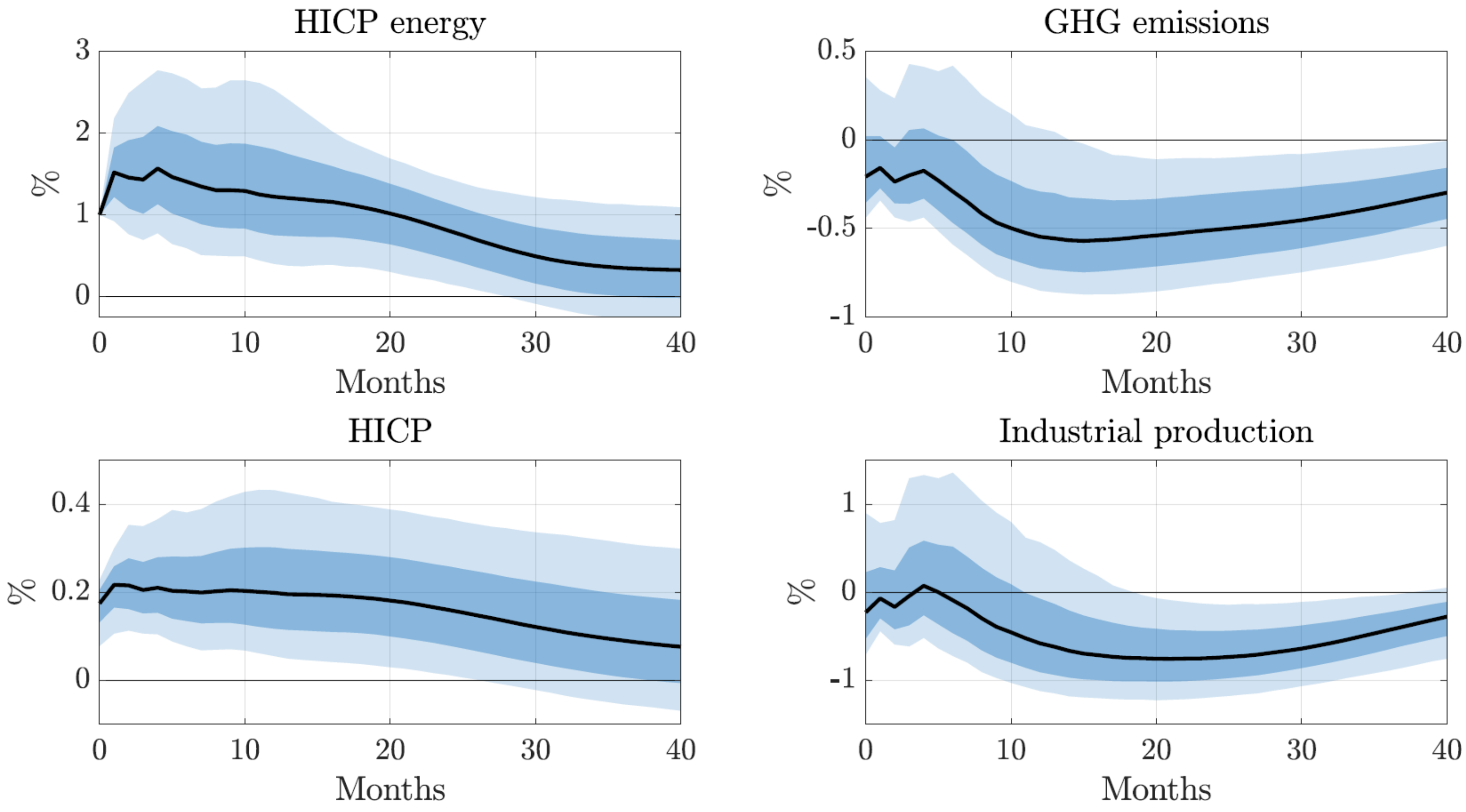
CAP AND TRADE: Känzig (2023)

Data:
- EU-wide macro time series
- EU-ETS prices

Method:
- SVAR-IV
- Instrument: ETS price changes around ETS announcement windows

Results:
- Inflationary pressures + decline in economic activity
- Decline in GHG emissions largely in line with direct effect being reduction in activity

Effect of a EU-ETS shock on Euro-wide:



Source: Käanzig (2023)

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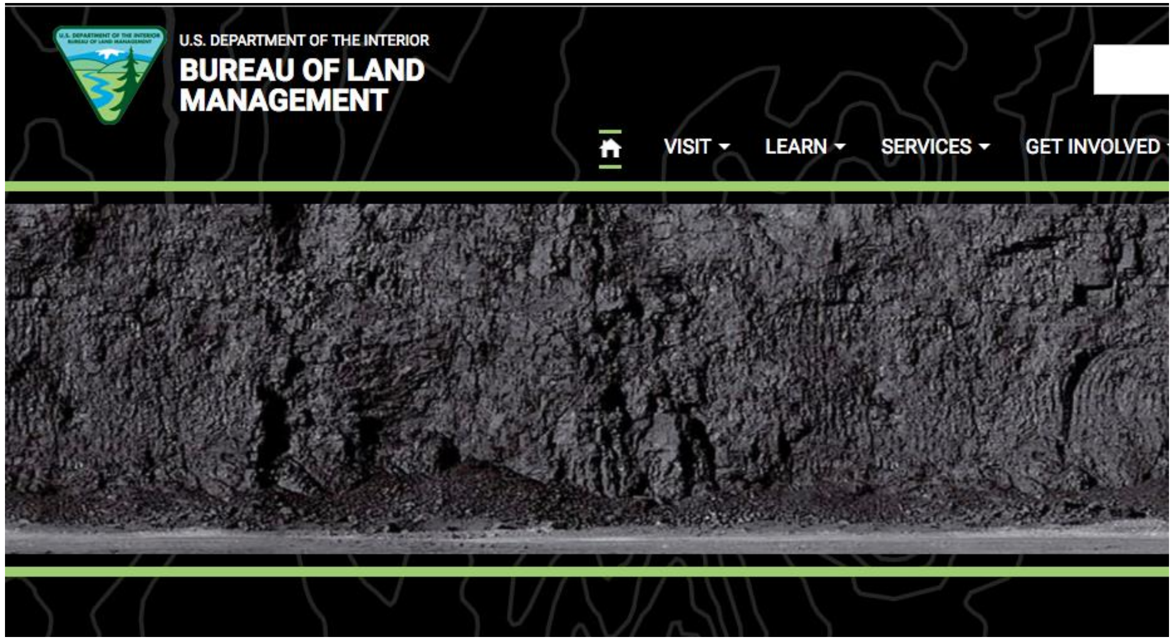
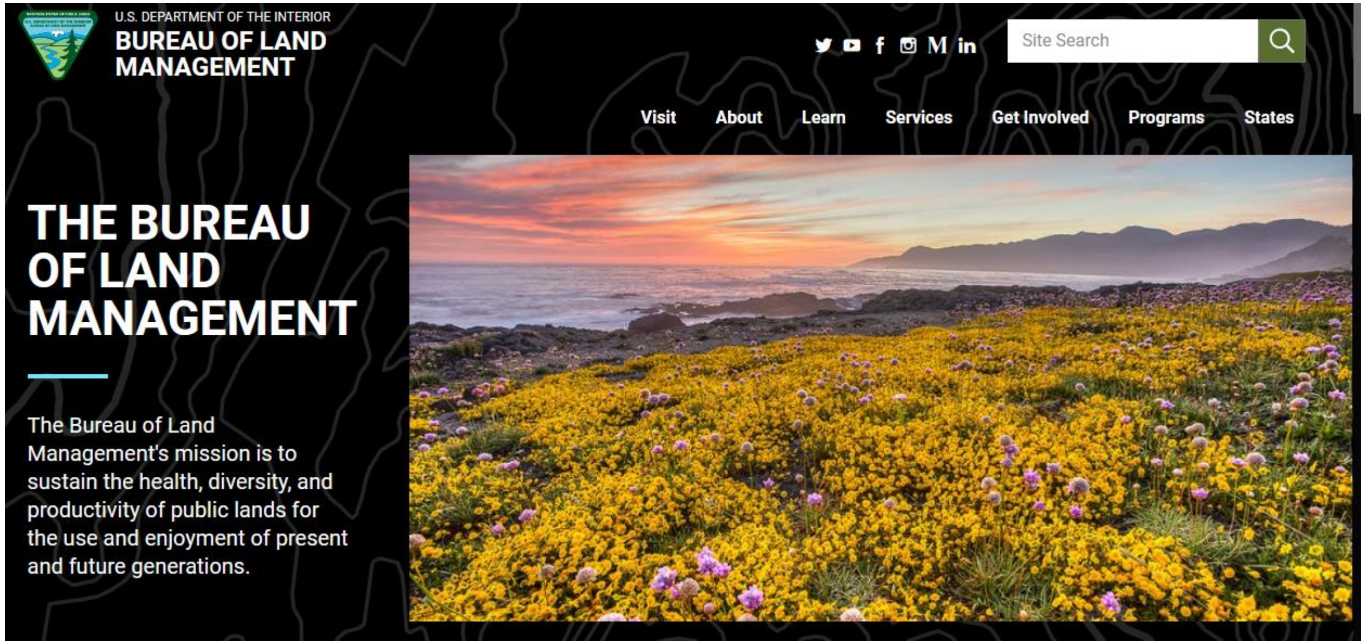
Example: Macro costs of climate policy uncertainty





Not just the U.S.!

- Carbon tax in Canada
- Carbon tax in Australia
- U.K. and EVs, FF production
- Germany and coal

Literature

Gavriilidis (2021)
Basaglia et al (2021)
Noailly et al (2022)
Fried, Novan, & Peterman (2021)
Engle et al (2020)
Sautner et al (2020)

Measuring climate policy uncertainty

Data set:

- Climate policy uncertainty index (CPU): Gavriilidis (2021); cf. Engel et al (2020)
  - Akin to Baker-Bloom-Davis Economic Policy Uncertainty construction
  - 15 million news articles from 8 newspapers starting mid-80s
  - Dictionary method:
    - climate (carbon dioxide, climate change, emission(s),…)
    - + policy (legislative, white house, regulation, carbon tax,…)
    - + uncertainty
    - - exclusions (business climate, economic climate,…)
  - including climate terms *and* policy terms *and* uncertainty
  - Correlation with BBD EPU ≈ 0.7
  - Monthly

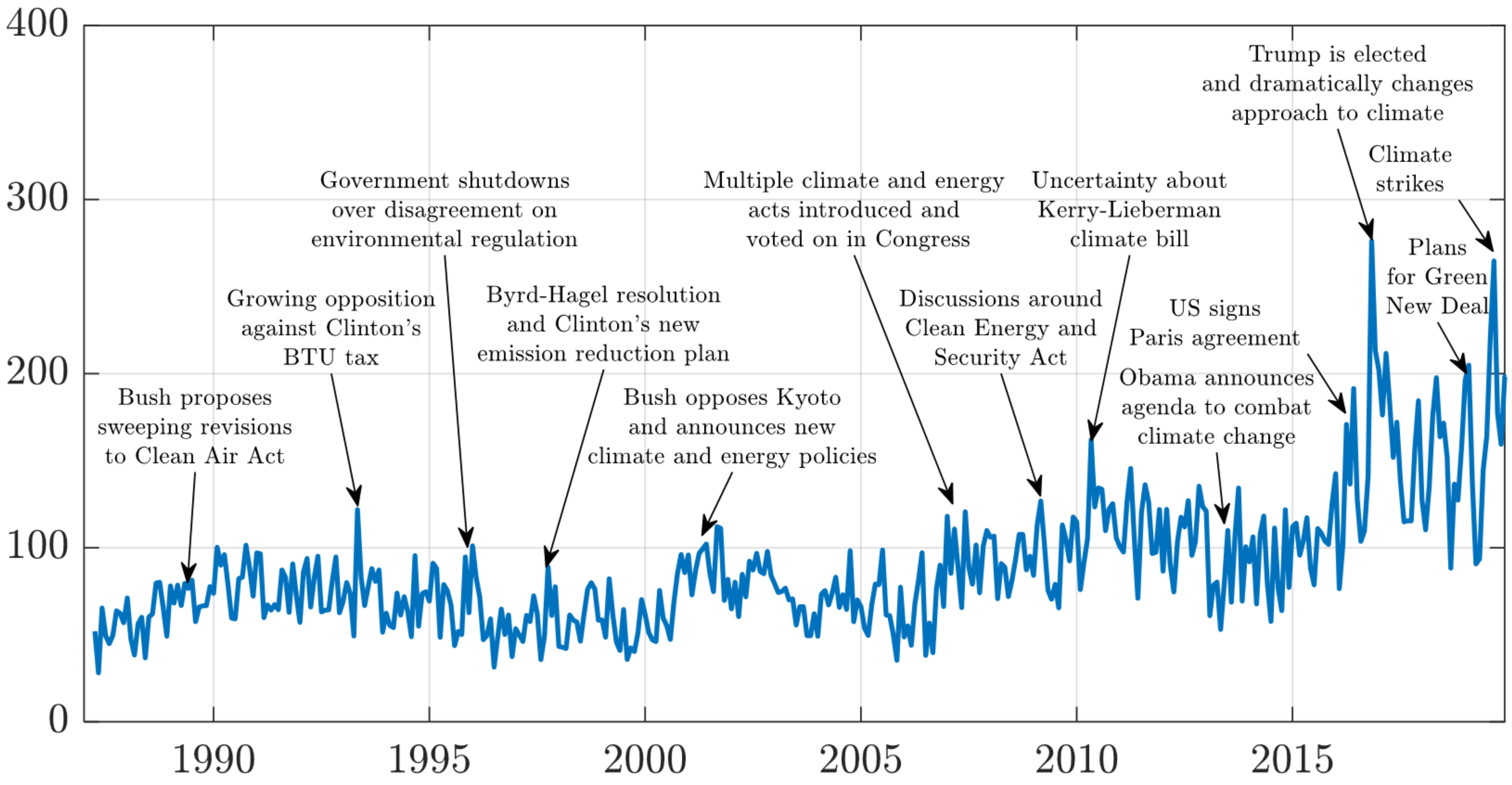
Method: LP & SVAR

- Identification: CPU shock satisfies conditional mean independence given contemporaneous control variables: BBD-EPU, IP, unemployment rate, PCE inflation, WTI price, 90-day T-bill rate

Caveats: Usual BBD EPU caveats

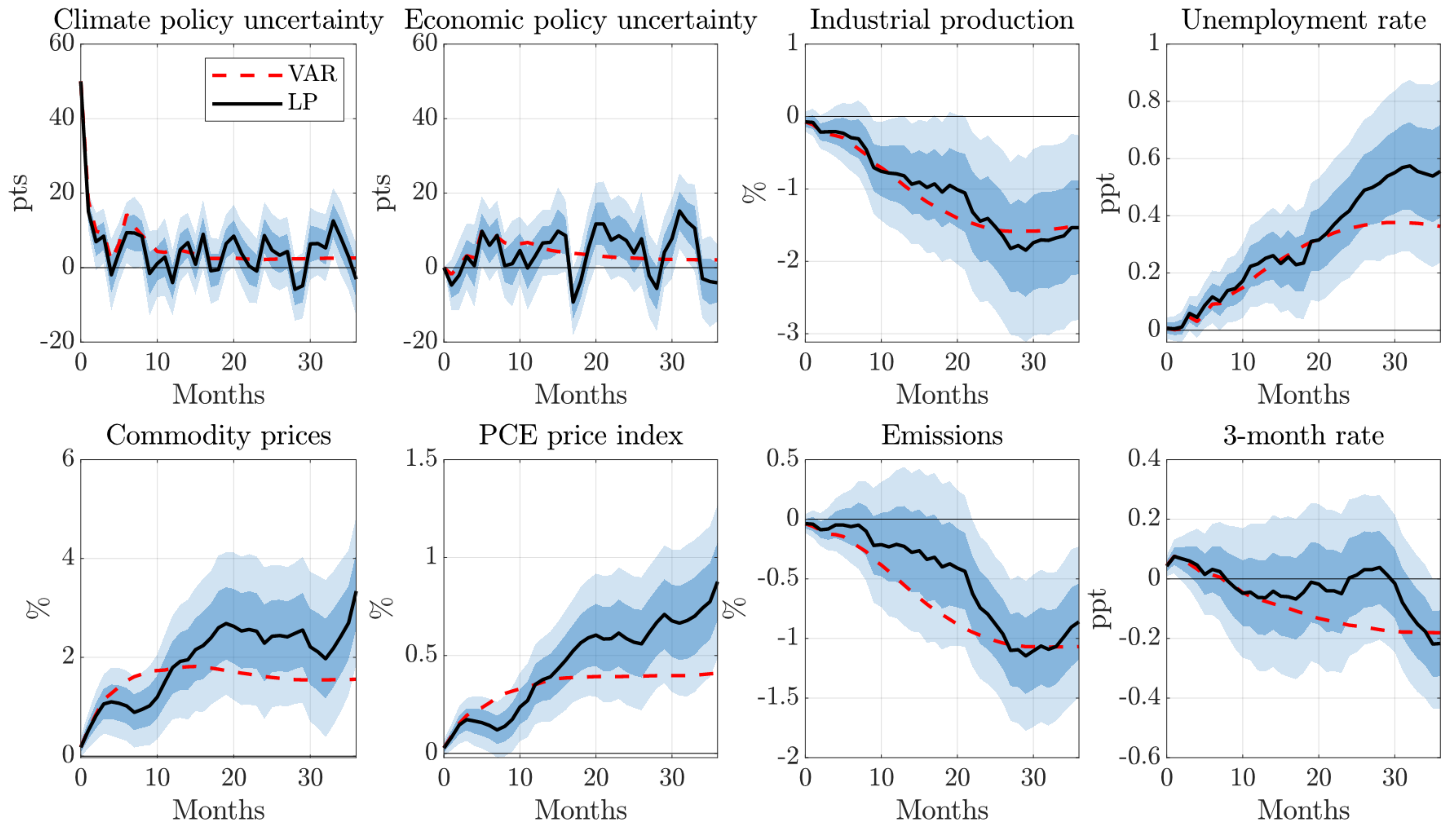
Measuring climate policy uncertainty

Climate policy uncertainty index



Source: Gavriilidis, Känzig, & Stock (in progress)

Climate policy uncertainty: IRFs, 50 point CPU shock, LP



High-level takeaways

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Changing natural gas market (Stock & Zaragosa-Watkins (2023))

Ukraine, natural gas prices, & cyclical implications of fossil fuel price shocks for US

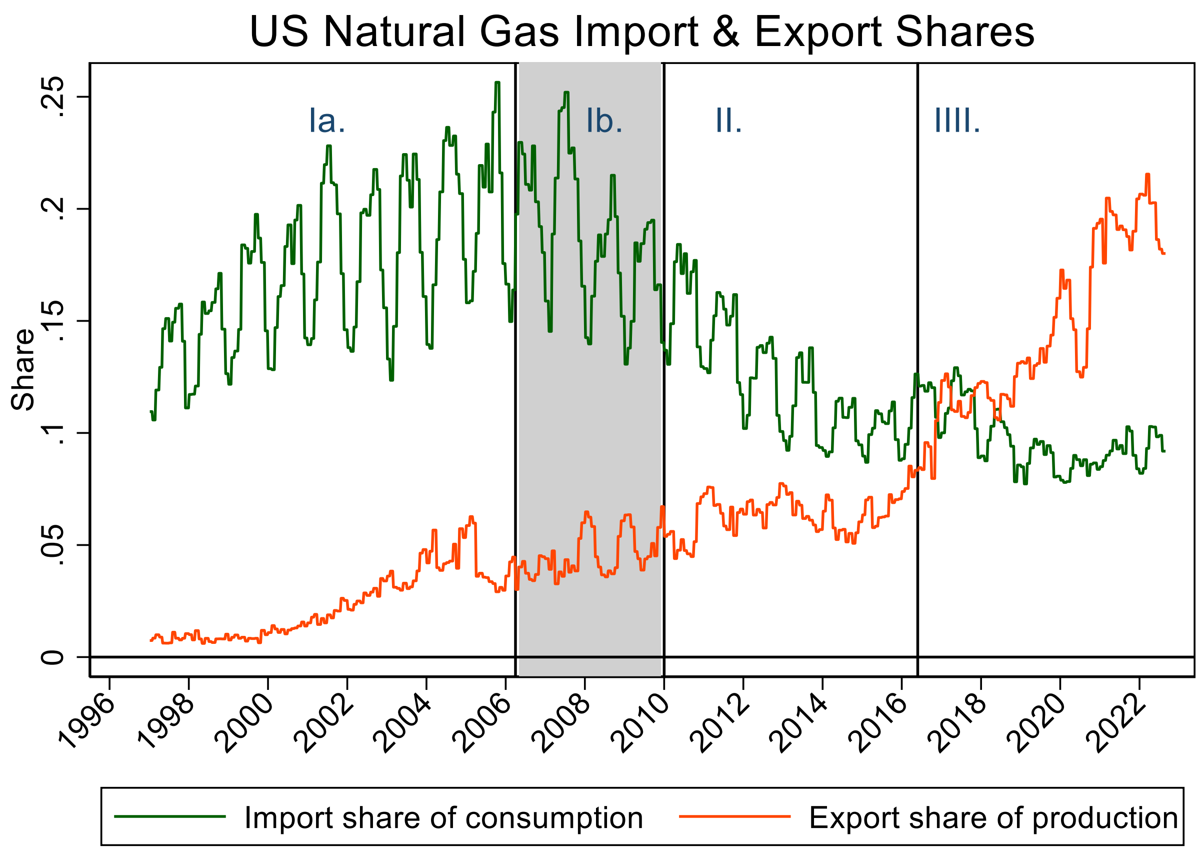
<u>Three regimes in US gas markets:</u>

I. <= ~2006: growing & large imports

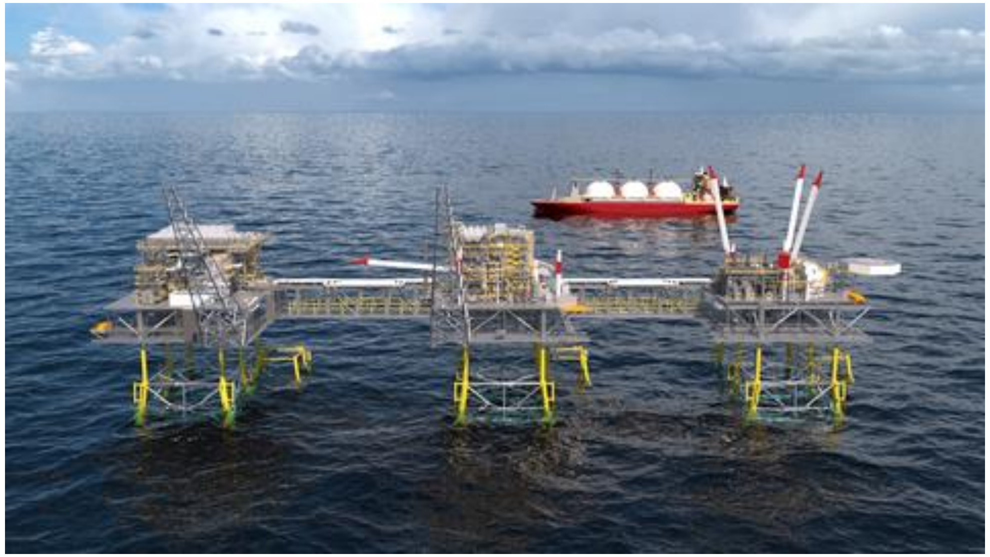
II. 2010 – 2016: Fracking & "locked in"

III. 2016 – present: LNG exports

Cheniere Sabine Pass Train 1 was placed into service May 2016.



Fast LNG facility

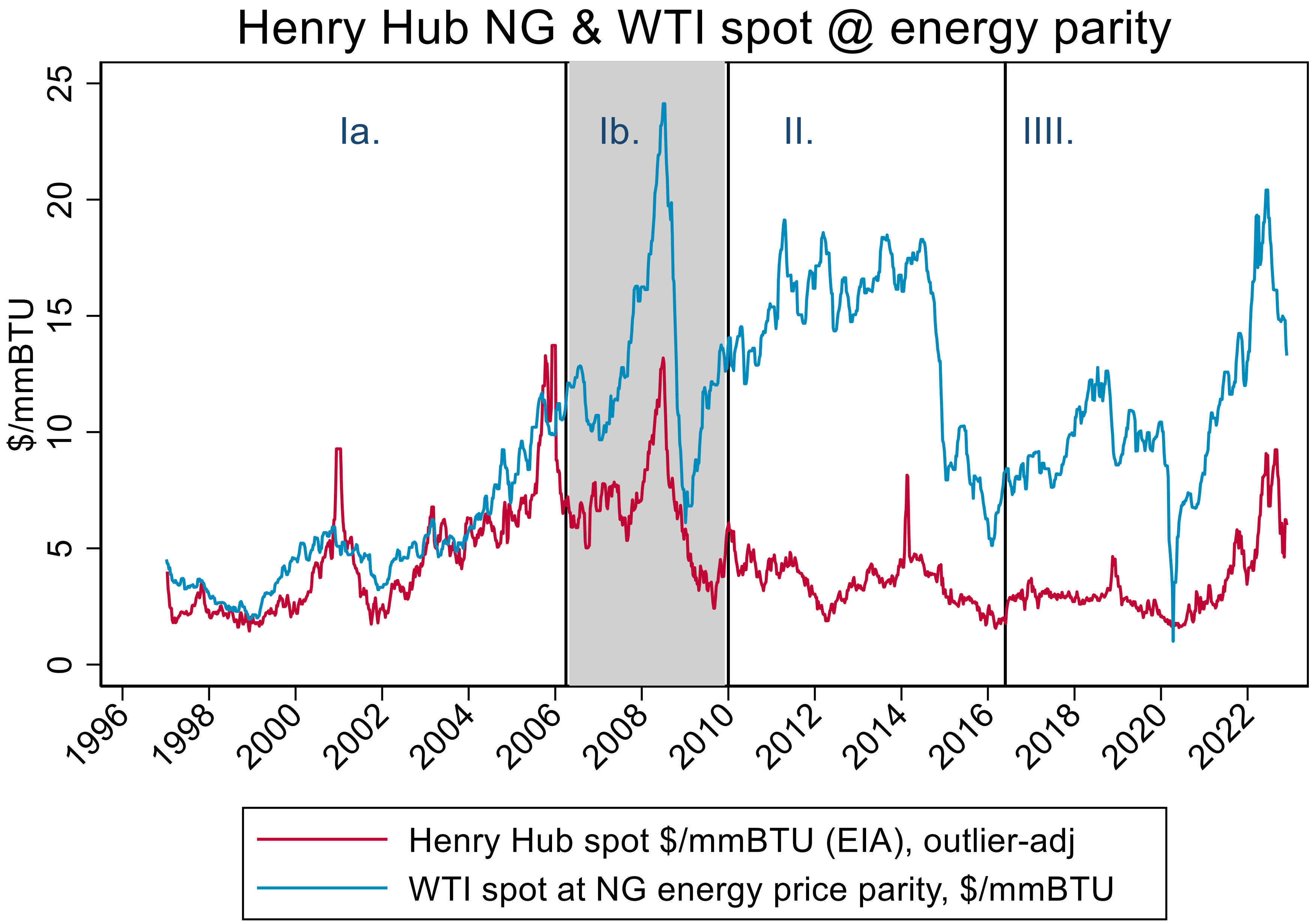


Natural gas prices, LNG, and macro implications: Summary

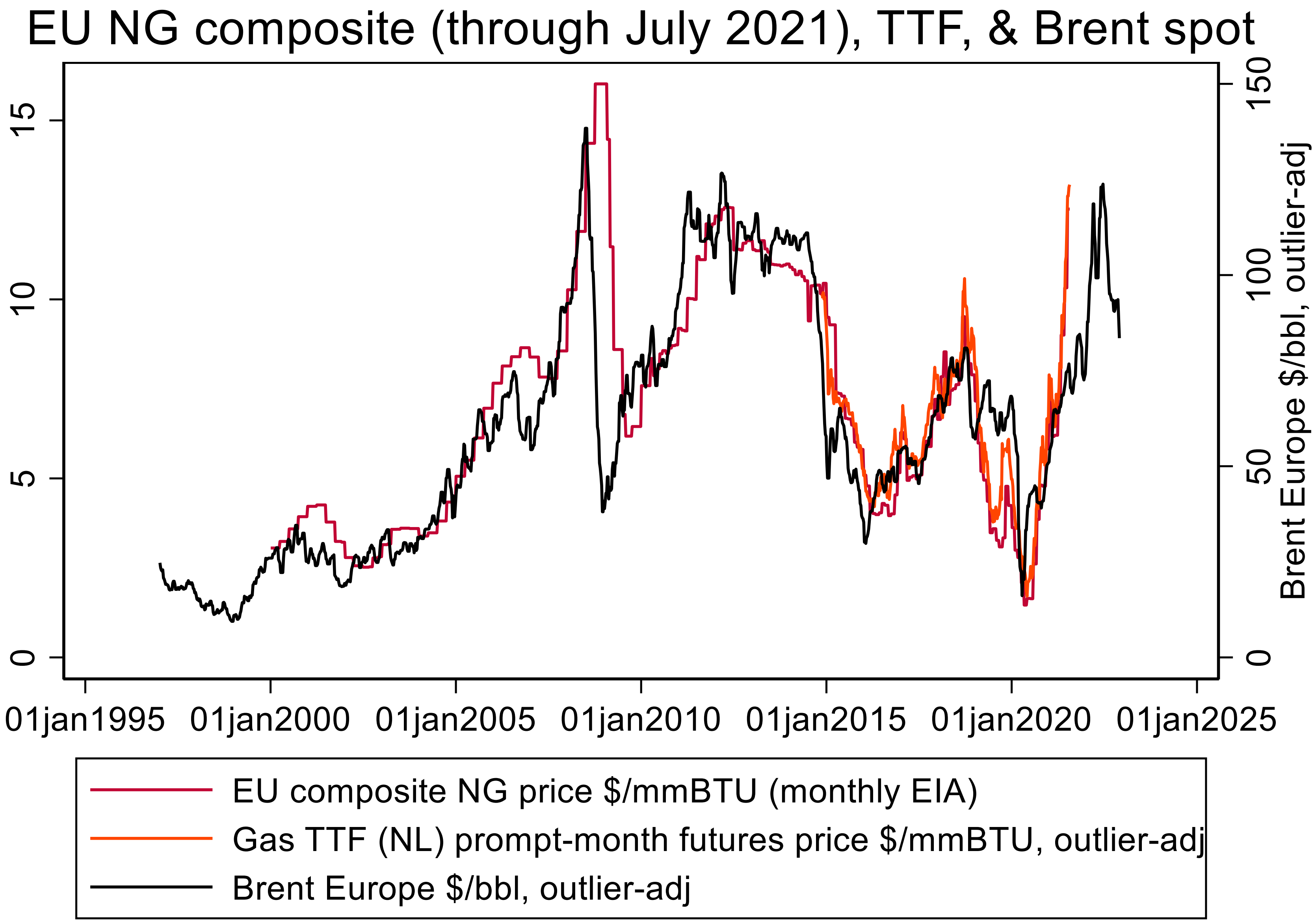
1. Because of increasing LNG exports, accelerated by the invasion of Ukraine, U.S. natural gas prices are reconnecting to global natural gas & oil markets

2. We can therefore anticipate a prolonged period of U.S. higher natural gas prices ($6-$8?)

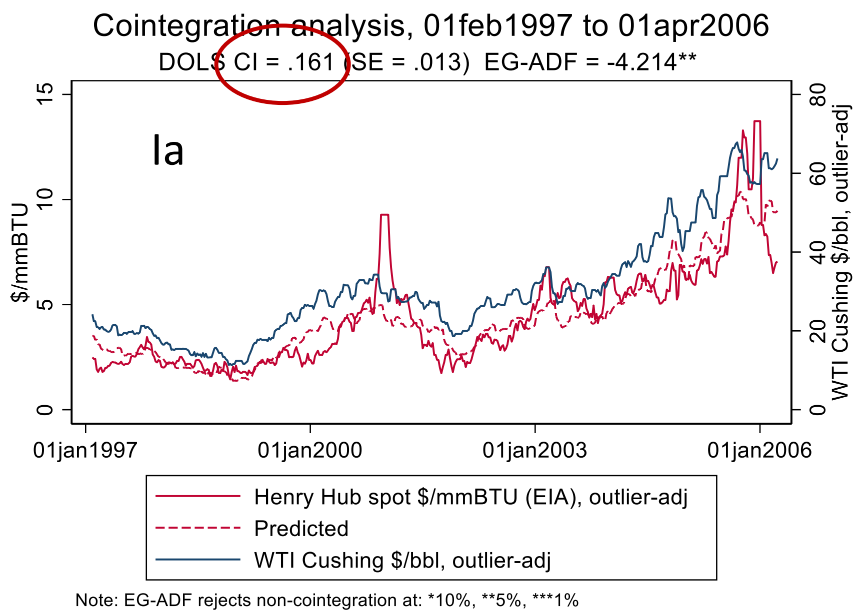
3. The impact of this price increase on power sector emissions, relative to recent projections (e.g., AEO 2022) is roughly that of a $50 carbon tax, and larger than the IRA

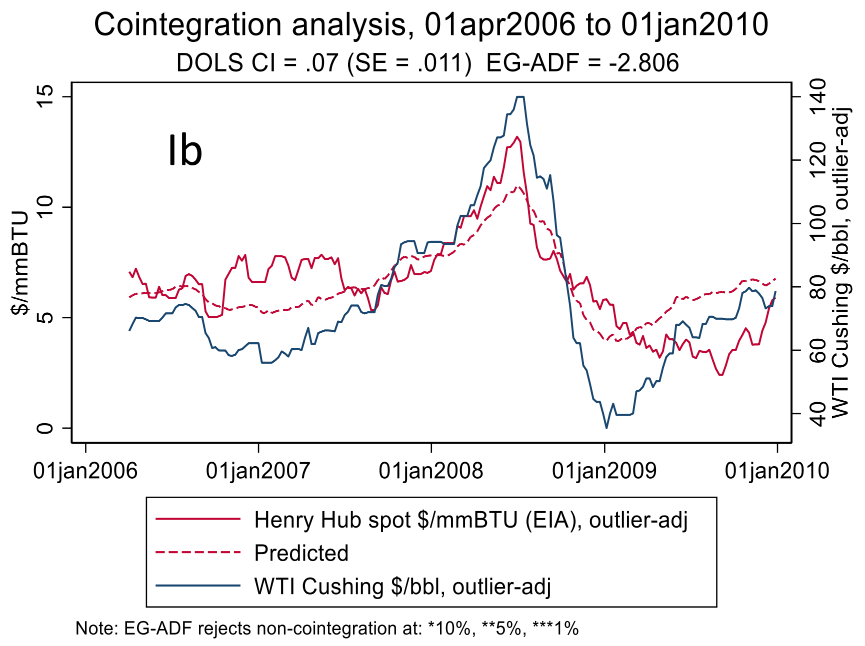


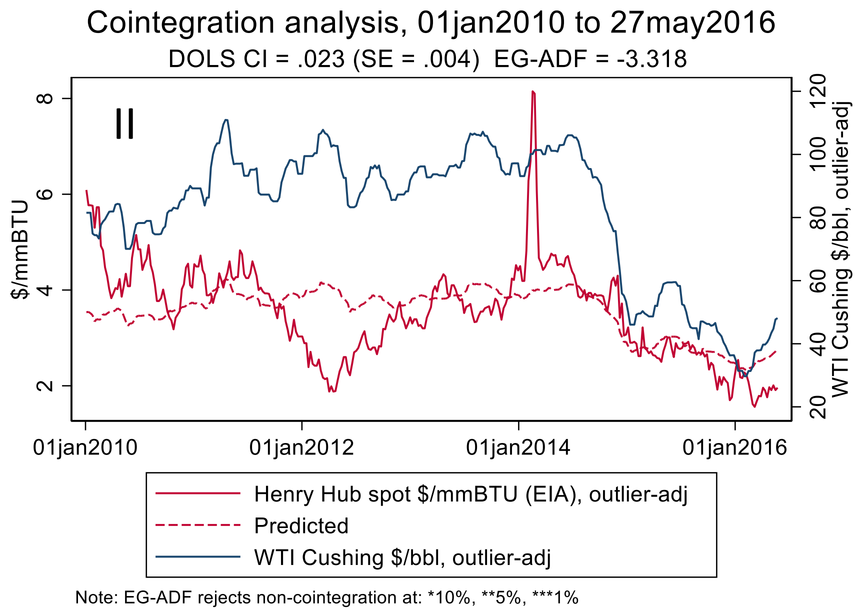
Global natural gas prices track oil prices

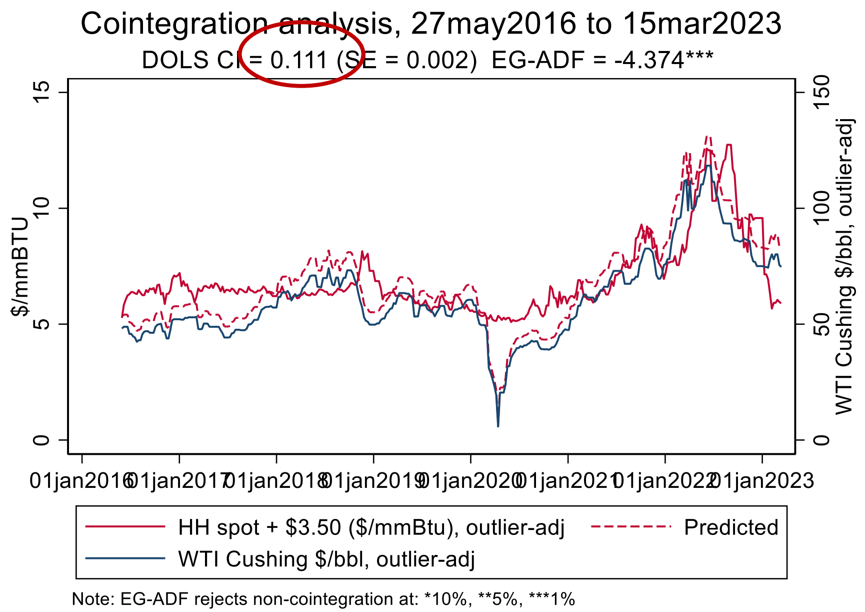


Cointegration results by institutional regime, U.S.









Implications

- **Implications for the macroeconomy**
  Increased domestic exposure to global energy price shocks

- **Implications for the energy transition**
  Back-of-envelope estimates of U.S. power sector emissions in 2030, relative to 2007 peak, for various natural gas prices

- **Implications for long-term energy markets?**
  - Ammonia, e-fuels, bio-based SAFs will all compete in the same global markets – presumably, alongside petroleum with CDR/DAC
  - Continuing threats to "energy security"?

Scenario	HH price (2022 $/mmBtu)	2030 emissions relative to 2007 peak	Delta from BAU (pp)
BAU	$3.10	46%	-
IRA only	$3.10	62%	-15 pp
LNG only	$5.10	57%	-11 pp
IRA + LNG	$5.10	72%	-26 pp
IRA + LNG	$7.10	76%	-30 pp

Notes: LNG emissions counterfactuals use Stock & Stuart (2021a) ReEDS simulations for the power sector

4. We know little about the economic implications of the energy transition

- Economic fluctuations from policy implementation & policy uncertainty
- Energy security & global energy markets of the future
- Long run effects on: r*, TFP growth, growth rate of (productive) capital

	Long run π*, r*, u*, μ
Physical	• Lower average crop yields • Lower productivity • sea level rise • adaptation costs,…
Transition (Human systems)	• green investment demand • shifts in types of jobs/skills • monetary policy decision (no accommodation of smooth increase) • Fiscal theory of price level concerns • Long run productivity growth • Growth of productive capital (think CDR)

High-level takeaways

5. **Macroeconomics of adaptation: provide underpinnings of future adaptation policy**

High-level takeaways

6. Much more work is needed on risk cascades, tail risks, and deep uncertainty of the energy transition

- Climate-prudential monetary policy (NGFS, ongoing)
- Risk cascades:
  - Example: wildfires and California home insurance as a (small) risk cascade
- Tail risk:
  - Example: Geopolitical risk

Events that economists missed include:

- Great Depression
- Oil crisis & inflation of 1970s
- Financial crisis
- COVID & post-COVID inflation
- Invasion of Ukraine

- What lurks in the energy transition?

Additional Slides

2. Mitigation risk: Mitigation policy and the energy transition

a. **Mitigation policy**
   i. Carbon pricing
   ii. Innovation policy
   iii. Mixed policies & sectoral/targeted policies
      - Acemoglu et al (2012), Stern-Stiglitz (2017), Cole et. al (2023)
   iv. International coordination
      - Climate clubs – Nordhaus (2015)
   v. Carbon dioxide removal and nature-based solutions
      - Overshoot commission (2023); 2-3% of GDP on CDR?
   vi. Corporate targets and voluntary measures
      - Kaplan and Ramanna (2021), Bolton and Kacperczyk (2022, 2023)
   vii. Degrowth
b. **Short- and medium-term macro effects of mitigation policies**
   i. Carbon tax
   ii. Cap-and-trade
   iii. Subsidies
   iv. Industrial policy
   v. Climate policy uncertainty
c. **Energy security**
d. **Long-run effects (r*, TFP growth, growth of (productive) capital**
e. **Risk cascades and risk amplifiers**
f. **Tail risk** (e.g., declining petro states, climate migration)

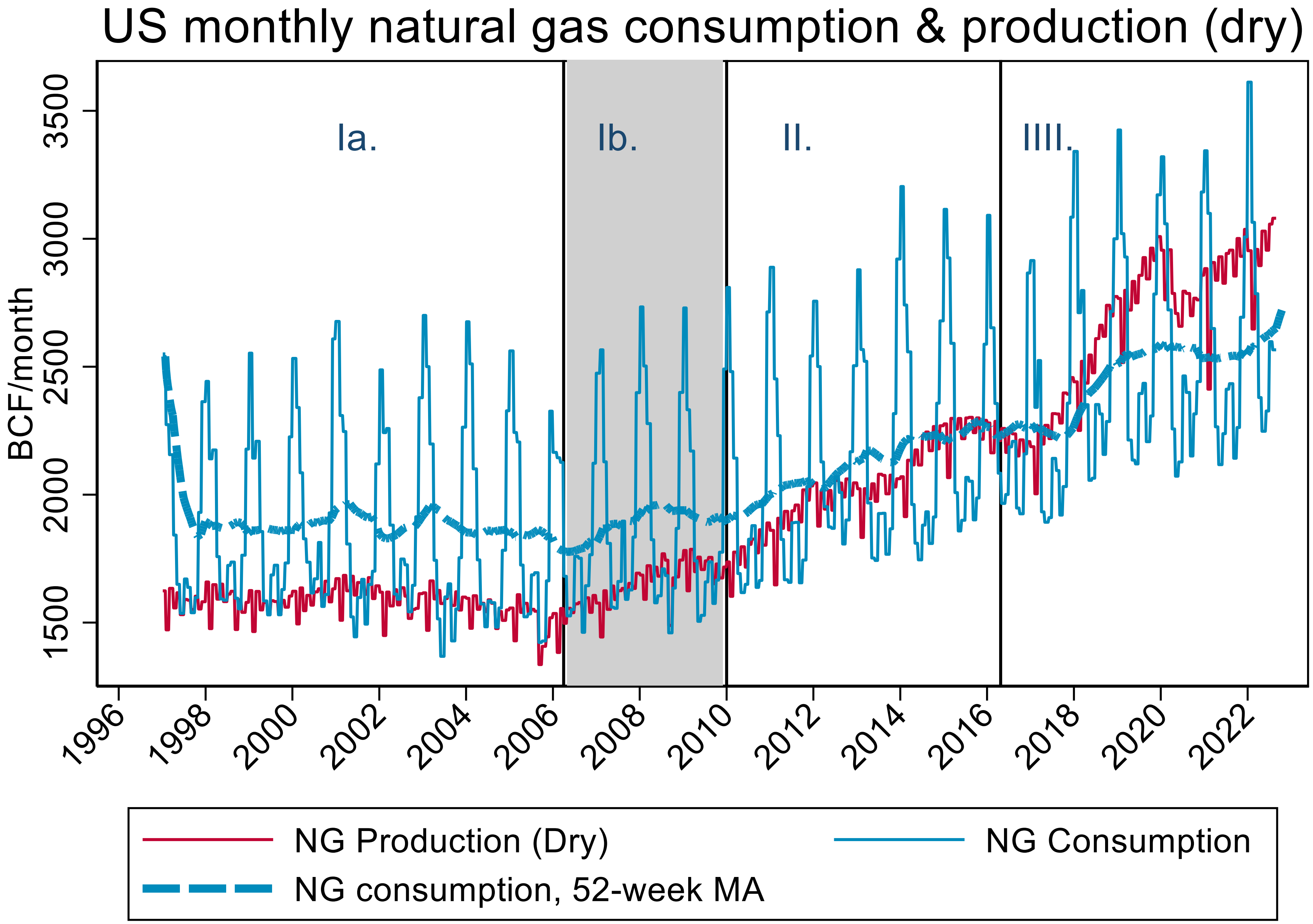
Prices: $/mmBTU

Quantities:

- 1 Mcf (1000 cubic feet) = 1.037 mmBTU
- In 2021, U.S. consumed 30 B mmBtu
- US Henry Hub 2021 average price = $6.45/mmBtu
- Total value = ~$200B
- Cf: crude oil consumption = ~$575B in 2021

Natural gas is difficult to transport. Two methods:

- Pipeline
- Liquified natural gas (LNG)



Background: Climate Risks (Carney 2015)

1. Physical

- Heat waves
- Storms
- Regional crop failures
- Sea level rise
- Climate migration

2. Transition

- Asset revaluation
- Energy price volatility
- Sectoral reallocation
- Food price volatility
- Policy effects

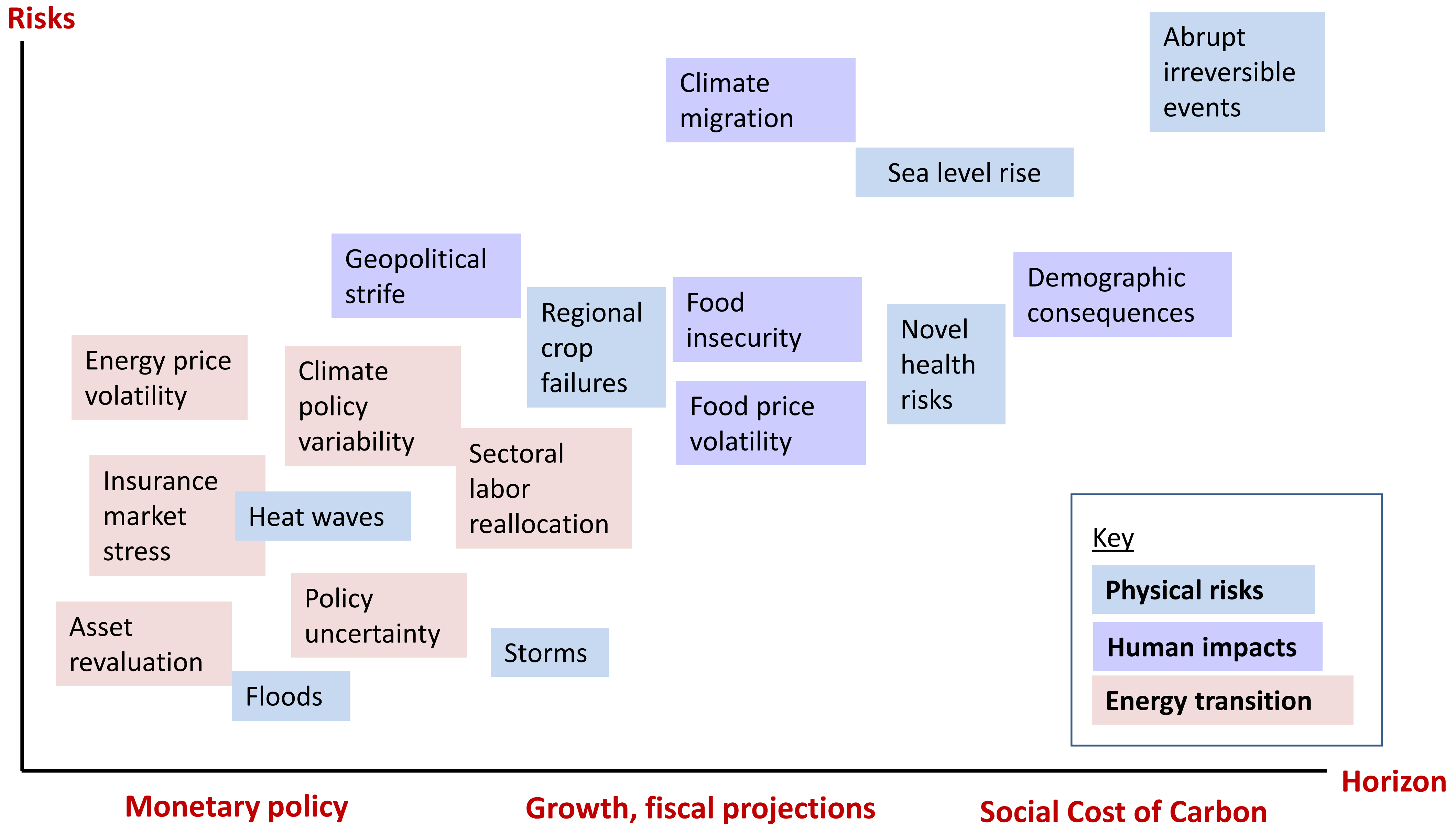
3. Liability

- Corporate (ExxonMobil suits, etc.)
- Sovereign (Loss and damage)

Timeline of macro impacts

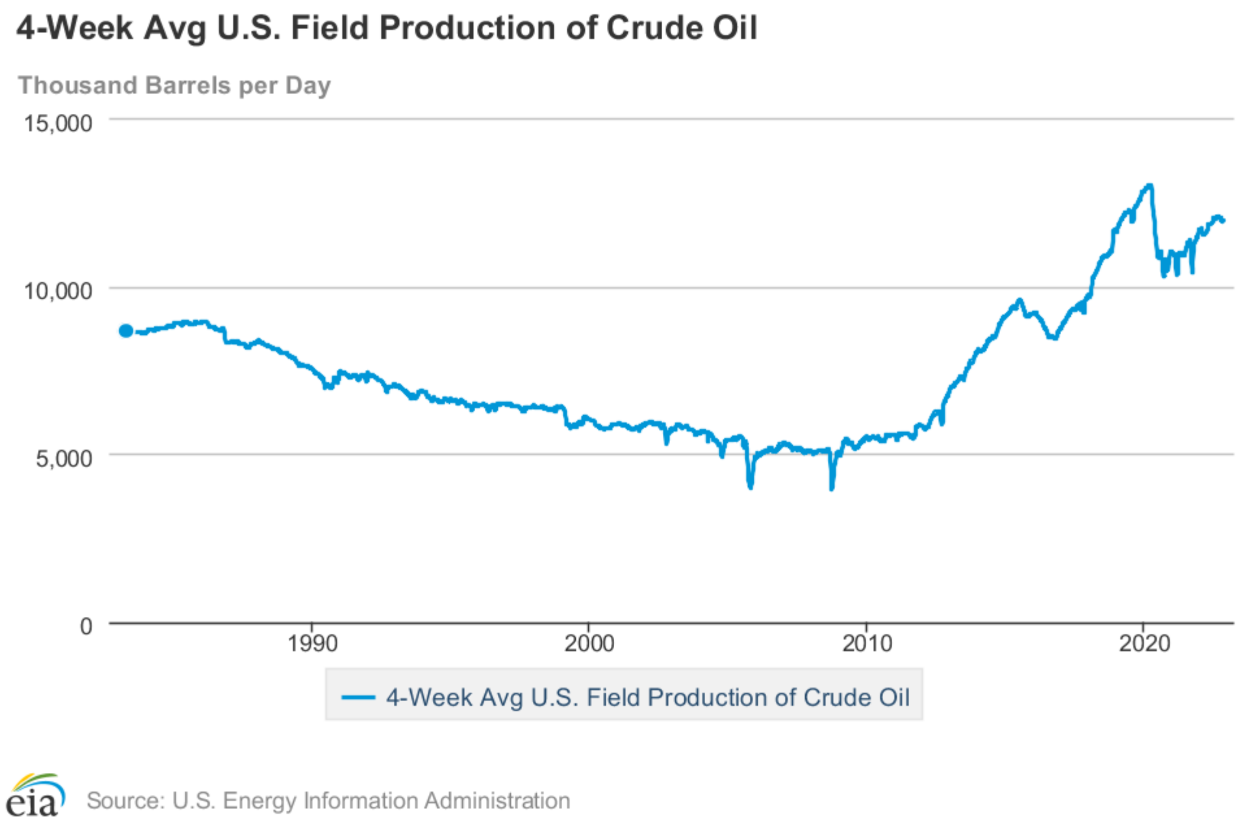
1. Low frequency
   - Long-term damages
   - Social Cost of Carbon
2. Business cycle frequency

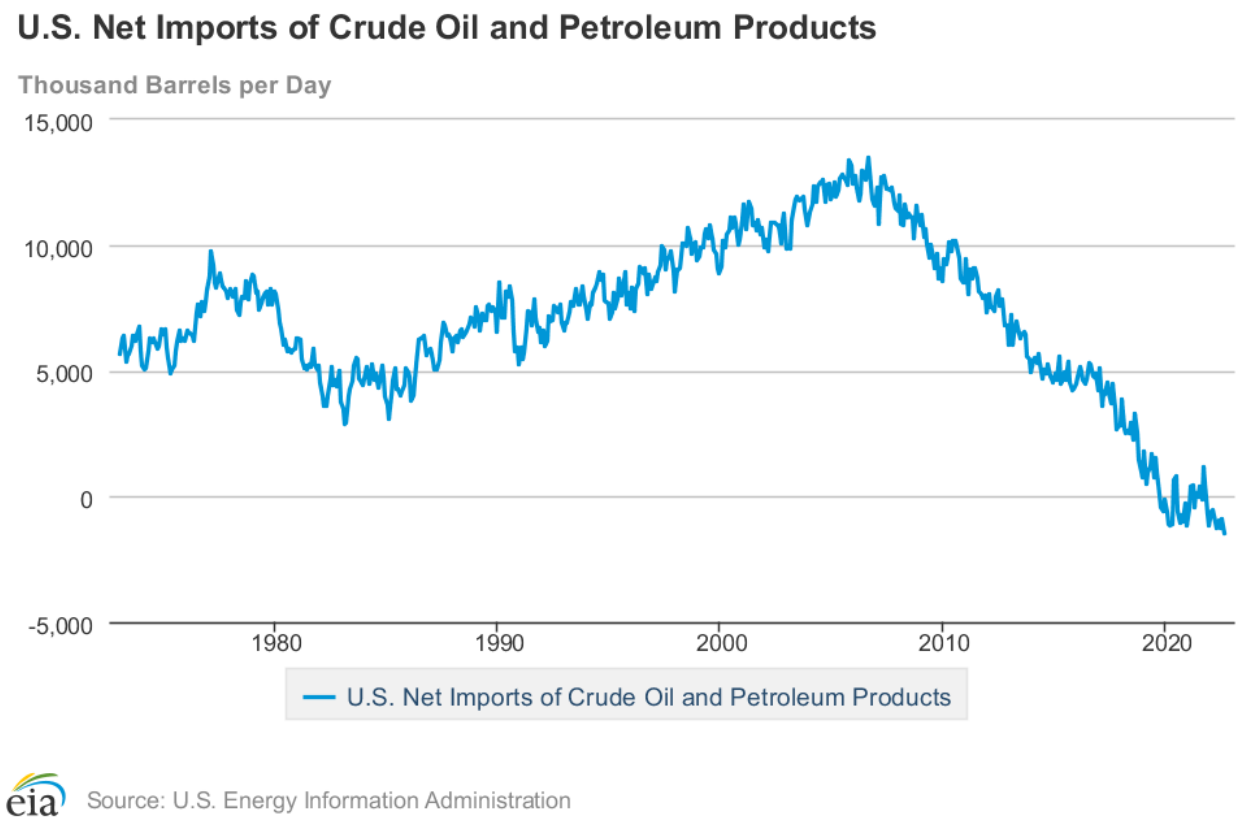
Background: Which climate impacts ("climate risks")?



Timing and magnitudes are illustrative.

The U.S. has become a net oil exporter



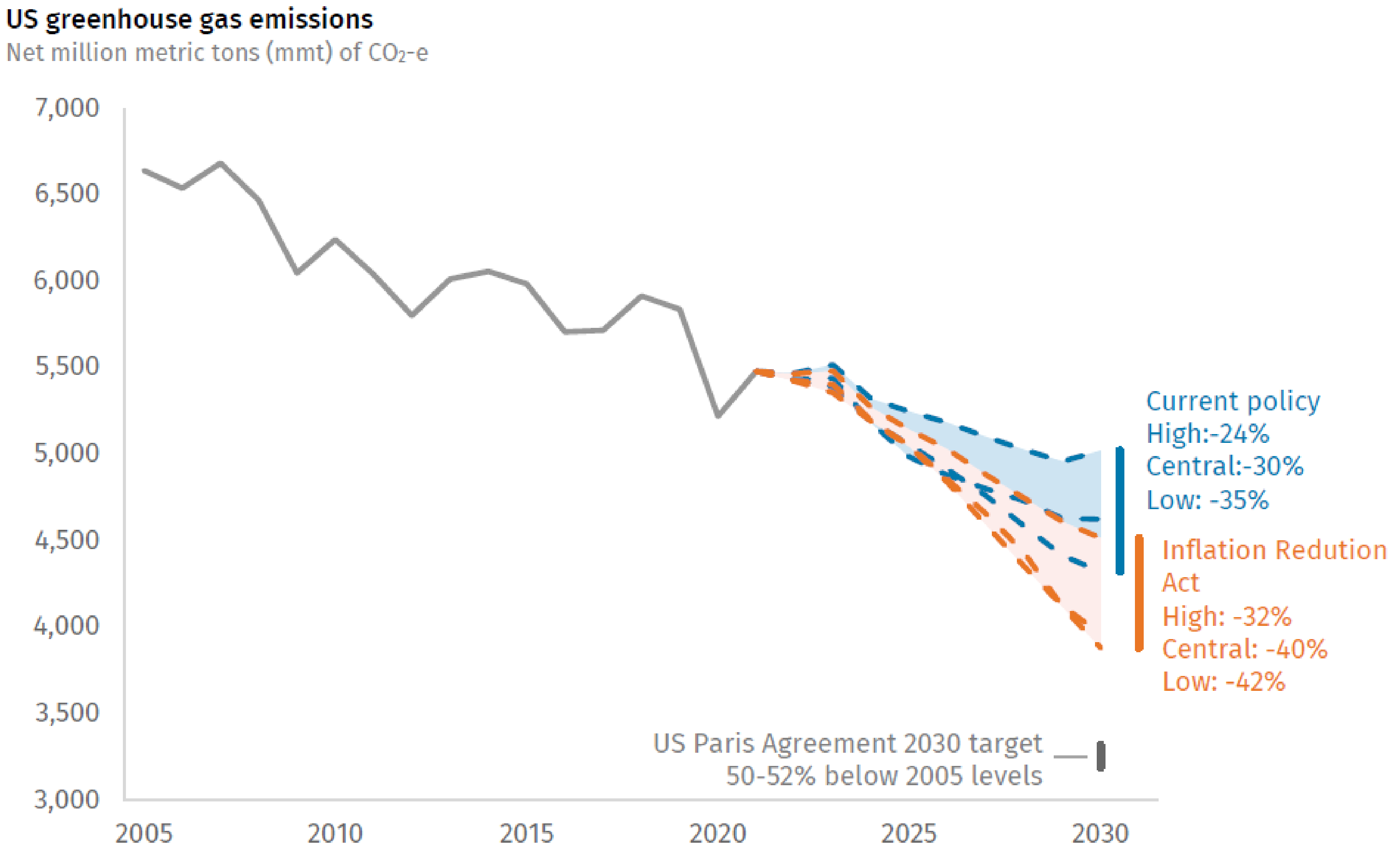


Key references on macro impacts of oil shocks: Känzig (AER, 2021), Baumeister & Kilian (BPEA, 2016)

IRA emissions reductions (Biden new Paris/Glasgow target: 50% reduction by 2030, rel. to 2005)

Rhodium

- 2030 projections with IRA: 32% - 42%
- IRA Delta = 7pp - 10pp



Source: Rhodium Group. The range reflects uncertainty around future fossil fuel prices, economic growth, and clean technology costs. It corresponds with high, central, and low emissions scenarios detailed in Taking Stock 2022.

Fiscal costs and cost per ton: EV components (LDVs only) of IIJA & IRA

	Policies				EV share & Emissions			Fiscal costs through 2031 ($B, not discounted)			
	Station subsidies		EV sales rebate		EV Sales Share	ΔCO_2 in 2030	Cost per ton				Inframarginal
	Budget ($B)	IRA	Rebate	Expenditures	by 2030	(mmt)	CO_2 avoided	Total	Chargers	Rebates	Rebates
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
0	-	-	-	-	0.366	-	-	-	-	-	-
I1	5	-	-	-	0.442	-31	97	6	6	-	-
I2	7.5	-	-	-	0.439	-40	107	9	9	-	-
I3	-	0.3	-	-	0.422	-15	90	4	4	-	-
I4	5	0.3	-	-	0.469	-42	102	10	10	-	-
I5	-	-	3604	6872	0.433	-20	63	286	-	286	123
I6	-	-	6410	6872	0.490	-37	66	332	-	332	219
I7	-	-	7208	10476	0.506	-43	67	528	-	528	246
I8	-	-	10014	10576	0.565	-63	71	608	-	608	342
I9	-	0.3	6410	6872	0.546	-54	80	382	6	376	219
I10	5	0.3	6410	6872	0.577	-80	95	451	11	440	219
E1	8	-	4400	4400	0.480	-64	100	263	10	252	150
E2	15	-	3900	3900	0.561	-86	107	273	18	256	133
E3	25	-	3500	3500	0.643	-99	110	275	28	248	120
E4	28	-	3400	3400	0.658	-100	110	273	30	243	116
E5	30	-	3250	3250	0.665	-100	111	265	32	233	111
E6	40	-	3100	3100	0.679	-110	113	263	40	223	106

Note: In I2, budget is split between $5 billion for level-3 stations and $2.5 billion for level-2 chargers.

Source: Cole, Droste, Knittel, Li, & Stock (AER P&P 2023)

Incentives included:

- $3750 EV purchase tax credit if FTA-sourced minerals, s.t. income & price caps
- $3750 EV purchase tax credit if battery assembled in North America , s.t. income & price caps
- $4000 used EV tax credit, s.t. income & price caps
- $5B interstate Fast charger state grants (IIJA)
- $2.5B disadvantaged community charger grants (IIJA)
- 30% charger tax credit (available to ~99% of municipalities)

CBO/JCT score of these IIJA + IRA provisions = $15.6B

Back of envelope:

8.5m EVs x $7500 = $64B in 2030

More? Mehrotra & Wolfram, BPEA, Spring 2023