CLIMATE POLICIES: TOOLS, CHALLENGES AND OBSTACLES

17TH EUROFRAME CONFERENCE ON ECONOMIC POLICY ISSUES IN THE EU

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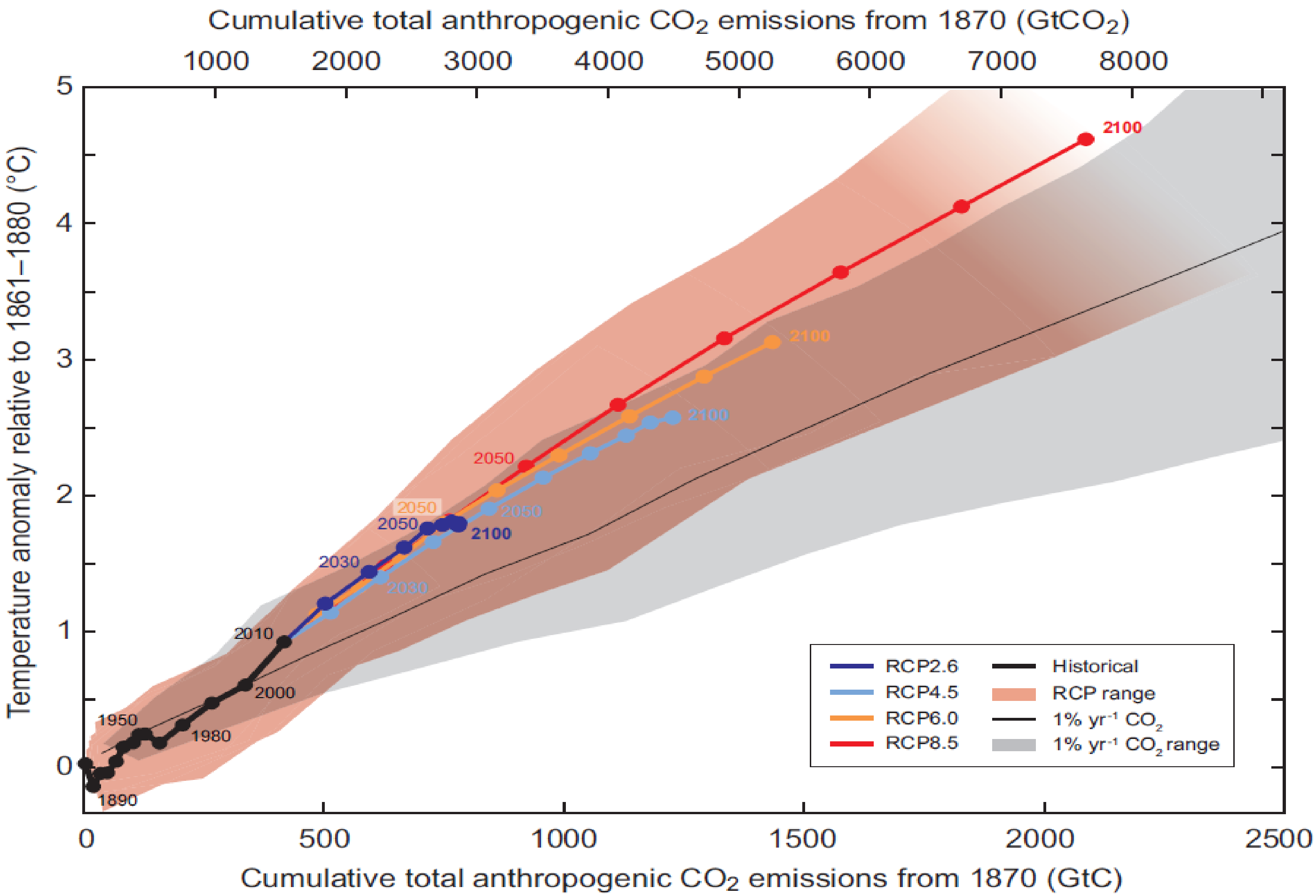
OVERVIEW

- Carbon pricing: welfare versus temperature cap
- Risk, uncertainty, and tipping points
- Challenges and obstacles
  - Risk of stranded carbon assets
  - Time scale and hedging climate risk
  - Big ask
  - Spatial carbon leakage
  - Green paradox
  - Policy failure and capture
  - Income distribution
  - Spatial needs
  - Climate scepticism

GOLDEN POLICY: CARBON PRICING

- Curbs demand for fossil fuel
- Encourages to leave more fossil fuel in crust of earth
- Induces substitution from carbon-intensive (tar sands?, coal, crude oil) to less carbon-intensive fossil fuel (gas)
- Induces substitution away from fossil fuel to renewables and brings forward the carbon-free era
- Boosts CCS and limits slash and burn of forests
- Boosts R&D into clean fuel alternatives and into energy-saving technology
- Encourages households, firms and government to spend more on CO2 mitigation and CO2 adaptation e.g. dikes)

Cumulative emissions drive global warming



Source: IPCC (2013)

Peak Global Warming and Safe Carbon Budget

- Temperature cap acts as political focal point
- Cumulative emissions drive peak global warming

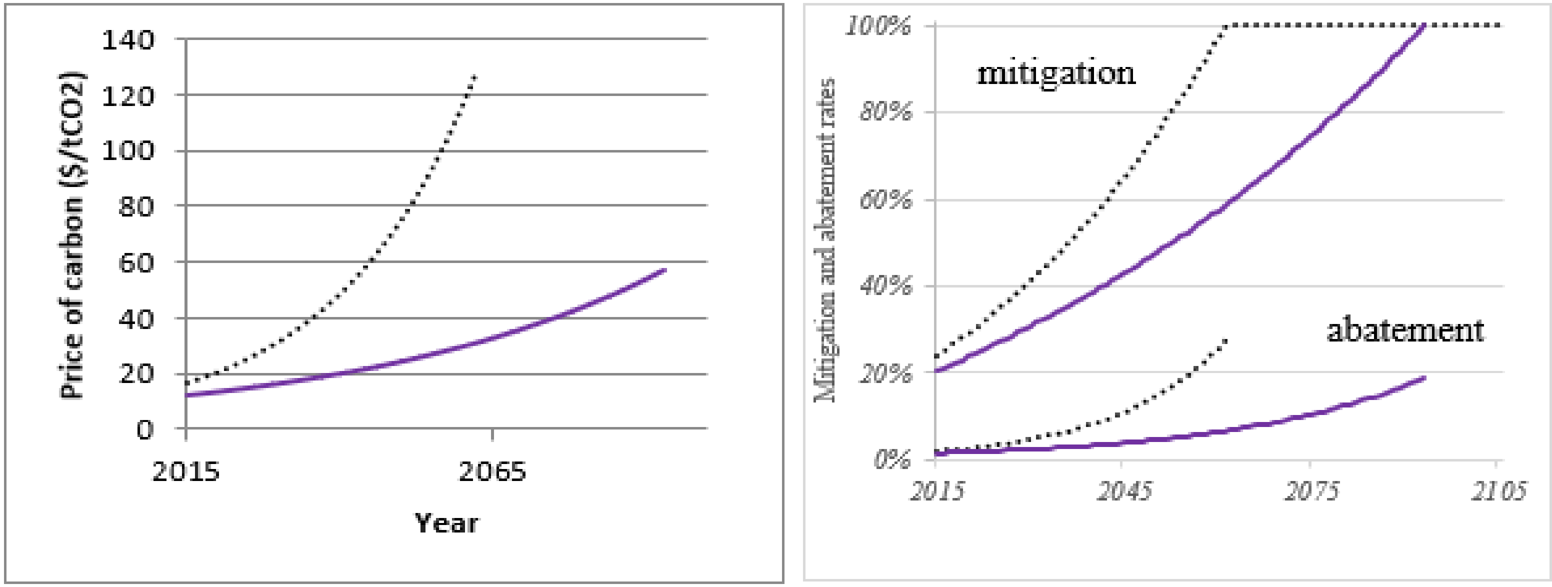
- Safe carbon budget is about 300 GtC to stay below 2 degrees Celsius: about 30 years at current use of fossil fuel use left

- The clock is ticking

- The price of carbon necessary to stay within 1.5 or 2 degrees cap must rise at a rate equal to the interest rate (Hotelling rule)
- Contrast with welfare-maximising approach

Solid lines: Pigouvian outcomes with Nordhaus damages
Dotted lines: outcomes under 2 degrees cap

Figure 3: Pigouvian versus carbon budget approaches to climate policy



Key: The mitigation rate is the share of renewables in total energy. The abatement rate is the fraction of emissions that is abated via CCS or other means. The solid lines correspond to the Pigouvian and the dotted line to the carbon budget approach.

Source: van der Ploeg (2018)

What interest rate to use?

- Most IAM's suggest *r* between 5 and 12%/year. UK even 15% per year. Procrastination of carbon pricing.
- Gollier (2019) speaks of the "The Big Green Bet":
  - Safe carbon budget is uncertain (political risk).
  - Future marginal abatement costs are uncertain.
  - Future growth in emissions and consumption growth are uncertain.
- Set growth of carbon prices to the safe interest rate plus *beta* times the risk premium, where *beta* is correlation coefficient between log MAC and log consumption. This gives 3.5% per year in real terms.

RISK, UNCERTAINTY, AND TIPPING POINTS

- Alternative: Pigouvian approach (social cost of carbon)
- "Tail risk" in economic growth prospects, global warming damages and the climate processes is captured by skewed distributions, disaster risks and tipping point risks
- Distinguish aversion to risk (RRA) from aversion to intertemporal fluctuations (1/EIS) or intergenerational inequality (IIA = 1/EIS)
- SCC = E[PDV of future marginal damages from emitting one ton of carbon today], so need risk-adjusted discount rate
- These "tail risks" push up the carbon price significantly (e.g. Cai and Lontzek, 2019, JPE; van den Bremer and van der Ploeg, 2021, AER)

The optimal carbon price and risk-adjusted discounted rate boil down to:

$$P = \frac{MDR \times TCRE}{\text{discount rate}} \times GDP + \text{corrections for climate and damage risks}$$

with

$$\text{discount rate} = \underset{\text{impatience effect}}{RTI} + \underbrace{IIA \times g}_{\text{affluence effect}} - \underset{\text{growing damages}}{g}$$

$$\underbrace{-\frac{1}{2}(1 + IIA)RRA\ \sigma_K^2}_{\text{prudence effect}} + \underbrace{RRA\ \sigma_K^2}_{\text{insurance effect}}$$

and $IIA = 1 / EIS$

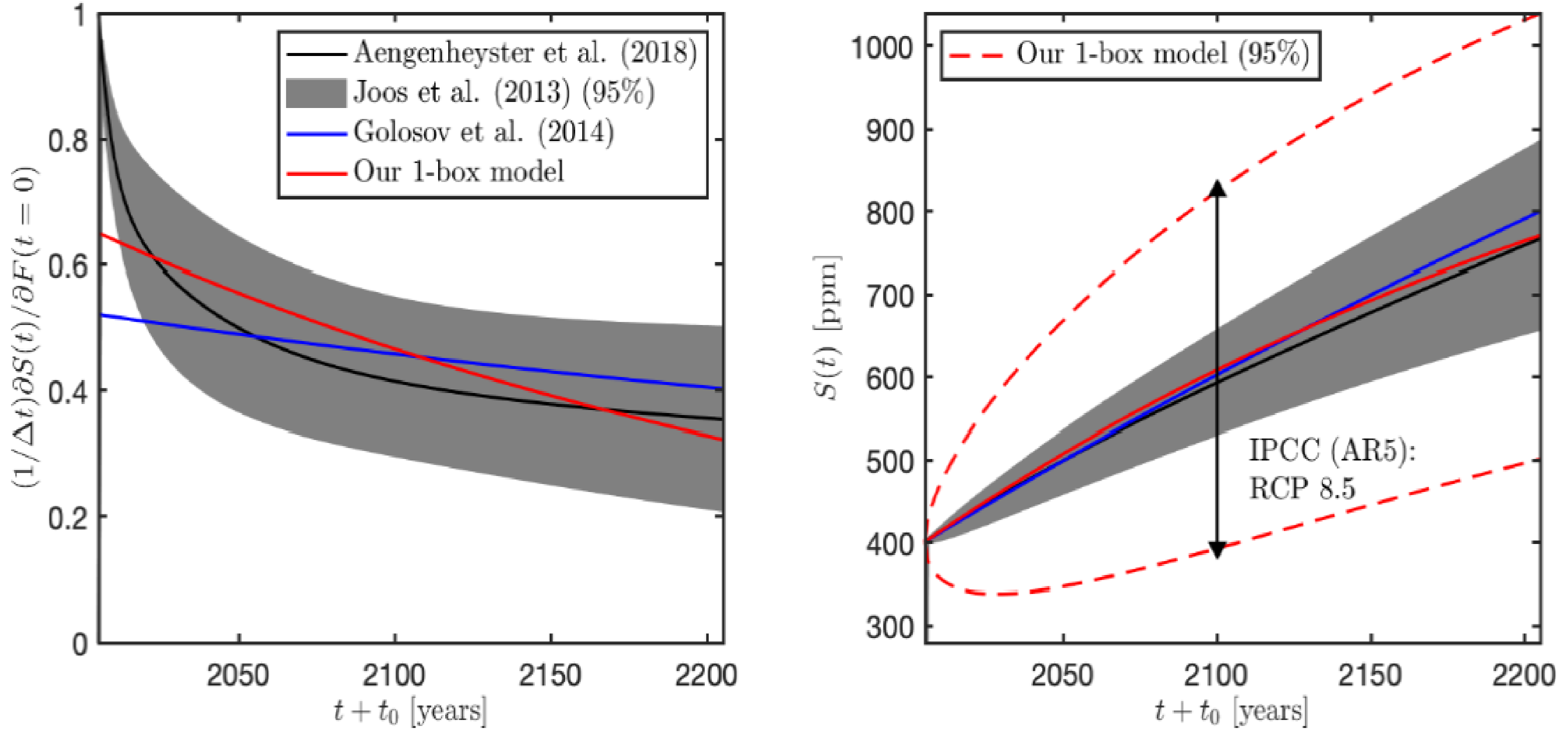
Climate sensitivity and damage risks

- Climate sensitivity uncertainty pushes up price only if relevant distribution is right skewed *or* damages are more convex
- Effect on carbon price is larger if climate sensitivity is more uncertain and distribution more skewed, climate sensitivity shocks are less temporary and the discount rate is smaller.

- Damage uncertainty only has direct effect on the carbon price if damage shocks are skewed, especially if they are more volatile ands persistent

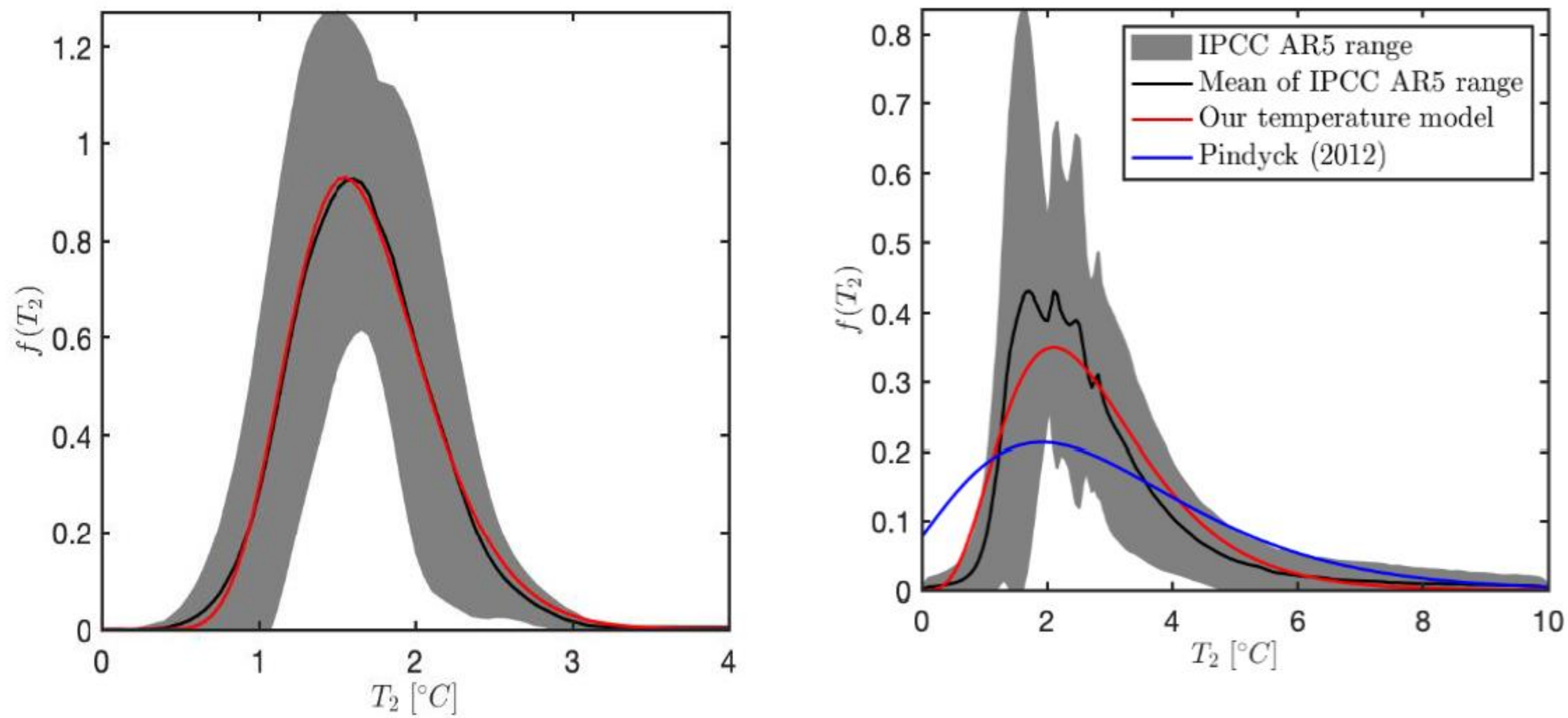
Correlated risks: Hedging climate risk

- Suppose in future states of nature asset returns are negatively associated with temperature, then the temperature beta is negative and it pays to invest more in fighting global warming and push up the SCC
- This may be so for industries selling winter garments, heating systems etc. But for industries producing wine in Sussex this beta is positive and they want a lower SCC
- Suppose in future states of nature assets returns are negatively associated with the damage ratio, then the damage beta is negative and the SCC is pushed up
- Not quite so for the Netherlands which has a strong water defences industry and so their asset returns benefit, i.e. want a lower SCC



(a) Impulse response function

(b) Stock of atmospheric carbon



(a) Transient climate response

(b) Equilibrium climate sensitivity

FIGURE 2. CLIMATE SENSITIVITY (PROBABILITY DENSITY FUNCTION)

$$\chi_0 = 1.1109,\ \bar{\chi} = 1.2619,\ \sigma_\chi = 0.020\%/\text{year}^{1/2}$$

$$\nu_\chi = 0.0086\%/\text{year},\ \theta_\chi = 3.0$$

TABLE 2. CLIMATE SENSITIVITY UNCERTAINTY

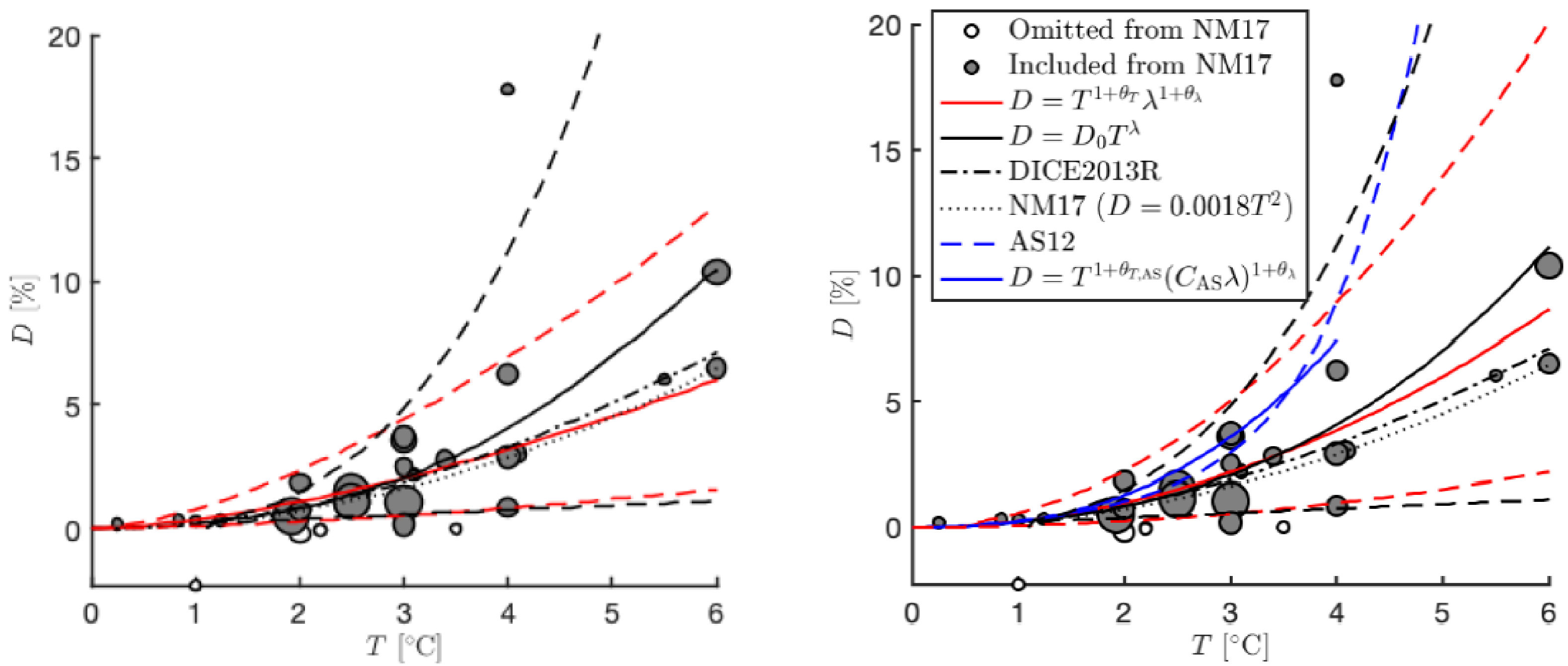
	TCR		ECS	
	IPCC (2014, AR5)	Our calibration	IPCC (2014, AR5)	Our calibration
$E[T_2]$	1.7°C	1.7°C	2.8°C	2.8°C
$var[T_2]$	0.19°C^2	0.20°C^2	1.5°C^2	1.7°C^2
$skew[T_2]$	0.16°C^3	0.054°C^3	2.4°C^3	2.5°C^3

TABLE 3. CLIMATE SENSITIVITY LIKELIHOOD

		IPCC (2014, AR5)	Our calibration
TCR	1-2.5°C	'very likely' (90-100%)	91%
	> 3°C	'extremely unlikely' (0-5%)	0.72%
ECS	1.5-4.5°C	'likely' (66-100%)	75%
	< 1°C	'extremely unlikely' (0-5%)	4.2%
	> 6°C	'very unlikely' (0-10%)	2.3%

$$\theta_T = 0.56\ (\theta_{ET} = 0),\ \bar{\lambda} = 0.21,\ \sigma_\lambda = 2.3\%/\text{year}^{1/2},\ \theta_\lambda = 2.7,$$

$$\nu_\lambda = 0.20/\text{year}$$



(a) Proportional damages ($\theta_T = 0.56, \theta_{ET} = 0$) (b) Convex damages ($\theta_T = 1, \theta_{ET} = 0.28$)

FIGURE 3. DAMAGE RATIO UNCERTAINTY

CALIBRATION OF ECONOMIC PART

- RRA = η = 4.32, EIS = 0.67, IIA = γ = 1.5
- Rate of impatience: ρ = 5.75%.
- Annual asset volatility: σ_K = 12.1% (1.5%).
- Risky r = 7.16% per year and safe r = 0.8% per year.
- Risk premium is RRA x σ_K^2 = 6.4% per year.

- Trend rate of growth is 2% per year, depreciation rate is 0.33% per year and investment adjustment cost parameter is 12.5 years.
- Flow impact of global warming damages Θ_0 is 2.07% of GDP per trillion tonnes of carbon in the atmosphere.

Economic, climatic and damage risks demand a much higher carbon price

TABLE 8. ESTIMATES OF THE SCC: COMPARISON WITH OTHER CALIBRATIONS

Model	Base	Golosov et al. (2014)	Gollier (2012)		Stern (2007) +AS12
Volatility based on	asset returns	-	asset returns	GDP	GDP
Deterministic SCC (\$/tCO_2)	11.5	19.0	14.4	14.4	86.9
Risk-adjusted SCC (\$/tCO_2)	**39.8**	**24.6**	**62.6**	**18.5**	**165.2**
Economic risk mark-up	163%	0%	225%	1%	0%
Carbon stock risk mark-up	0%	0%	0%	0%	-1%
Climate sensitivity risk mark-up	41%	13%	57%	12%	65%
Damage ratio mark-up	43%	16%	54%	16%	26%
Total risk mark-up	247%	29%	336%	29%	90%
Discount rate $r^{(0)}$ (per year)	2.9%	3.5%	2.5%	4.0%	2.5%

Estimates in this table are for *proportional* damages ($\theta_{ET} = 0$), except for the final column, which assumes highly convex AS12 damages. The base case is for $\rho = 1.5\%$/year (*ethics-based* calibration).

Risk of tipping points boost the carbon price even more: precautionary response!

Disaster risk and tipping points

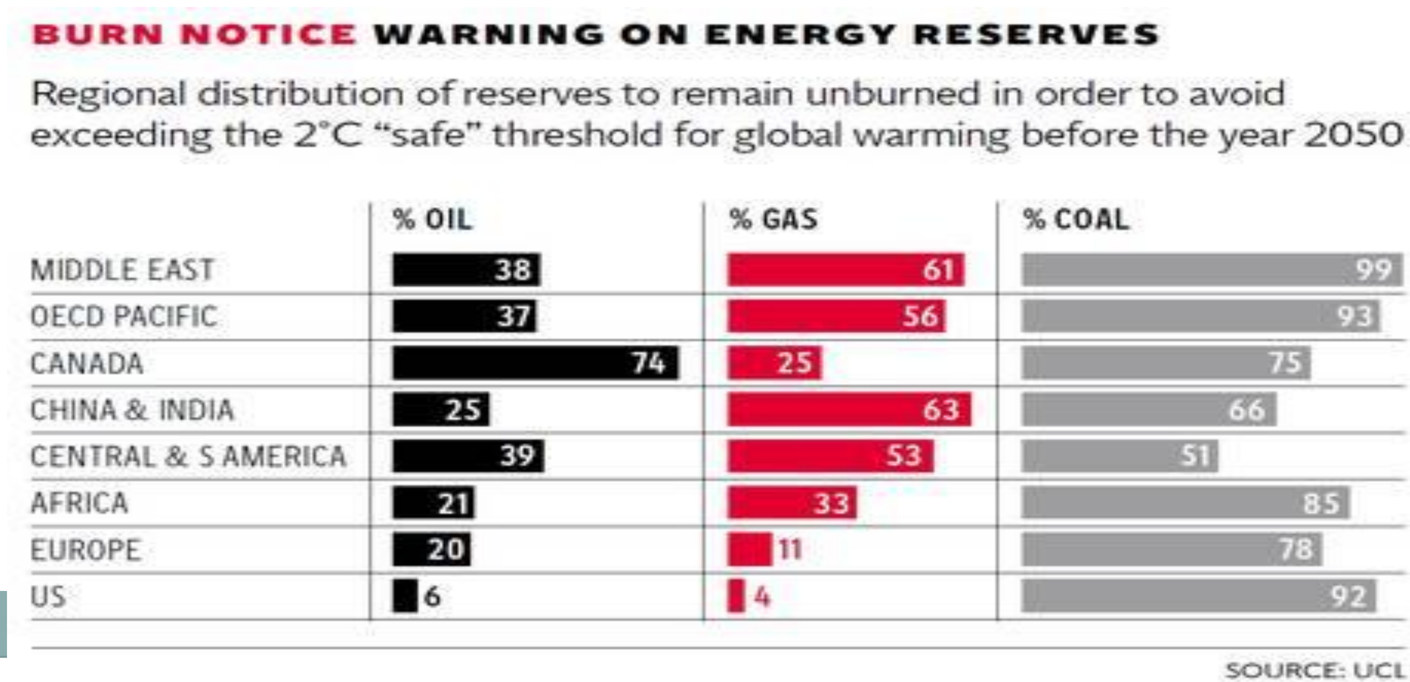
- If damage uncertainty is gradually resolved *and* preference for early resolution of uncertainty (RRA > 1/EIS), the optimal carbon price has tendency to fall (Daniel et al., PNAS, 2019)
- But swamped by rising carbon price if growth is high enough
- Recurring macro disasters push up price of carbon, especially if frequency increases with temperature
- Nine tipping points (collapse of Antarctic and Greenland Ice Sheets, melting of permafrost, reversal of Gulf Stream, etc.): this pushes up carbon price a lot (Cai and Lenton, 2019, JPE)
- Physical transition risk: tipping points more likely as planet hots up

OBSTACLE 1: RISK OF STRANDED CARBON ASSETS

- To keep global warming below 2 or 1.5 degrees the world can only burn a couple of hundreds or tens GtC.
- Reserves of big oil and gas companies are much bigger and that is not counting reserves of the state companies.
- If climate policy is credible, serious risk of stranded fossil fuel assets and may as well short the oil and gas majors.
- What should Russia, Nigeria or Algeria do? Race to burn the last ton of carbon?
- Ongoing explosion of carbon discoveries and reserves cannot go on if planetary warming has to stay below 1.5 degrees Celsius. Need carbon pricing and climate club.

McGlade and Ekins (2015, *Nature*)

- Globally keep 1/3 of oil (Canada, Arctic), ½ of gas and 4/5 of coal (mainly China, Russia, US) reserves unburnt. Reserves are 3x and resources 10-11x the carbon budget. In Middle East 260 billion barrels of oil that should not be burnt.



Peak demand is the new *peak oil*, even more with covid-19

"[Investors'] biggest fear is that oil demand growth is no longer a given in perpetuity, with some predicting that by the end of the next decade the industry could be facing a peak in consumption, as government policies try to curb the use of fossil fuels."

"After all, no chief executive wants to be left holding multibillion-dollar oilfields the world no longer wants or needs."

A Shakespearean moment

The Big Read Oil + Add to myFT

Oil producers face their 'life or death' question

Fear of an imminent peak in demand means companies are less likely to invest. So does that make shortages and a price rise inevitable?

Why do assets get stranded?

- (1) surprise intensification of climate policy and (2) irreversibility of or costs for adjusting investment in dirty capital stocks.
- Adjustment costs: intertemporal or intra-sectoral.
- Stranded assets imply scrapping of dirty capital and discrete crash in share prices of carbon-based industries. Hence, **carbon bubble**.
- Dirty and clean capital in final goods production.
- Carbon-based investments in electricity generation.
- Not just exploration and exploitation investments by oil, gas and coal industry (locking up carbon) but also investment in electricity, steel, etc. at risk.

Stranded capital in power industry

- Pfeiffer et al. (2016): “2°C capital stock” = if operated to the end of its normal economic lifetime, implies warming of 2°C or more (with 50% probability).
- Using IPCC carbon budgets & AR5 scenario, “2°C capital stock” is reached in 2017 even if other sectors do their share. Hence, no new emitting infrastructure can be built unless other infrastructure is scrapped or retrofitted with CCS!
- Pfeiffer et al. (2017) show that keeping warming below 1.5-2°C cuts utilisation of coal-fired electricity in the period up to 2050 from 60 to 29%.

Oversight and regulatory authorities

- Governors of central banks have warned for carbon bubbles and financial and fiduciary risks of holding large investments in fossil fuel; e.g., Carney (2015).
- Insurance companies and especially pension funds should be concerned too.
- Need 2°C stress tests for investment portfolios!
- Not clear which capital market regulators are held responsible for carbon-related systematic risks and who is responsible for ensuring that full corporate disclosure of carbon risks takes place.
- Follow Sweden and the divestment campaign?

Investors and markets are at risk from $2.2 trillion of stranded fossil fuel assets

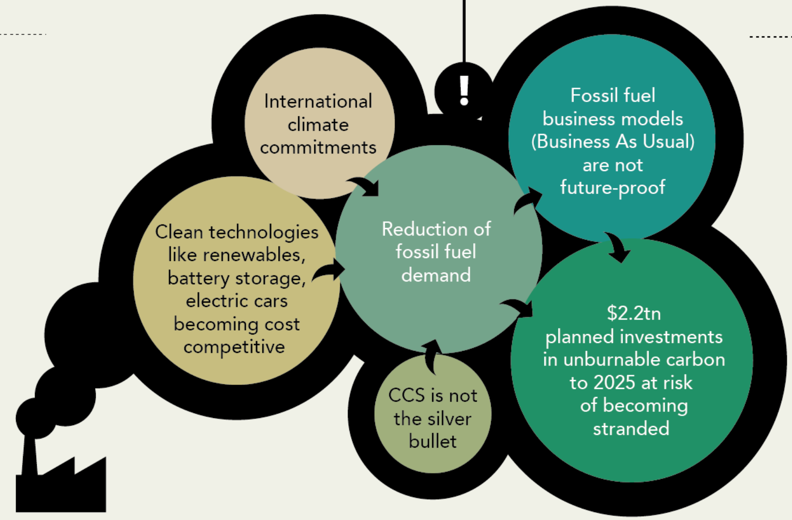
Carbon Tracker Initiative

Follow us @carbonbubble
#strandedassets

Coal is the most carbon intensive fossil fuel. No new coal mines will be needed and nearly **$220bln** of projects are at risk.

Oil demand will peak around 2020 and more than **$1.4 trillion** of projects are at risk.

Growth in **gas** will disappoint industry expectations, especially in expensive LNG. Planned spending of more than **$520bln** is at risk.

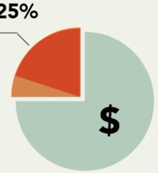


Which are the companies with most financial exposure?

We identified the **20 companies** with most capex in the danger zone.

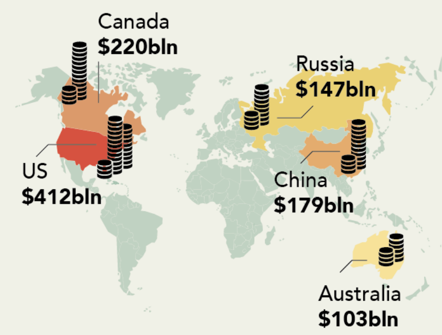
Top 3:

Shell, Exxon, Pemex should each avoid potential investment of over **$70bln**



Oil and gas majors' potential investment on projects that **won't be needed in a 2°C scenario**

Which are the countries with most financial exposure?



Do the 2°C stress-test

Institutional Investors
Derisk portfolio by identifying companies aligned with a 2°C demand scenario or engaging with those that are not

Companies
Provide information on the decisions taken to align corporate strategy with a 2°C demand scenario

Governments
Stress test national resources, infrastructure and energy plans against a 2°C demand scenario

Analysts & Advisors
Provide sensitivity analysis of which stocks are more resilient to a 2°C demand scenario

Source: "The $2 trillion stranded assets danger zone: How fossil fuel firms risk destroying investor returns", Carbon Tracker 2015

The report can be downloaded at http://www.carbontracker.org/report/stranded-assets-danger-zone/

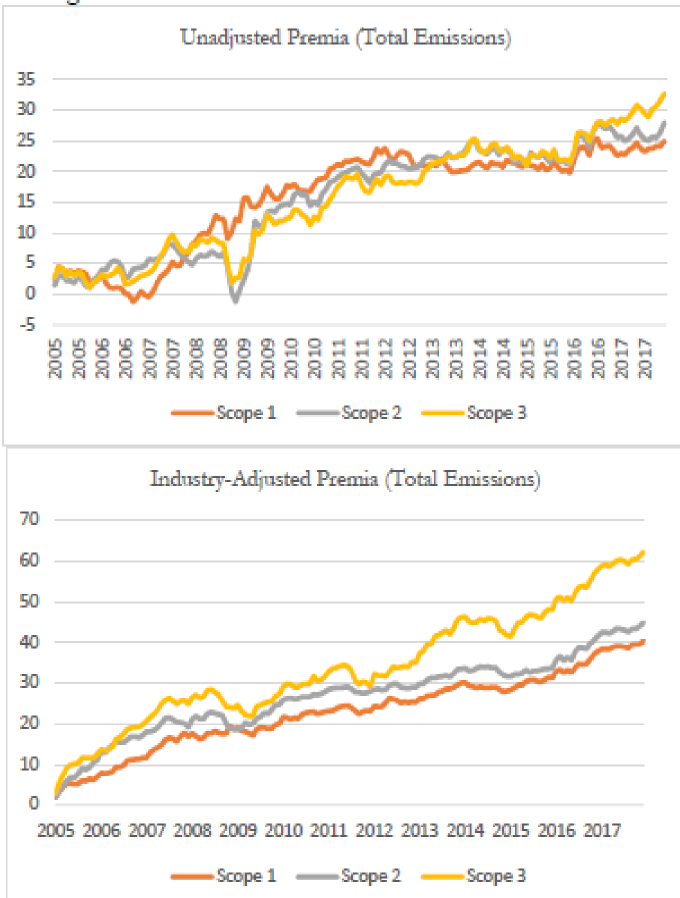
Mixed Empirical evidence

- Bolton and Kacperczyk (2020a): carbon-intensive firms (steel, cement, oil majors, etc.) in US show higher stock market returns after controlling for size, book to market, momentum, etc. as investors already demand compensation for the carbon risk; this carbon risk premium cannot be explained via unexpected profitability or other risk premia (see next three slides for a snapshot of results)
- Bolton and Kacperczyk (2020a): similar exercise for cross section of 14,400 firms in 77 countries shows evidence of *rising* carbon risk premia for carbon-intensive stocks
- Institutional investors are divesting away from carbon-intensive firms

But:

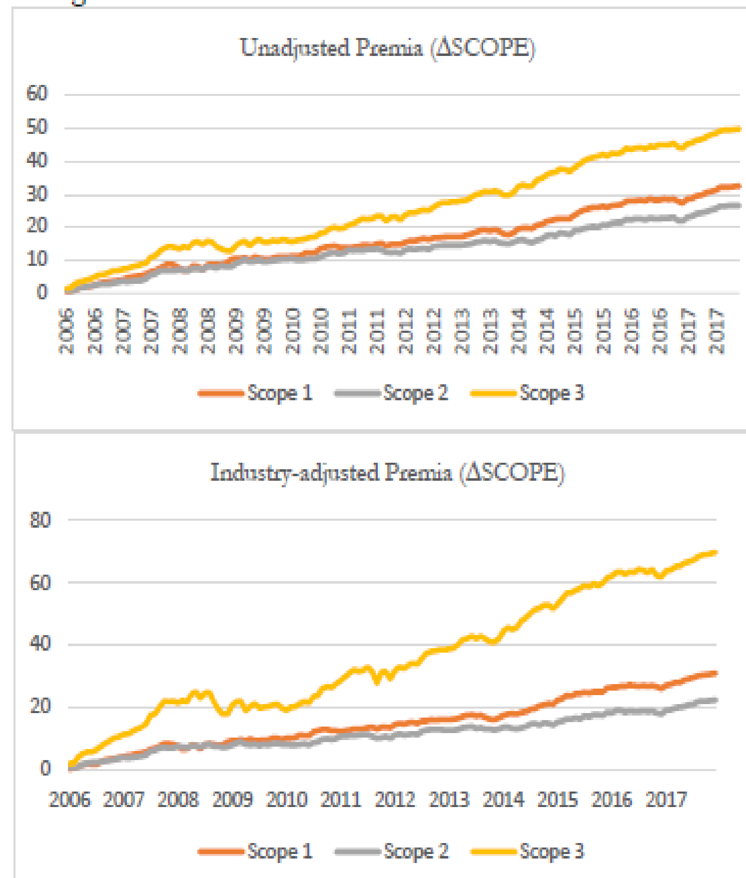
- In, Park and Mong (2019, Stanford): looking at 736 US firms from 2005-2015, EMI (carbon-efficient minus carbon-inefficient) portfolio has from 2010 onwards positive abnormal returns; investment strategy of going long on carbon-efficient firms and going short on carbon-inefficient firms would earn abnormal returns of 3.5%-5.4% per year (not driven by low *r*'s after GFC); carbon-efficient firms are "good" in terms of financial characteristics and governance

Figure 4. Carbon Cumulative Return Premia: Level Effect



Note: Figures plot cumulative carbon premia with and without industry fixed effects.

Figure 5. Carbon Cumulative Return Premia: Growth Effect



Note: Figures plot cumulative carbon premia with and without industry fixed effects.

Table 8: Carbon Emissions and Stock Returns

The sample period is 2005-2017. The dependent variable is *RET*. All variables are defined in Table 1. We report the results of the pooled regression with standard errors clustered at the firm and year level. All regressions include year-month fixed effects. In columns (4) through (6), we additionally include industry-fixed effects. Panel A reports the results for the natural logarithm of total firm-level emissions; Panel B reports the results for the percentage change in carbon total emissions; Panel C reports the results for carbon emission intensity. ***1% significance; **5% significance; *10% significance.

Panel A: Total emissions

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
LOG (SCOPE 1 TOT)	0.051**			0.181***		
	(0.022)			(0.044)		
LOG (SCOPE 2 TOT)		0.103**			0.179***	
		(0.039)			(0.052)	
LOG (SCOPE 3 TOT)			0.148***			0.327***
			(0.040)			(0.082)
LOGSIZE	-0.141	-0.188	-0.198	-0.304*	-0.329*	-0.411**
	(0.161)	(0.166)	(0.164)	(0.152)	(0.161)	(0.177)
B/M	0.303	0.312	0.291	0.444	0.430	0.361
	(0.277)	(0.285)	(0.276)	(0.269)	(0.264)	(0.265)
LEVERAGE	-0.558**	-0.579**	-0.491*	-0.686***	-0.697***	-0.778***
	(0.254)	(0.261)	(0.256)	(0.180)	(0.177)	(0.171)
MOM	0.389	0.417	0.407	0.339	0.351	0.355
	(0.280)	(0.277)	(0.279)	(0.293)	(0.293)	(0.292)
INVEST/A	-2.319	-1.971	-1.608	0.342	0.324	0.782
	(1.708)	(1.760)	(1.795)	(2.039)	(2.063)	(1.970)
ROE	0.007	0.006	0.006	0.005	0.005	0.004
	(0.005)	(0.004)	(0.004)	(0.003)	(0.003)	(0.003)
HHI	0.080	0.007	0.185*	0.189**	0.102	0.167*
	(0.107)	(0.112)	(0.103)	(0.082)	(0.088)	(0.082)
LOGPPE	-0.009	-0.016	-0.037	0.027	0.029	-0.008
	(0.097)	(0.083)	(0.086)	(0.050)	(0.049)	(0.044)
BETA	0.079	0.041	0.066	0.066	0.060	0.082
	(0.132)	(0.133)	(0.132)	(0.157)	(0.156)	(0.155)
VOLAT	0.906	0.611	0.680	0.752	0.620	0.697
	(3.637)	(3.488)	(3.571)	(3.274)	(3.276)	(3.256)
Year/month F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Industry F.E.	No	No	No	Yes	Yes	Yes
Observations	185,392	185,320	185,488	185,392	185,320	185,488
R-squared	0.200	0.201	0.201	0.203	0.203	0.203

Panel B: Growth rate in total emissions

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
ΔSCOPE 1	0.718***			0.706***		
	(0.181)			(0.164)		
ΔSCOPE 2		0.400**			0.379**	
		(0.150)			(0.143)	
ΔSCOPE 3			1.311***			1.303***
			(0.388)			(0.383)
LOGSIZE	-0.025	-0.013	-0.041	-0.104	-0.094	-0.122
	(0.105)	(0.107)	(0.107)	(0.109)	(0.110)	(0.113)
B/M	0.256	0.242	0.297	0.590*	0.571*	0.633*
	(0.268)	(0.271)	(0.254)	(0.307)	(0.307)	(0.290)
LEVERAGE	-0.454*	-0.434*	-0.454*	-0.788***	-0.778***	-0.785***
	(0.214)	(0.213)	(0.211)	(0.230)	(0.233)	(0.230)
MOM	0.251	0.271	0.197	0.196	0.216	0.146
	(0.266)	(0.270)	(0.259)	(0.262)	(0.265)	(0.255)
INVEST/A	-2.668	-2.366	-2.808	-0.565	-0.377	-0.775
	(1.858)	(1.884)	(1.933)	(2.302)	(2.250)	(2.344)
ROE	0.006**	0.006*	0.007**	0.005	0.004	0.005
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
HHI	-0.122	-0.083	-0.146	-0.028	-0.008	-0.048
	(0.152)	(0.151)	(0.150)	(0.111)	(0.112)	(0.115)
LOGPPE	0.011	0.001	0.025	0.072*	0.062	0.088*
	(0.054)	(0.052)	(0.056)	(0.038)	(0.038)	(0.042)
BETA	0.132	0.147	0.126	0.185	0.200	0.170
	(0.167)	(0.168)	(0.168)	(0.167)	(0.167)	(0.169)
VOLAT	1.858	1.956	1.923	1.511	1.593	1.578
	(4.426)	(4.407)	(4.478)	(4.175)	(4.171)	(4.221)
Year/month F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Industry F.E.	No	No	No	Yes	Yes	Yes
Observations	154,001	153,905	154,073	154,001	153,905	154,073
R-squared	0.215	0.215	0.215	0.218	0.218	0.218

Mixed Empirical evidence ctd.

- Garvey, Iyer and Nash (2018): firms that have a lower ratio of carbon emissions to sales (the "E in ESG") and are less dependent on carbon have stronger future profitability and higher stock returns

- Plantinga and Scholtens (2020): looking at 7,000 companies over 40 years, they find that investment portfolios that exclude fossil fuel production companies do not perform worse than unrestricted portfolios, so they suggest that divesting from fossil fuel companies does not hurt stock market performance

DONADELLI, GRÜNING and HITZEMANN (2020, CEBRA)

- Focuses at the fossil fuel industry to circumvent classification issues
- Price-dividend ratio high but fell since 2008 at time of bust of commodity price boom
- Better econometrics to explain changes in value along trends in climate change awareness:
  - Explains market to book ratio of about 4,000 firms over 1970-2018
  - Uses panel regression to control for market-wide valuation and other trends
  - Depends on awareness of climate change risks (from Google searches, closely correlated with environmental policy stringency)
  - Controls for cash/assets, debt/assets, log assets, R&D/sales
- Empirical findings:
  - Stock market value of US oil and fossil fuel firms has fallen a lot over last 20 years compared to other firms
  - Markets have started to price in the climate transition (negative coefficient on climate awareness index)

Being stranded with fossil fuel reserves? Climate policy risk and the pricing of bank loans – Delis, de Greiff and Ongena (2019)

- Evidence for pricing of risk of stranded fossil fuel reserves in corporate loan market
- Evidence 2007-17 consistent with carbon bubble: banks do not price in climate policy risk in their lending decisions, but post 2015 banks are pricing this risk in
- Carbon bubble: firm that depend on fossil fuel are overvalued; once climate policy is stepped up or solar gets really cheap, fossil fuel resources get stranded
- Current reserves 2900 $GtCO_2$ and total recoverable reserves are 11,000 $GtCO_2$, but carbon budget for 2 degrees is only about 300 GtC or 1100 $GtCO_2$ and hence 2 degrees means huge amount of stranded carbon (cf. McGalde and Ekin, 2015, Nature)
- Conjecture: banks charge higher interest on loans in view of carbon risk

- **Data:** 72,742 syndicated loans and loans spreads from Dealscan – nice to use as banks are well informed and care about reputation; have medium-term maturities
- Merge loan data with firm-year accounting data from Compustat
- **Dependent variable (CL):** all-in-spread-draw (AISD), i.e. spread of loan facility over LIBOR plus any facility fee (also check for AISU which only has fees)
- **Explanatory variable:** climate policy stringency – climate change cooperation index (C3I) or climate change performance index (CCPI), so use ClimatePolicyExposure_ft = RelativeReserves_fct x ClimatePolicyIndex_ct where f is firm, c is country and t is year
- **Model 1:** CL_lbft = a0 + a1 FF_ft + a2 CPE_ft + a3 FF_ft x CPI_ft +loan level and firm level controls + e_lbft, where FF is dummy (1 if firms owns fossil fuel reserves), L are loan level controls
- **Findings:** a3 is not statistically significant, so use model 2
- **Model 2:** same but add bank x year fixed effects to control for supply side explanations; still a3 not statistically significant; perhaps climate awareness more recent

- **Model 3:** as model 1 but with an indicator for post year, interaction terms and relevant double interaction terms
- Loan cost is not empirically significantly affected by risk that fossil fuel becomes unusable post 2011 but using post 2015 and only CCPI climate policy measure only, statistically significant at 10% level (columns (5) and (6))
- Weak evidence that banks are pricing in climate risk
- **Model 4:** model 3 but continuous indicator for fossil fuel exposure of a firm instead of a dummy (i.e. proven reserves over total assets)
- Statistically significant post 2015, so banks are pricing in climate risk post 2015 (i.e. there is no carbon bubble .. anymore)
- 1 standard deviation increase in CPE implies a higher AISD by 16 basis points
- 1% increase in fossil fuel reserves implies an increase of 6.9 basis points in AISD
- Results also hold when controlling for monthly oil price
- **Other findings:** green banks charge fossil fuel firms much higher interest

Model 4

Table 8

Climate policy exposure (CCPI) and proved reserves over total assets

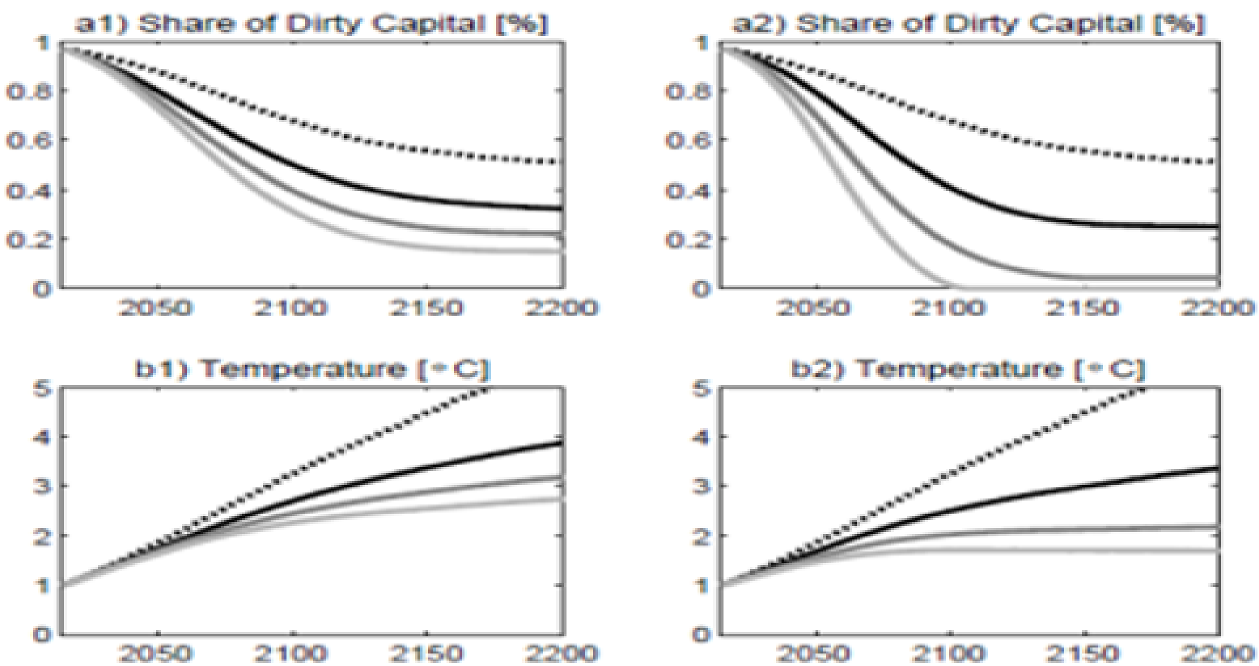
The table reports coefficients and t statistics in parentheses. The dependent variable is *AISD* and the climate policy exposure is measured by the CCPI. All variables are as defined in Table 1. The lower part of the table denotes the type of fixed effects and clustering used in each specification. Column (1) contains only loan characteristics, column (2) only firm and macro-level controls. Specifications (3) and (4) include loan, firm and macro controls. For readability, omitted variables due to collinearity are left out. (* $p<0.10$, ** $p<0.05$, *** $p<0.01$)

	(1)	(2)	(3)	(4)
Proved Reserves over Total Assets	-7.580	-30.382	-48.994	-44.145
	(-0.178)	(-0.759)	(-1.471)	(-1.202)
Climate Policy Exposure (CCPI)	**0.701***	**0.700***	**0.706***	**0.713***
	(1.945)	(1.898)	(1.894)	(1.846)
Proved Reserves over Total Assets *Climate Policy Exposure (CCPI)	0.087	0.572	1.046	0.914
	(0.067)	(0.471)	(1.009)	(0.794)
Proved Reserves over Total Assets*Post2015	**-933.287*****	**-800.644*****	**-726.637*****	**-759.065*****
	(-3.841)	(-10.293)	(-8.284)	(-14.588)
Post2015*Climate Policy Exposure (CCPI)	**-1.886*****	**-2.445*****	**-2.333*****	**-2.343*****
	(-3.430)	(-3.350)	(-3.786)	(-3.873)
Proved Reserves over Total Assets*Post2015*Climate Policy Exposure (CCPI)	**27.876*****	**26.863*****	**25.501*****	**26.364*****
	(4.138)	(9.871)	(9.412)	(15.110)
Loan Amount	**-22.794*****		**-13.216*****	**-13.201*****
	(-16.317)		(-8.692)	(-8.918)
Maturity	**17.043*****		0.154	-0.235
	(5.001)		(0.024)	(-0.037)
Collateral	**31.654****		**20.201***	**18.960***
	(2.251)		(1.797)	(1.680)
Number of Lenders	**-1.311*****		-0.013	-0.004
	(-3.229)		(-0.044)	(-0.013)
Performance	**-36.157*****		**-20.570*****	**-20.643*****
	(-10.881)		(-8.062)	(-8.111)
Number of Covenants	1.153		**4.044*****	**3.898*****
	(0.774)		(2.797)	(2.751)
Firm Size		**-24.675*****	**-16.320*****	**-16.340*****
		(-19.654)	(-12.906)	(-12.964)
Market to Book		**-19.584*****	**-17.162*****	**-17.192*****
		(-10.740)	(-9.085)	(-9.048)
Asset Tangibility		**-0.087*****	**-0.079****	**-0.078****
		[illegible]	[illegible]	[illegible]

Hambel et al. (2021)

Dotted lines: hypothetical scenario with no climate damage so no climate action and full diversification (dirty capital share → 50%)

Figure 4: Effect of optimal carbon pricing on capital reallocation and temperature



Key: The dotted lines indicate a hypothetical scenario without global warming damages. The black solid lines standard calibration, whereas the grey and light grey lines show what happens if damage effects are, respectively, 2 and 3 times as high. The left panels apply if temperature affects output negatively and the right panels if temperature increase the incidence of climate-related disasters.

Source: Hambel et al. (2020)

“A run on oil”, Barnett (2020)

- Studies effects of risk climate policy risk on macro outcomes and asset prices
- Unknown arrival of stepping up of climate policy generates a run on oil while oil reserves decrease due to risk of future climate policy stranding oil reserves (cf. Green Paradox)
- Also gives downward shift and dynamic fall in the oil spot price
- Duffie-Epstein preferences with RRA > 1/EIS
- Firms use labour, capital and energy inputs in production & have GBM in capital accumulation
- Firms face adjustment costs for investment and logarithmic depreciation
- Oil firms have linear technology and maximise E PDV of profits by choosing extraction and exploration
- Competitive labour, product and oil markets
- Temperature is driven by cumulative emissions; damages proportional to output
- Climate policy is a Poisson jump process with arrival rate increasing in temperature

OBSTACLE 2:
TIME SCALE AND HEDGING CLIMATE RISK

- Climate risks are very, very far in the future.
- So need very low discount rates for discounting benefits 100 years from now.
- A climate hedge is an investment project that yields a really big return in 100 or 200 years if global warming then turns out to be much hotter than expected.
- What are these projects apart from dykes, water defences, etc?

OBSTACLE 3: BIG ASK

- International free riding. Climate clubs?

- Big ask from current generations to make sacrifices to curb global warming for future, perhaps much richer, generations → run up debt to give transfers and get intergenerational win-win outcome
- Kotlikoff et al. (2021): Intergenerational win-win

- Pension-climate deals?

OBSTACLE 4: SPATIAL CARBON LEAKAGE

- Carbon leakage: if Kyoto countries put a price on CO_2 emissions, some of it will be shifted to producers especially if fuel demand is elastic and supply inelastic. Gift to non-Kyoto countries! Renders CO_2 policy ineffective unless it truly is a global deal including at least China and India.
- Border tax adjustments. If not possible, output-based rebates for industries that suffer most from dirty competition from abroad.
- EU: BTA, but make sure to take away the free allowances
- Coase: bribe … buy up forest
- For uniform carbon price throughout the world, need international transfers from rich to poor countries.

International challenges

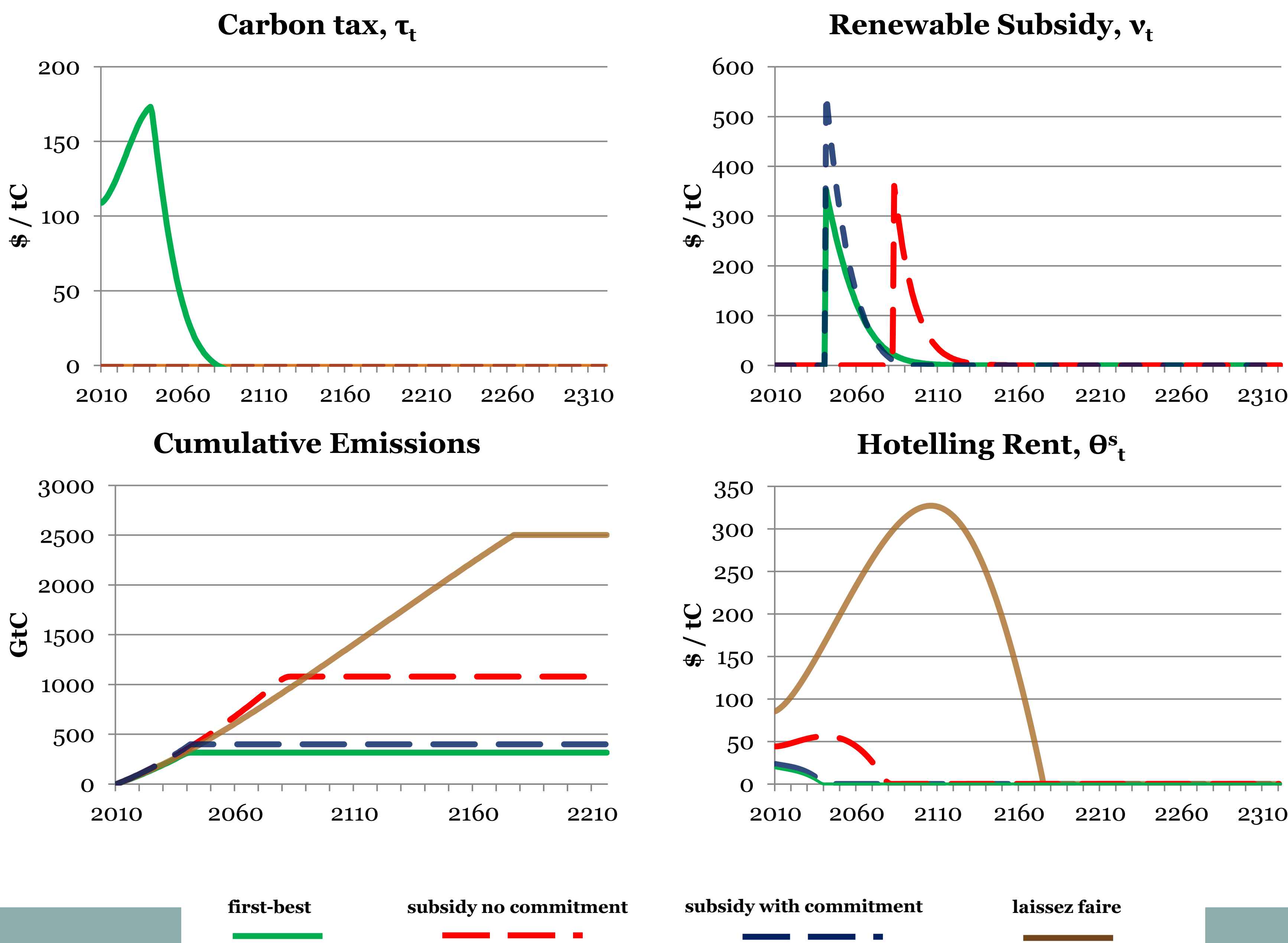
- Problem is complicated, since big polluters are rich and big polluters to be (China, India) want to develop.

OBSTACLE 5: GREEN PARADOX

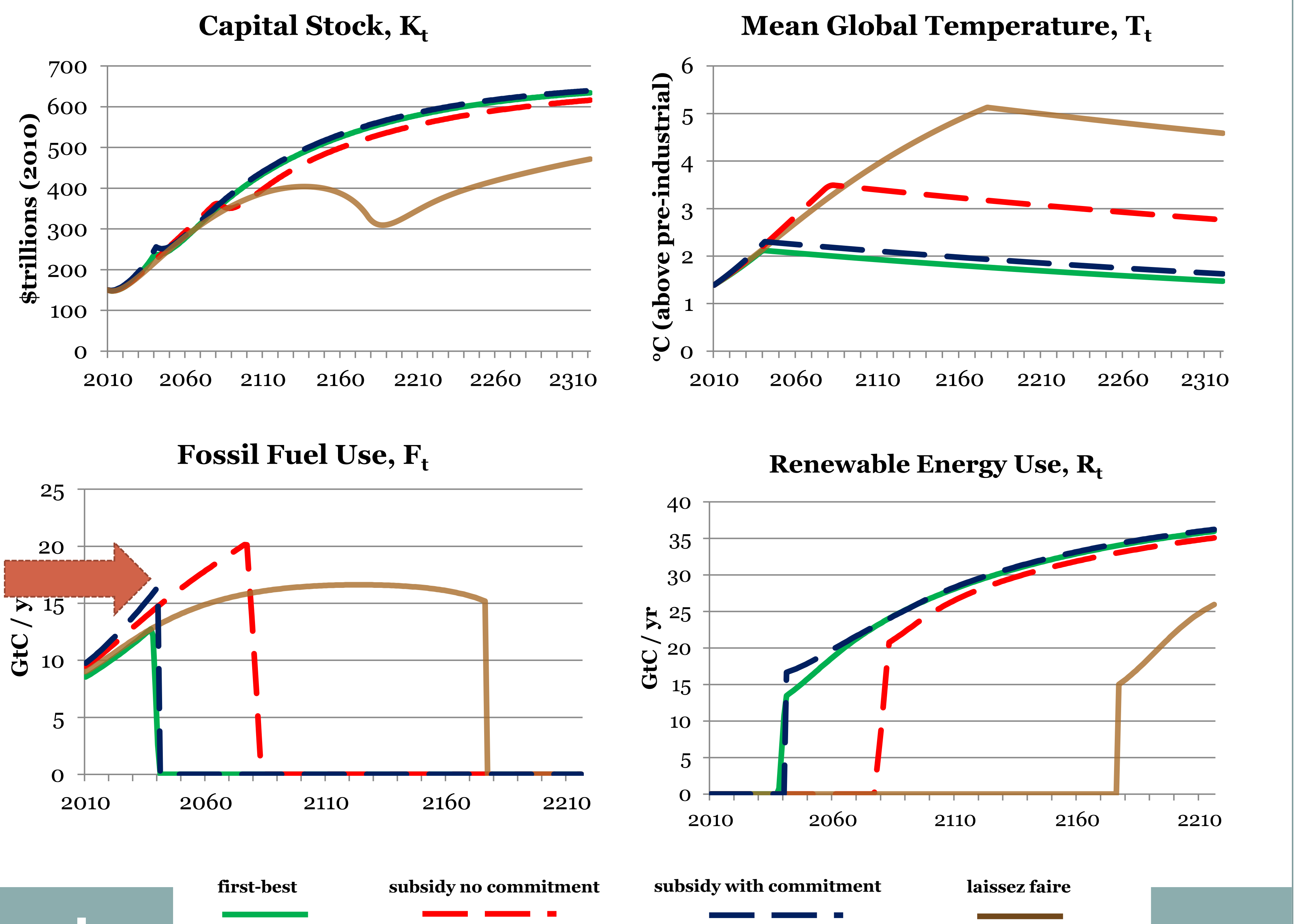
Politicians: procrastinate and prefer carrot to the stick. Europe has focused on renewable energy subsidies, not carbon pricing.

Anticipation of green policies: sheiks pump oil faster to avoid capital losses, which accelerates global warming.

Welfare goes up if price elasticity of demand is low, of supply is high, and ecological discount rate is high.



Carbon tax, τ_t
$ / tC
200
150
100
50
0
2010
2060
2110
2160
2210
2260
2310
Renewable Subsidy, ν_t
$ / tC
600
500
400
300
200
100
0
2010
2060
2110
2160
2210
2260
2310
Cumulative Emissions
GtC
3000
2500
2000
1500
1000
500
0
2010
2060
2110
2160
2210
Hotelling Rent, θ^s_t
$ / tC
350
300
250
200
150
100
50
0
2010
2060
2110
2160
2210
2260
2310
first-best
subsidy no commitment
subsidy with commitment
laissez faire

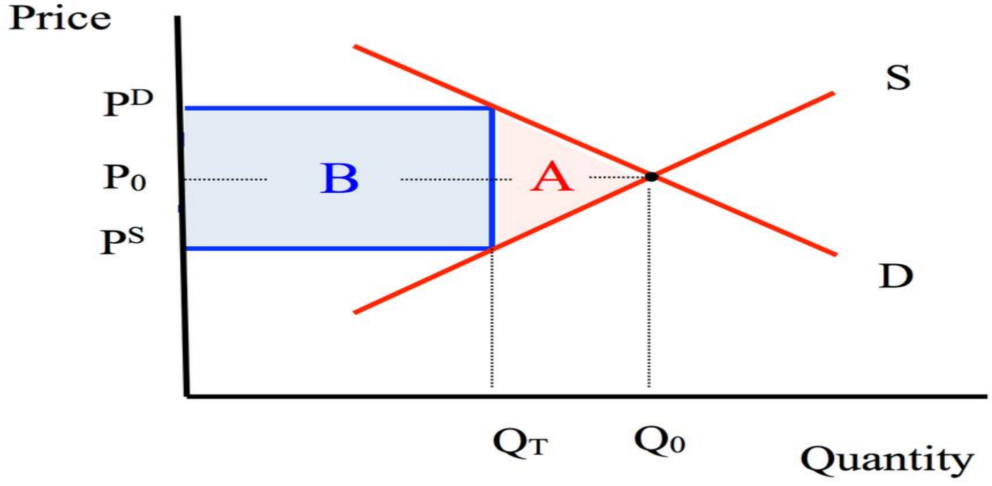

Capital Stock, K_t
$trillions (2010)
700
600
500
400
300
200
100
0
2010
2060
2110
2160
2210
2260
2310
Mean Global Temperature, T_t
°C (above pre-industrial)
6
5
4
3
2
1
0
2010
2060
2110
2160
2210
2260
2310
Fossil Fuel Use, F_t
GtC / yr
25
20
15
10
5
0
2010
2060
2110
2160
2210
Renewable Energy Use, R_t
GtC / yr
40
35
30
25
20
15
10
5
0
2010
2060
2110
2160
2210
first-best
subsidy no commitment
subsidy with commitment
laissez faire

OBSTACLE 6: POLICY FAILURE & CAPTURE

- Non-price controls are susceptible to capture: energy efficiency standards, mandatory sequestration, renewable mandates, etc.
- Bio-fuel mandate puts up land price & creates food poverty.
- Exceptions too: ETS – grandfathering; if coal is excluded from tax or subsidised.
- Government picks winners & faces lobbies: solar, wind, …
- Solar costs are dropping dramatically: infant industry? Subsidies tend to become addictive.

Deadweight cost of carbon tax is A (proportional to square of the tax), but only if tax revenue B is not wasted (e.g. if it is fully rebated)

Subsidies and rent seeking are wasteful: cost may be A + B



OBSTACLE 7: CLIMATE POLICY HURTS THE POOR RELATIVELY MORE

- Fossil fuel subsidies are staggering $5.3 trillion a year (6.5% of world GDP) versus renewable subsidies of only $120 billion/year.
- Get rid of these subsidies asap, but dirty coal is consumed relatively more by the poor.
- Replace subsidies with general tax deductions for the poor, which is a cheaper way to redistribute.

Gathering political support for green tax reform - van der ploeg, Rezai and Tovar (2020)

- Use German household data to estimate an EASI demand system for 8 commodities
- Very flexible EAI demand system (Lewbel and Pendakur, 2009) which ensures Slutsky symmetry and ensures that budget shares add up
- Allows for nonlinear Engel curves and various household characteristics
- Estimate labour supply using wage data and German income tax schedule
- Match emissions data with household consumption bundles
- Simulate effects of carbon price of 100 Euro per tCO2 using revenue to fund general budget, lump-sum transfer ("tax-and-dividend" and/or uniform lowering of labour income taxes
- Using equivalent variations we find that transfers leave 70% worse off, while income tax reform make the majority of households better off.
- The preference for lower taxes is driven by single households while those with kids largely prefer transfers. The rural/urban divide is secondary to these.

Motivation

- Great policy ambition in European Union (-55% by 2030, carbon neutrality by 2050) which will require pricing all users of fossil fuels. However, despite a general commitment to a “just transition”, wider considerations of the potential distributional impacts are absent in initial policy announcements.
- Green tax reform is unpopular, because it hurts typically the poor most. Less so if a lifetime perspective is taken. Less so if a general equilibrium perspective is taken.
- Many proposals of “carbon-tax-cum-dividend” (CTCD) try to “maximise fairness and political viability” of climate policy, since this makes the regressive policy progressive, benefits the poor disproportionally and lowers inequality.
- These studies suggest that a CTCD policy can count on political majority support in popular votes. The double dividend of a greener policy and lower income inequality suggests that a CTCD policy is politically viable and superior to other forms of carbon tax schemes.
- E.g. Horowitz et al. (2017) find that 70% of people are better off if revenue from taxing greenhouse gases at \$49/tCO2 is rebated as a lump-sum of \$583 per person
- But is such a CTCD policy feasible (political economy of carbon pricing) once effects on labour supply and the tax base and nonlinear Engel curves are taken account of?
- What about horizontal equity?

Previous Literature

- **Incidence of carbon taxes and revenue recycling:** e.g. Poterba (1991), Metcalf (1999), West and Williams (2004), Bento et al. (2009), Grainger and Kohlstad (2010), Rausch et al. (2011), Flues and Thomas (2015), Williams et al. (2015), Rausch and Schwarz (2016), Berry (2019), Pizer and Sexton (2019)
  explicitly on CTCD: Treasury (2017), Klenert et al. (2018), Carattini (2018, 2019), Cronin et al. (2019), Edenhofer et al. (2019); Anderson et al. (2019)
- **Double Dividend:** Bovenberg and de Mooij (1994), Bovenberg and van der Ploeg (1994, 1998); Goulder (1995), Parry (1995), Bovenberg (1999), Jacobs and the Mooij (2015) – mostly homogenous agent approach
- **Non-linear Engel curves:** West and Williams (2007), Lewbel and Pendakur (2009), Tovar and Wölfing (2018), Jacobs and van der Ploeg (2019)

Households: EASI demand

We use the EVS data set with 23,000 German households *h* (cross-sectional, not longitudinal)

$$w_{hi} = \sum_{r=0}^{R} b_{ir} \log(v_h)^r + \sum_{j=1}^{I} a_{ij} \log(q_{hi}) + \sum_{k=1}^{K} \left[d_{ik} z_{hk} \log(v_h) + g_{ik} z_{hk} \right]$$

with goods aggregated into 8 types *i*, budget share *w*, consumer prices *q*, and household characteristics *z*.

We allow for *K* = 8 characteristics: single / non-single; age <> 65, with 0, 1, 2 children, and other.

We control for heating type, age and size of dwelling, and community size (< 20k, 20k – 100k, >100k) and gender of household head.

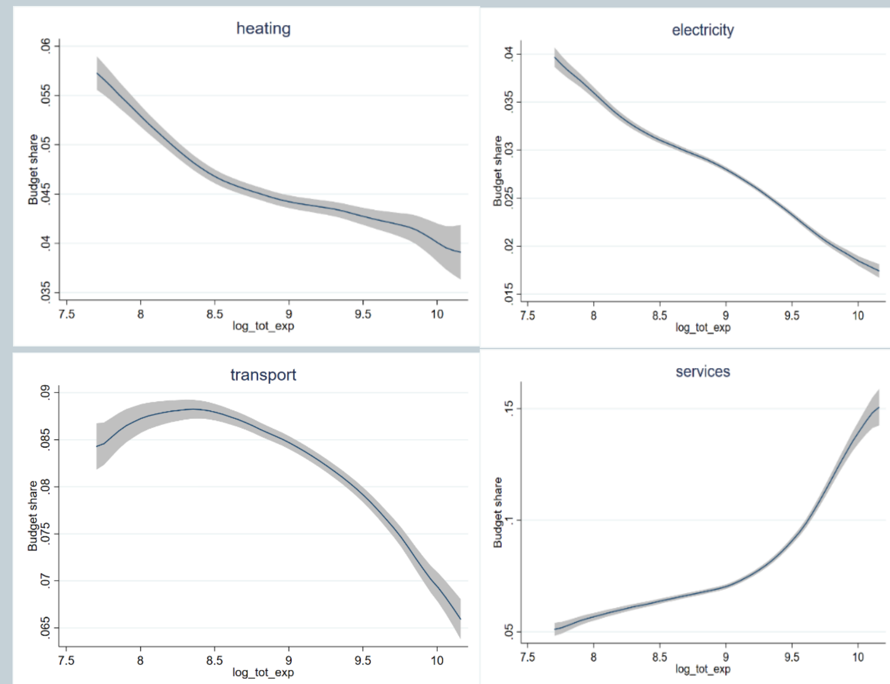
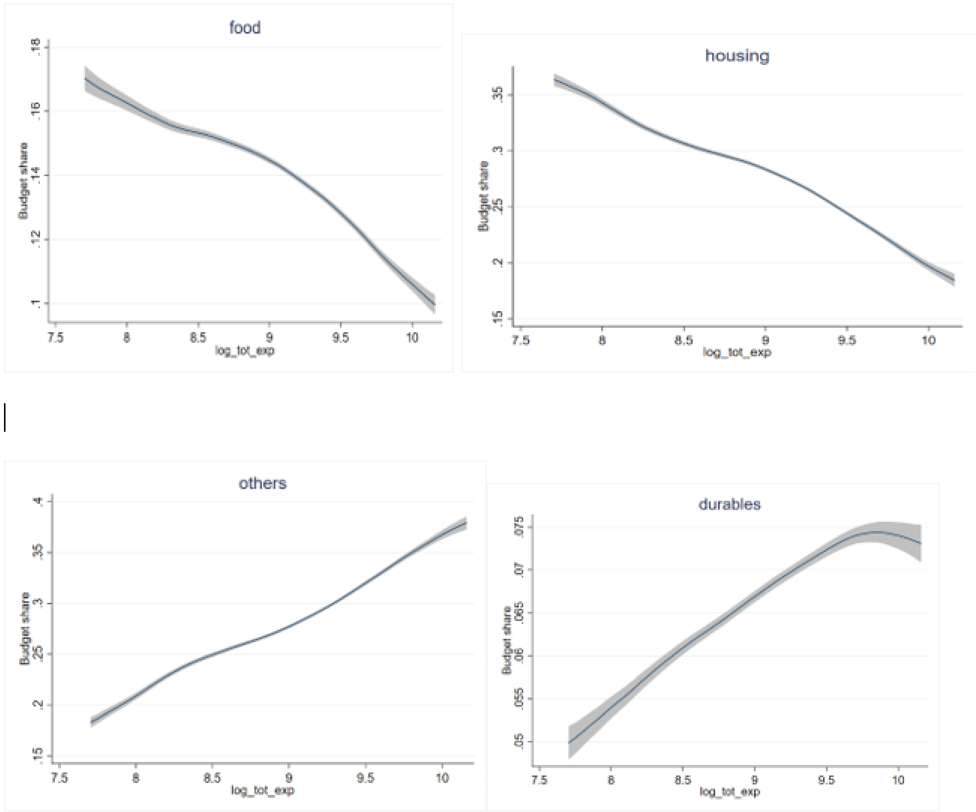


Figure 1: Engel curves for the consumption of different commodities

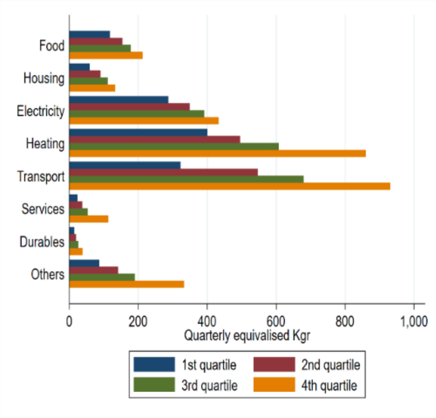


Households: emissions (kg CO2) and emission intensities (kg CO2 per Euro) due to quarterly consumption across household distribution

Footprint data is provided by the German Central Statistical Office following the COICOP classification and are estimated using an input-output approach.

Overall emissions increase with income (richer household have a larger footprint), but emissions intensity falls with income. This suggests that transferring one Euro from a poor to a rich household would decrease overall emissions.

We allow for direct and/or indirect emissions.



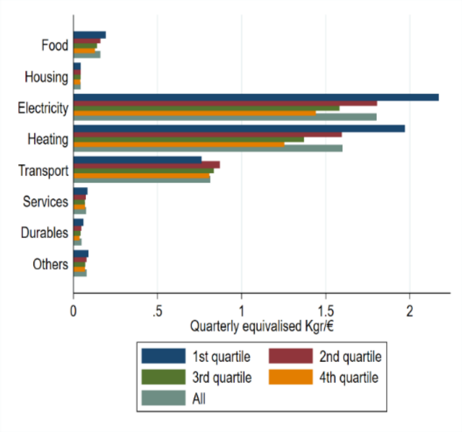
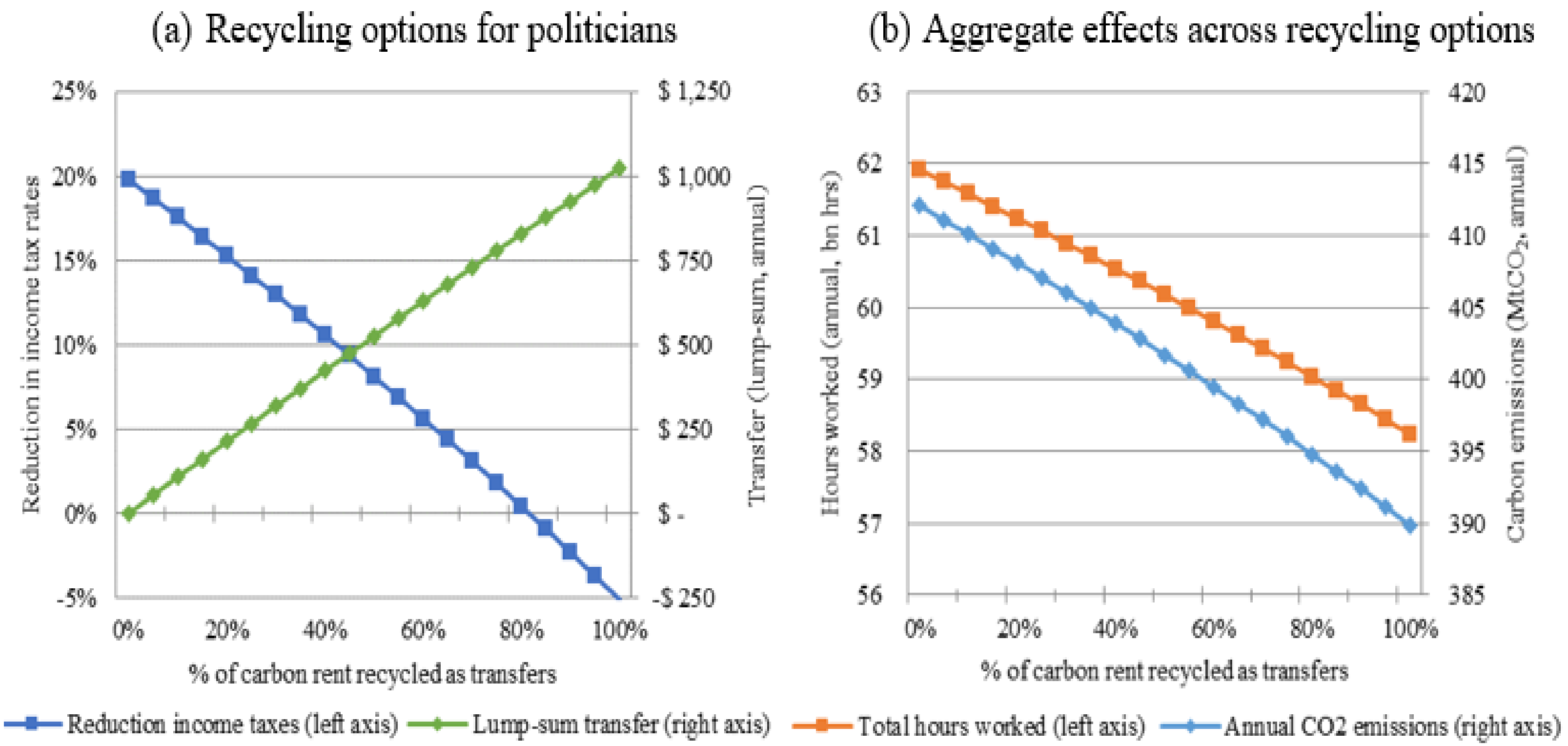
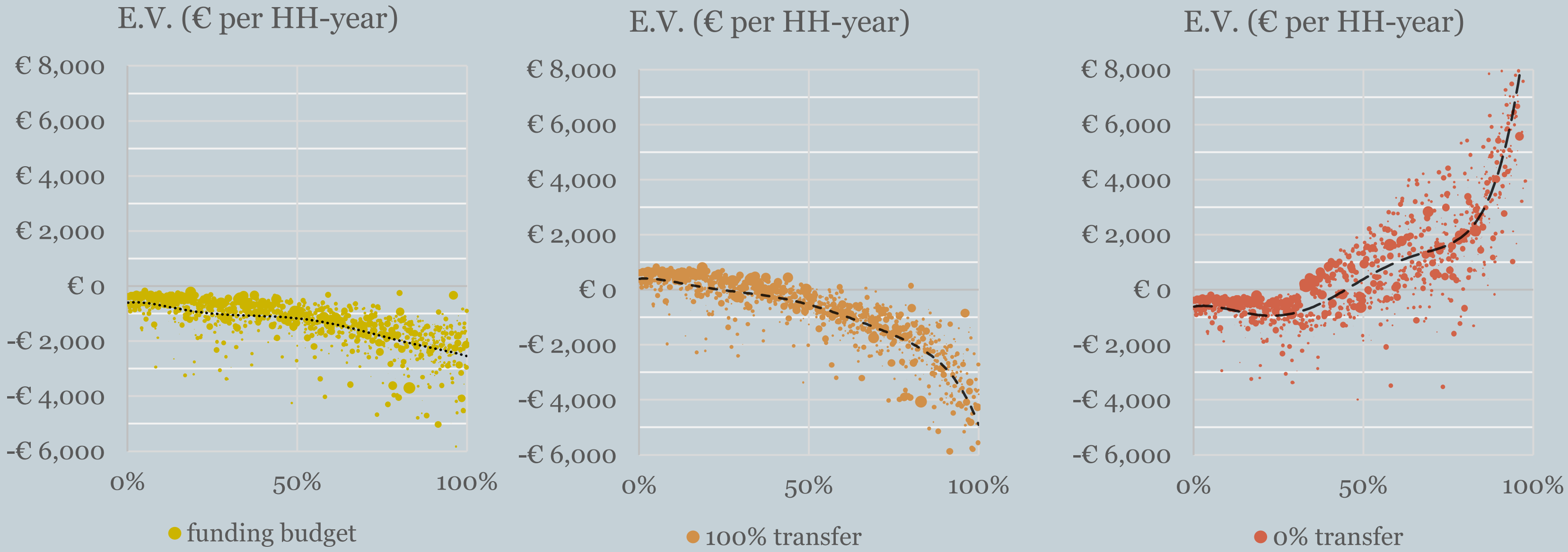


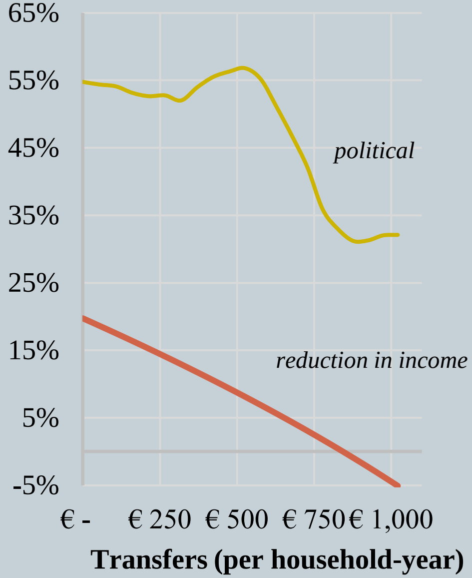
Figure 6: Recycling options of pricing carbon at €100/tCO_2 and their aggregate effects

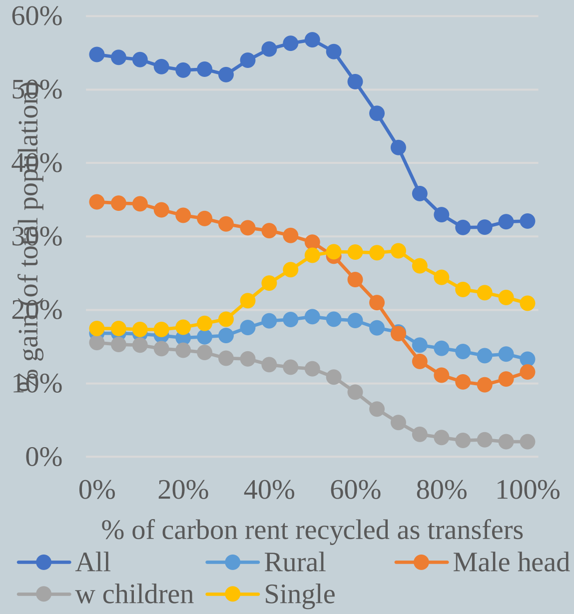


Distributional effects: equivalent variations for different recycling schemes



Political arithmetic of carbon pricing





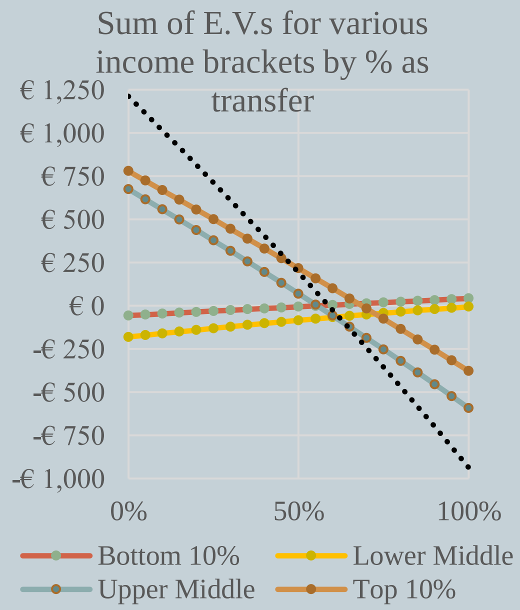


Table 4: Aggregates for 10% emission reduction with different recycling schemes

	Carbon tax (€/tCO_2)	Hours worked (million hours)		Consumption (billion Euros)		GINI income	GINI expenditure
Baseline	0	59,935		1,194		0.475	0.276
10% Reduction in CO_2							
Lowering government debt	87	59,083	- 1.4%	1,183	- 0.9%	0.475	0.275
Carbon dividend, lump-sum	109	58,898	- 1.7%	1,216	1.9%	0.474	0.267
Lowering income taxes	212	63,395	5.8%	1,359	13.9%	0.486	0.299

Political acceptability of carbon pricing

(based on vdP, Rezai and Tovar, 2020 – German households)

- Avoid "yellow vests": use revenues from carbon tax to lower income tax and hand out carbon dividends to get it across the line in most efficient manner
- Easier when trust is high
- ***Only get majority support for green tax reform if part of revenue is used to lower income taxes and boost economic activity and the tax base***

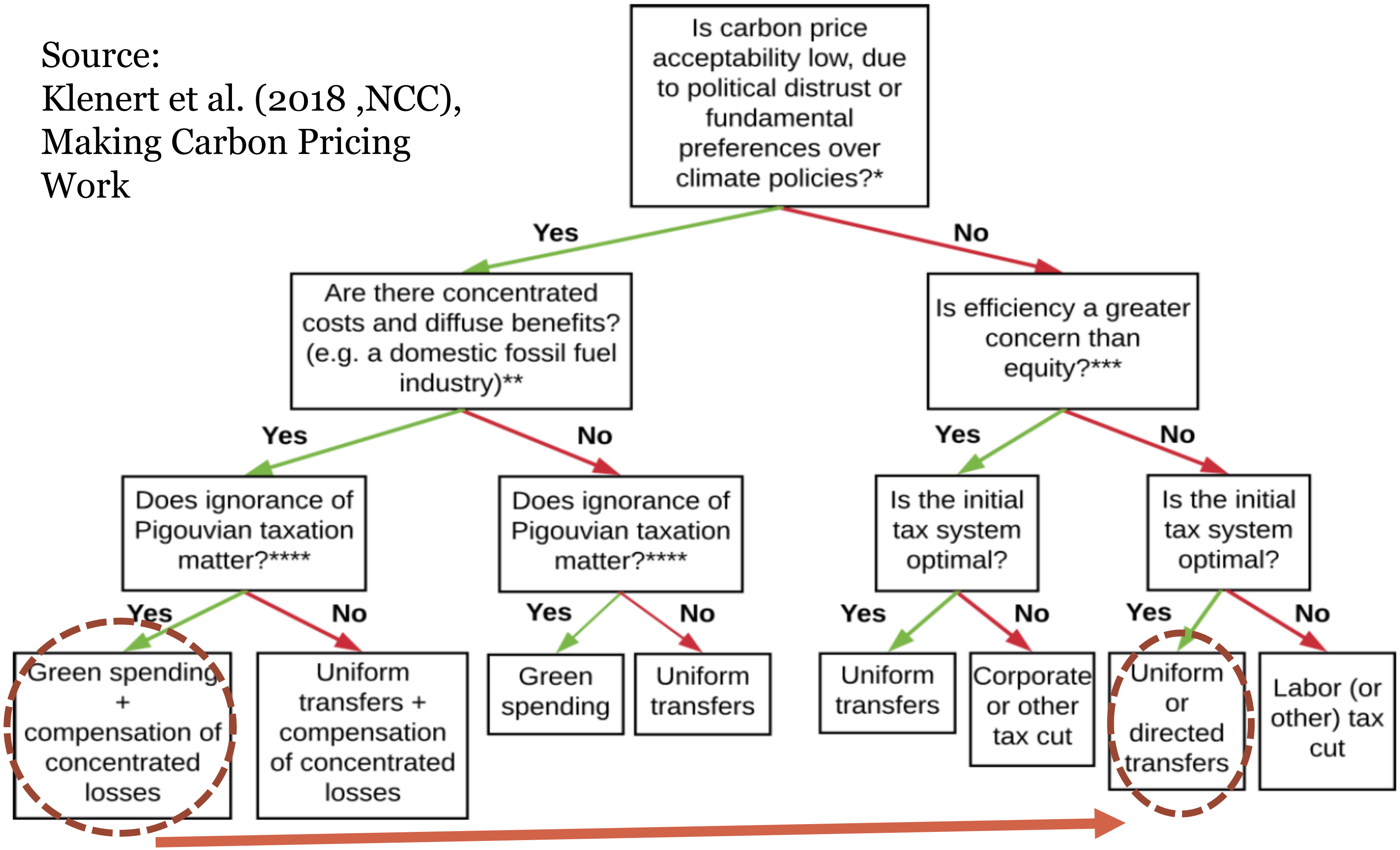
Table 3: Percentage of households benefitting (with positive equivalent variation)

	All HH	Rural HH	HH head male	HH with children	Single HH
Carbon tax of € 100/tCO$_2$					
Lowering public debt	0%	0%	0%	0%	0%
Carbon dividend, lump-sum	32%	45%	18%	12%	64%
Lowering income taxes	55%	52%	60%	77%	46%

How to recycle carbon dividends?

- Carbon pricing is regressive.
- Ensure political acceptability with an upfront, visible and uniform “carbon dividend” or even a directed transfer to the lowest incomes.
- France: insulation subsidies for low incomes.
- Or subsidies for electrical cars, tax credits for energy-efficient buildings.
- Firms that are most at risk of leakage get rebates proportional to productoin (second-best to BTA).
- See flowchart from Mattauch et al. (2019, NCC).

Source:
Klenert et al. (2018 ,NCC), Making Carbon Pricing Work



Obstacle 8: Spatial needs

- "Spatial planning": need space for windmills, solar panels, waterstof-factories and CCS both in the landscape and in the soil.
- This is a huge challenge – much bigger than the (misguided) Betuwe rail line.
- NIMBY politics.

OBSTACLE 9: CLIMATE SCEPTICISM

Pay-offs	Believe in God	Do not believe in God
God exists with prob π	+ ∝ (infinity)	–∝ (minus infinity)
God does not exist with prob 1 – π	– 1 (finite loss)	+ 1 (finite gain)

PASCAL' WAGER:

$\pi \times \propto + (1 - \pi) \times (-1) = + \propto$ always exceeds $\pi \times (-\propto) + (1 - \pi) \times (+1) = - \propto$

provided π is positive, however small.
Hence, agnostics (doubters) should believe in God.
Only atheists have $\pi = 0$ and should not believe in God.

Table 3: Welfare gains under climate model uncertainty

(% initial world GDP, relative to BAU under the science view)

Climate view	Price carbon	Don't price carbon
Science	17%	0%
Denier	34%	41%
min welfare	**17%**	0%
max regret	**7%**	17%

Key: Pricing carbon increase welfare by 17% if scientists are correct but lowers welfare by 7% if deniers are right. The welfare under carbon pricing is lower if climate scientists are right (17%) than if climate deniers are right (34%).

Table 4: Peak warming and carbon prices under different priors that deniers are correct

	Prior that deniers hold correct view										
	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Peak Warming	3.3 °C	3.5 °C	3.6 °C	3.8 °C	3.9 °C	4.2 °C	4.5 °C	4.8 °C	5.4 °C	6.3 °C	7.0 °C
Carbon Price (2020, per tCO2)	$ 21.1	$ 19.1	$ 17.1	$ 15.0	$ 12.9	$ 10.8	$ 8.7	$ 6.6	$ 4.4	$ 2.2	$ 0.0

Key: Peak warming levels increase from 3.3°C to 7°C and carbon prices (in 2020) decrease from $21.1 to $0 per tCO2 as the prior that deniers are correct, π, rises from 0% to 100%.

What to do?

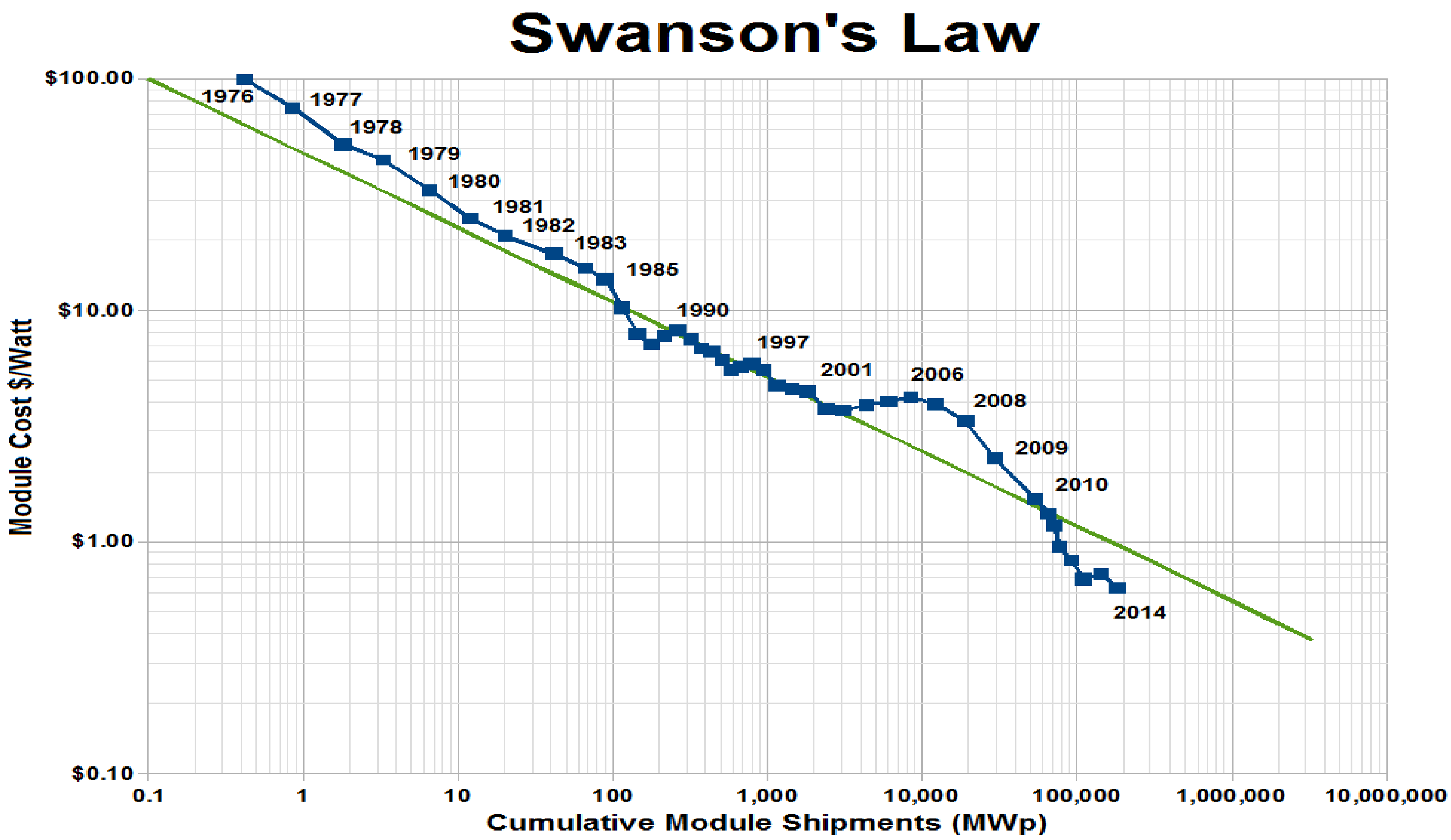
- Get rid of explicit and implicit fossil fuel subsidies.
- Moratorium on coal
- From 2025 no more diesel- or petrol-based transport.
- Give a clear signal: start with say 40 EUR/tCO2 en let it rise at a rate of say 2% or 5% to 75 of 200 EUR/tCO2 in 2050 (cf. France starts with 40 and rise to 100 EUR/tCO2 in 2030; Sweden 100 EUR/tCO2; Finland, Norway, Switzerland also high CO2 prices).
- On top of European permit schemes.
- CO2 prices also has collateral benefits of less air pollution. These are local, so no international freerider problems.
- Subsidise green R&D to internalise learning-by-doing benefits.
- Each year delay makes realising our climate targets more costly.

- Invest in clean infrastructure, efficient retrofitting of buildings, investment in education and training, natural capital investment, and clean R&D.
- Invest in control of pandemic (test, track and contain), vaccines, border checks & safe travel and trade, food security and shorter local supply chains including sanitary standards, renewable energy (batteries, solar, wind, electric vehicles), circular economy, ad secure ICT networks.
- Make sure new jobs and sectors are wherever possible Corona-proof (e.g. part-time in office, part-time at home, less commuting is win-win): improve resilience.
- "Create army of zero-carbon workers, retraining and redeploying those who can't work into different industries, from home insulation to wind turbine manufacture to tree planting".
- Be aware: fossil fuel incumbents time and time again frustrate any green plan.

Measures for financing green recovery

- Do not bailout carbon-intensive firms in the pandemic unless they fundamentally reform
- Make sure all firms are carbon-free or can prove that they capture and sequester all their carbon emissions
- Credit market imperfections in pandemic: soft and easy-to-access loans
- Part renewable energy subsidy to internalise learning-by-doing externalities and to get things going
- Government as launching customer and finance facilitator, especially cities
- Spatial planning pandemic and climate proof: central government, provinces, cities
- Golden Covid-19 opportunity: do not keep living zombies from the fossil era alive, but invest in the inevitable companies that are going to make the green transition possible ("never waste a crisis")
- Independent carbon central bank: carbon reductions are too important to leave to the discretion of politicians (and lobby groups)

Note of optimism: cost solar panels drops 20% for every doubling of cumulative shipped volume



THANK YOU!

Some numbers on Gollier's discount rate with a temperature cap

- Risk-free interest rate = 1.14%/year
- Risk premium if prospect is an unleveraged claim on aggregate consumption = 2.42%.
- Risk premium if leveraged claim on aggregate consumption (dividend prop. to C^3, say) = 7.26%.
- Return on risky assets = 8.4%/year.
- Rate of growth in carbon price = 1.14 + beta x 2.42%.
- Beta = 1.04 (from model), so **set rate of growth in carbon price to 3.47% per year**.
- Lower than in IAM exercises: less procrastination.

Why?

- In future states of nature MAC shocks are positively correlated with consumption and thus negatively correlated with MU of consumption.
- Take case where prosperity is main source of uncertainty. If prosperity is higher than expected, emit more than expected and must abate more to stay below cap. Hence, MAC is higher than expected and *beta* > 0.
- Use growth of carbon prices > safe interest rate so less frontloading of abatement.

- N.b. Gollier (2017) use Barro-style disaster shocks to calibrate volatility.

Alternative story

- If uncertainty in green technical progress is most important, *beta* < 0 and use a lower interest rate and strong frontloading of abatement.
- Why? Suppose green technical progress is stronger than expected, total and MC of abatement fall stronger than expected. Hence, consumption is larger and MU lower in future state of nature.
- Negative correlation implies *beta* < 0, lower *r* and slower growth in carbon prices.

So is Hotelling path okay?

- As you long as you account for risk, yes.
- Must make sure asset prices and carbon prices, and their risk premia, are coherent. So green investors should be paid a premium on their return to compensate for the risk they take. So some price flexibility is part of it.
- But what if there are hold-up problems in investment?
- And what if there are political commitment problems?
- In any case, also need upfront vigorous path of green learning-by-doing subsidies for quick energy transition.