OPTIMAL CLIMATE POLICIES WITH GRADUAL DAMAGES AND TIPPING POINTS

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Price carbon consumption

- Via a global carbon tax or national carbon taxes with border tax adjustments.
- Or have emissions trading scheme if done globally.
- Europe’s policies are a failure: carbon production is priced and has gone down but carbon consumption including imports from China etc is not and has gone up.
- Europe has grandfathered emission rights and has given exceptions to steel and greenhouse industry.
- Europe has focused instead on renewables: wind and even more expensive solar energy.

How does carbon pricing work?

- *It curbs demand for fossil fuel: less car trips, heating a degree less, etc. It encourages to leave more fossil fuel in the crust of the earth.*
- It induces substitution from carbon-intensive fossil fuel (tar sands?, coal, crude oil) to less carbon-intensive fossil fuel (gas).
- *It induces substitution away from fossil fuel to renewables and brings forward the carbon-free era.*
- It encourages CCS and limits slash and burn of forests.
- It encourages R&D into clean fuel alternatives and into energy-saving technology.
- It encourages households, firms and government to spend more on CO2 mitigation as well as on CO2 adaptation (dykes, etc.).

Social cost of carbon (SCC)

- The SCC is the present discounted value of all future marginal global warming damages of emitting an extra ton of carbon.
- The SCC is highly sensitive to the social rate of discount: Nordhaus versus Stern.
- The SCC is higher for rich than for poor countries.
- The cost of extracting the last barrel of oil plus the social cost of carbon must equal the cost of renewables.
- Later on we give a simple rule for the SCC.

US uses SCC=78$/tC based on 3%

Social Cost of Carbon, 2010 – 2050 (in 2007 dollars)

Discount Rate	5%	3%	2,50%	3%
Year	Avg	Avg	Avg	95th
2010	17,23	78,47	128,71	237,99
2015	20,90	87,27	140,81	266,96
2020	24,94	96,44	152,91	295,93
2025	30,07	108,54	168,32	331,50
2030	35,57	120,28	183,35	366,70
2035	41,07	132,01	198,75	402,27
2040	46,57	143,75	214,15	437,47
2045	52,07	154,38	226,25	468,64
2050	57,57	164,65	238,36	499,45

A simple model of the carbon cycle

From Golosov et al. (2014): based on Nordhaus (2008). No lag between carbon stock and temperature as in Gerlagh and Liski (2014). No modelling of lower & bottom oceans as in Bolin and Erikkson (1958). No sudden positive feedback.

$$E_{t+1}^{P} = E_{t}^{P} + \varphi_L F_t, \quad \varphi_L = 0.2, \quad E_0^P = 103 \text{ GtC}$$

$$E_{t+1}^{T} = (1-\varphi)E_{t}^{T} + \varphi_0 (1-\varphi_L) F_t, \quad \varphi = 0.0228,$$

$$\varphi_0 = 0.393, \quad E_0^T = 699 \text{ GtC}$$

$$T_t = \omega \ln\left(E_t / 280\right) / \ln(2), \omega = 3, \quad E_t \equiv (E_t^P + E_t^T) / 2.13 \text{ ppmv CO2}$$

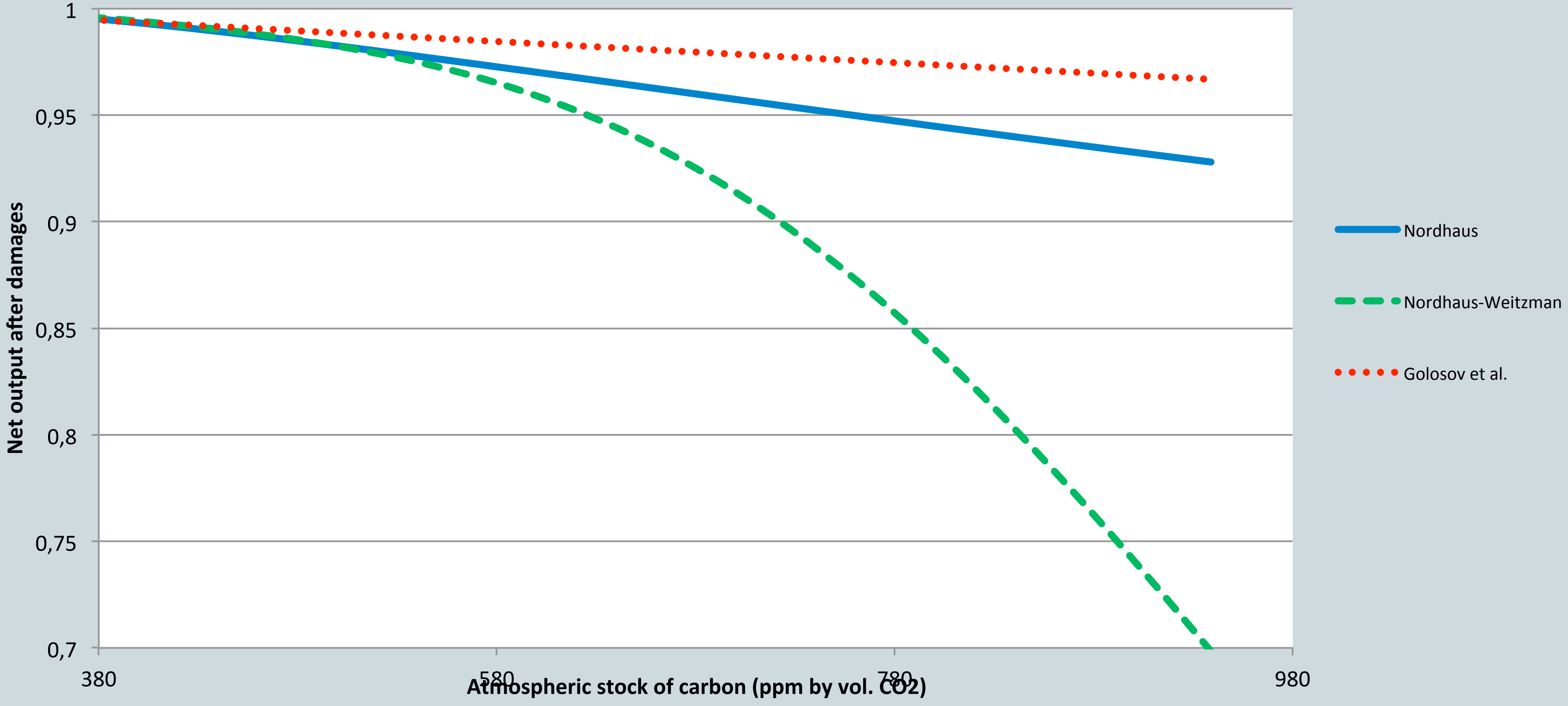
$$S_{t+1} = S_t - F_t, \quad S_0 = 4000 \text{ GtC}$$

Carbon cycle supposes:

- 20% of carbon emissions stays up forever in the atmosphere and the remaining part has a mean lifetime of 300 years.
- The parameter φ_0 is calibrated so that about half of the carbon impulse is removed after thirty years.
- The equilibrium climate sensitivity ω is set to 3 in line with IPCC (2007). Has been revised downwards.
- Ignores time lag of about 40 years between peak temperature and emissions (Gerlagh and Liski, 2013).
- Ignores positive feedback and catastrophes: e.g., release of carbon from the ocean floors at higher temperatures.

What's left of output after damages from warming?

Our IAM has more convex damages than Nordhaus at higher degrees of global warming!



Global warming damages: what is left?

- Nordhaus' RICE (2007): $$Z(T) = \frac{1}{1+0.00284T^2} = \frac{1}{1+(T/18.8)^2}.$$
- Golosov et al. (2013): $$Z(E_t) \cong \exp\left[-2.379\times 10^{-5}(2.13E_t - 581)\right].$$
- Ackerman & Stanton (2012): $$Z(T) = \frac{1}{1+(T/20.2)^2+(T/6.08)^{6.76}}.$$
- RICE is actually fairly flat. We use it in our simple rule.
- The last one captures relatively high damages at high temperatures. We use this later on in our IAM.

ASSUMPTIONS TO GET A SIMPLE RULE FOR THE SCC (Rezai and van der Ploeg, 2015)

- Social Cost of Carbon (SCC) ≡ the present value of all future damages from the global warming caused by emitting one ton of carbon today. Assume:
  - Ramsey growth dynamics must faster than carbon cycle dynamics, so can use trend rate of economic growth *g*
  - A fifth of emissions stays up in atmosphere forever and of rest 60% is absorbed by oceans and earth surface within a year and remainder decays at rate of 1/300 years. After 3 decades half has left the atmosphere. $LEFT_t = 0.2 + 0.4 \times 0.8 \times (1\text{-}0.0023)^{t\text{-}1}$ is left after *t* years of one ton emitted in atmosphere today.
  - Damages are 2.38% of global GDP per trillions tons of extra carbon in atmosphere, so damage of one ton emitted today after t years is $0.0238 \times GDP_t \times LEFT_t$. Approximates damages from RICE fairly well (cf. red and blue line 2 slides back).
  - Average time it takes between an increase in carbon and increase in global mean temperature is 40 years.

SIMPLE RULE FOR THE SCC

- We thus get the following rule for the SCC:

$$SCC = \left(\left[\frac{0.2}{r} + \frac{0.32}{r + 0.0023} \right] \times 0.0238 \times GDP \right) \times \left(\frac{1}{1 + r \times 40} \right),$$

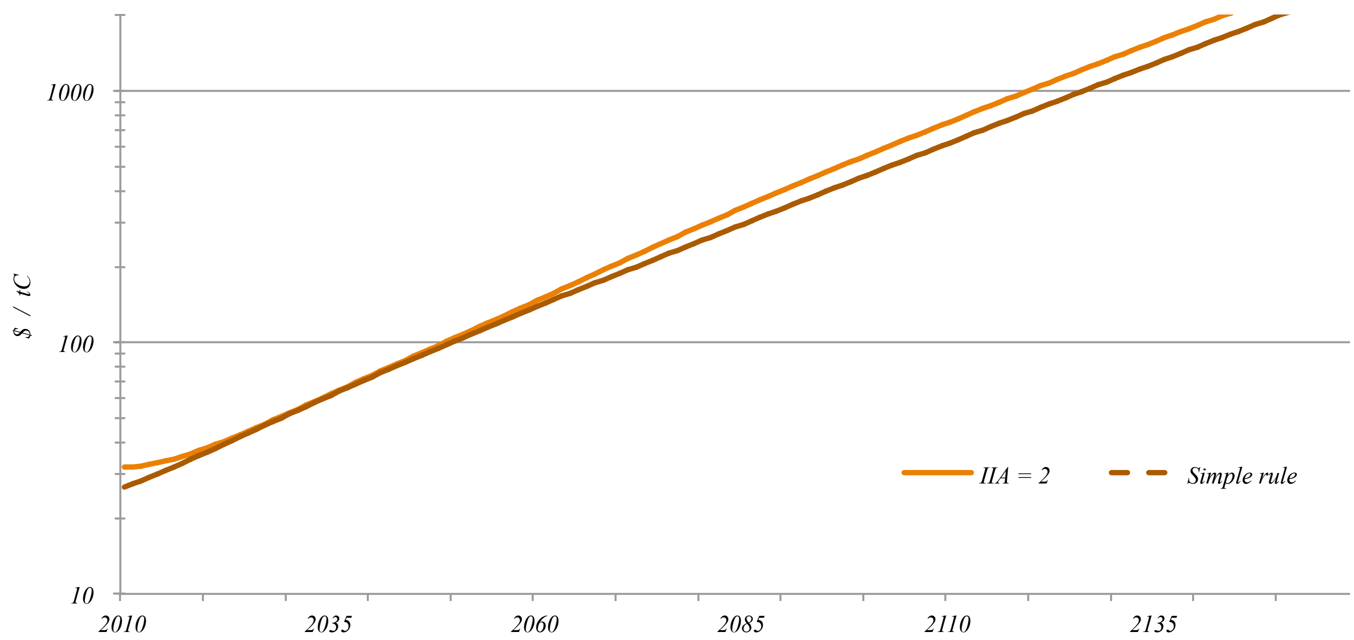
- where the appropriate rate of discount to discount damages follows from the Keynes-Ramsey rule: $r = \rho + (IIA - 1) \times g.$

- Hence, a lower weight to welfare of future generations (higher ρ), a bigger aversion to intergenerational inequality aversion (higher IIA), and richer future generations (higher g) curb desire to make sacrifices to curb future global warming and lead to higher carbon price.
- Since climate damages are proportional to world GDP, the global carbon tax is proportional to world GDP too.

B-O-T-E figures for the global carbon tax

- Let g = 2%, *IIA* = 2 and ρ = 0. World GDP was in 2014 equal to 76 trillion \$. Hence, *SCC* is in 2014 55 \$/tC or 15 \$/tCO2 or 13 cents per gallon petrol. *SCC* subsequently rises in line with GDP at 2%/year.
- Discounting welfare of future generations at ρ = 2% pushes down the *SCC* to 20 \$/tC or 5.5 \$/tCO2.
- Doubling the *IIA* to 4 gives *SCC* of 10 \$/tC.
- Pessimistically halving trend growth to g = 1% gives *SCC* of 132\$/tC which then grows in line with global GDP at a mere 1% per year.
- Golosov et al. (2014, *Ectrica*): *IIA* = 1, ρ = 1.4% gives high *SCC* of 81 \$/tC.
- Easy to extend to allow for damages of global warming (Dell, et al., 2012, AEJ: Macro) to the trend growth rate, pushing up the *SCC* a lot. Curbs carbon budget to 452 GtC & max. temp to 2.3C.
- Simple rules performs extremely well in IAM.

Social Cost of Carbon, τ_t



		Fossil fuel Only	Renewable Only	Carbon used	maximum temperature	Welfare loss
IIA=2	First best	2010-2060	2061 –	955 GtC	3.1 °C	0%
	Business as usual	2010-2078	2079 –	1640 GtC	4.0 °C	- 3%
	Simple rule	2010-2061	2062 –	960 GtC	3.1 °C	- 0.001%

Simple rule: more general damages

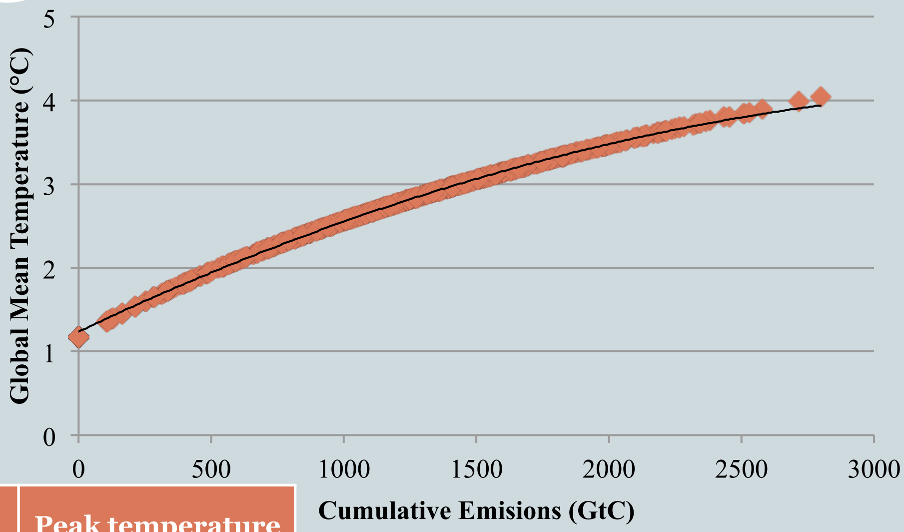
- If the elasticity of marginal climate damages w.r.t. world GDP is ε, then:

$$SCC_t \cong \left(\frac{0.2}{\rho + (IIA - \varepsilon)g} + \frac{0.32}{\rho + (IIA - \varepsilon)g + 0.0023} \right) \times \left(1 + 40 \times \left[\rho + (IIA - \varepsilon)g\right]\right)^{-1} \times 0.0238 \times GDP_t^{\varepsilon} GDP_0^{1-\varepsilon}.$$

- So additive damages ($\varepsilon = 0$) leads to a much lower *SCC* with a much bigger carbon budget of 1600 GtC. Substitutability matters!
- Dell et al. (2012, *AEJ: Macro*) estimates effect of 1° C on poor and rich countries growth rate is -1.171pp and -0.152pp, respectively. Moore and Diaz (2015, *NCC*) cofirm that this pushes up *SCC* by several factors.

IAM with Oxford carbon cycle

Simple rule predicts carbon budget (i.e. cumulative emissions) and peak temperature very well too.



	Parameters				Cumulative emissions		Peak temperature	
Scenario	RTI	IIA	g	r	IAM	Rule	IAM	Rule
Conventional (2x2x2)	2%	2	2%	6 %	1,500 GtC	1,293 GtC	3.2°C	3.1°C
Baseline (Nordhaus)	1.5%	1.45	2%	4.4 %	1,078 GtC	1,025 GtC	2.8°C	2.8°C
Lower discounting	0.1%	1.45	2%	3 %	700 GtC	525 GtC	2.4°C	2.2°C
Lower IIA	1.5%	1	2%	3.5 %	727 GtC	748 GtC	2.4°C	2.4°C
Lower trend growth	1.5%	1.45	1%	3 %	862 GtC	820 GtC	2.6°C	2.5°C
Business-As-Usual	IAM Cumulative emissions: 2290 - 2530 GtC Peak temperature: 3.9 – 4.1°C Rule Cumulative emissions: 2230 - 2275 GtC Peak temperature: 3.8 – 3.9°C							

ABANDONING FOSSIL FUEL: HOW MUCH AND HOW FAST (Rezai and van der Ploeg, 2014)

- To determine first-best optimal global climate policy – time paths for carbon tax and renewable subsidy – within context of green Ramsey growth IAM with exhaustible fossil fuel and directed technical change (learning by doing in renewable use): “Third Way” for climate policy.
- To determine how fast to abandon fossil fuel and switch to renewable energy and the carbon-free economy.
- To determine how much fossil fuel to leave unburnt in the crust of the earth (‘stranded assets’).
- To compare with “business-as-usual” outcome.
- And to compare with second-best climate policies where pricing carbon is infeasible and one has to rely on renewable subsidy only. This yields the Green Paradox.

Features of our IAM

- Fossil fuel extraction costs rise as left reserves are left, which gives rise to untapped fossil fuel.
- Price of fossil fuel consists of this cost, the scarcity rent and the social cost of carbon.
- Renewable energy becomes cheaper as more is used (DRTS). This gives rise to an intermediate phase where renewable and fossil fuel energy are used together.
- Price of renewable energy corresponds to this cost minus any learning-by-doing subsidy.
- IAM allows for temporary population boom and ongoing technical progress.
- Allow for additive and multiplicative global warming damages.
- Take simplified carbon cycle from Golosov et al. (2013).

Punch lines

- What is needed is an aggressive renewable subsidy to bring renewable energy quickly into use and a gradually rising carbon tax to price and phase out fossil fuel energy.
- Golosov et al. (2014) assume log utility, Cobb-Douglas production, 100% depreciation, zero fossil fuel extraction costs, exponential damages, and no population growth. They find that the optimal carbon tax and aggregate consumption are a fixed proportion of world GDP.
- Our IAM assumes CES production, EIS = 0.5, less than 100% depreciation and more realistic global warming damages and finds that the relationship between the optimal carbon tax and GDP is hump-shaped.
- The Golosov et al. (2014) formula for the carbon tax performs not well if the tax has to address multiple market failures.

A Green Ramsey IAM

- Social planner has objective with η = E.I.S. and discount rate ρ and maximizes utilitarian welfare:

$$\sum_{t=0}^{\infty}(1+\rho)^{-t}L_t U_t(C_t/L_t) = \sum_{t=0}^{\infty}(1+\rho)^{-t}L_t\left[\frac{(C_t/L_t)^{1-1/\eta}-1}{1-1/\eta}\right] \text{ subject to}$$

$$K_{t+1} = (1-\delta)K_t + Z(T_t)H(K_t, L_t, F_t + R_t) - G(S_t)F_t - b(B_t)R_t - C_t,$$

$$B_{t+1} = B_t + R_t, \quad B_0 = 0,$$

$$E_{t+1}^P = E_t^P + \varphi_L F_t,$$

$$E_{t+1}^T = (1-\varphi)E_t^T + \varphi_0(1-\varphi_L)F_t,$$

$$T_t = \omega \ln\left(E_t/280\right)/\ln(2), \quad E_t = E_t^P + E_t^T,$$

$$S_{t+1} = S_t - F_t.$$

Efficiency conditions

- Keynes-Ramsey rule (Euler equation):

$$\frac{C_{t+1}/L_{t+1}}{C_t/L_t} = \left(\frac{1+r_{t+1}}{1+\rho}\right)^{\eta}, \quad r_{t+1} \equiv Z_{t+1}H_{K_{t+1}} - \delta.$$

- Fossil fuel and renewable use:

$$Z_t H_{F_t+R_t} \leq G(S_t) + \theta_t^S + \theta_t^E, \quad F_t \geq 0, \quad \text{c.s.},$$

$$Z_t H_{F_t+R_t} \leq b(B_t) - \theta_t^B, \quad R_t \geq 0, \quad \text{c.s.}$$

- Dynamics of the scarcity rent (Hotelling rule):

$$\theta_{t+1}^S = (1+r_{t+1})\theta_t^S + G'(S_{t+1})F_{t+1} \quad \Rightarrow \quad \theta_t^S = -\sum_{s=0}^{\infty}\left[G'(S_{t+1+s})F_{t+1+s}\Delta_{t+s}\right].$$

Efficiency conditions (continued)

- Compound discount factors: $\Delta_{t+s} \equiv \prod_{s'=0}^{s} (1 + r_{t+1+s'})^{-1}, s \geq 0.$
- Dynamics of social benefit of learning by doing:

$$\theta_{t+1}^{B} = (1 + r_{t+1})\theta_t^{B} + b'(B_{t+1})R_{t+1} \quad \Rightarrow \quad \theta_t^{B} = -\sum_{s=0}^{\infty} \left[b'(B_{t+1+s})R_{t+1+s}\Delta_{t+s} \right].$$

- Dynamics of the social cost of carbon (SCC):

$$\theta_{t+1}^{PE} = (1 + r_{t+1})\theta_t^{PE} + Z'(E_{t+1}^{P} + E_{t+1}^{T})H_{t+1},$$

$$(1 - \varphi)\theta_{t+1}^{TE} = (1 + r_{t+1})\theta_t^{TE} + Z'(E_{t+1}^{P} + E_{t+1}^{T})H_{t+1} \quad \Rightarrow$$

$$\theta_t^{E} = -\sum_{s=0}^{\infty} \left[\left\{ \varphi_L + \varphi_0 (1 - \varphi_L)(1 - \varphi)^{s} \right\} \Delta_{t+s} Z'(E_{t+1+s}^{P} + E_{t+1+s}^{P}) H_{t+1+s} \right].$$

Golosov et al. (2014) formula for the SCC

- Assume η = 1, Cobb-Douglas production, δ = 1, ξ =1 and $G(S_t)$ = 0 to show that SCC is proportional to world GDP:

$$\theta_t^{E,\,Golosov\,c.s.} = 2.379\times 10^{-5}\left[\left(\frac{1+\rho}{\rho}\right)\varphi_L + \left(\frac{1+\rho}{\rho+\varphi}\right)\varphi_0(1-\varphi_L)\right] Z(E_t^P + E_t^T) H(K_t, L_t, F_t + R_t).$$

- A lower discount rate ρ pushes up the SCC.
- A bigger proportion of atmospheric carbon φ_L which does not decay pushes up the SCC.
- Faster decay of the other part (higher φ) depresses SCC.
- The optimal ratio of the carbon tax to GDP is independent of technology and the depreciation rate.
- Does not take account of other market distortions.

Calibration of our IAM

- E.I.S. $= \eta = 0.5$, CRIIA = 2, ρ = 10%/decade = 0.96%/year
- $G(S) = 0.35\, S_0/S$, where 0.35 follows from fossil fuel production costs being 5-7% share of initial energy in GDP (350 $/tC or 35$/barrel of oil) and S_0 = 4000 GtC. Hence, extraction costs quadruple if another 2000 GtC is extracted (half of IPPC (2007) because we also have all carbon-based energy other than oil.
- K_0 = 200 trillion $, δ = 0.5 per decade = 6.7% per year.
- $L(t) = 8.6 - 2.98 \exp(-0.35t)$, since population is 6.5 billion in 2010 and grows initially at 1% per year and flattens off to a plateau of 8.6 billion.
- $A_t^L = 3 – 2.443 \exp(-0.2t)$, so starts at 2% per year and flattens off at 3 times initial level.

Calibration of our IAM continued

- CES production function with $\alpha = 0.35$, $\beta = 0.06$, and $\vartheta = 0$ (Leontief) or 0.5 (CES):

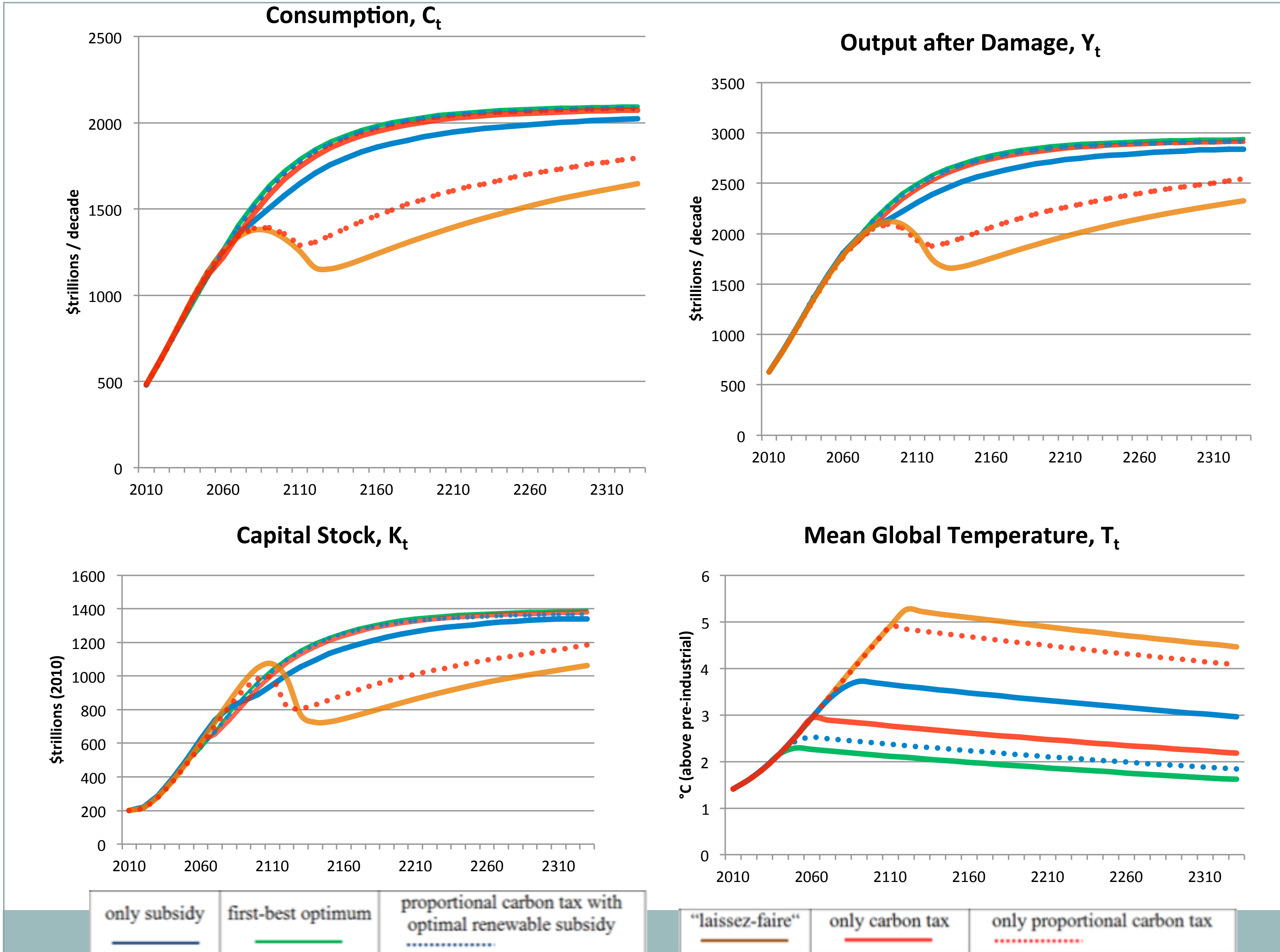
$$H_t = H_0 \left[(1-\beta) \left(\frac{A K_t^{\alpha} (A_t^L L_t)^{1-\alpha}}{H_0} \right)^{1-1/\vartheta} + \beta \left(\frac{F_t + R_t}{\sigma H_0} \right)^{1-1/\vartheta} \right]^{\frac{1}{1-1/\vartheta}}.$$

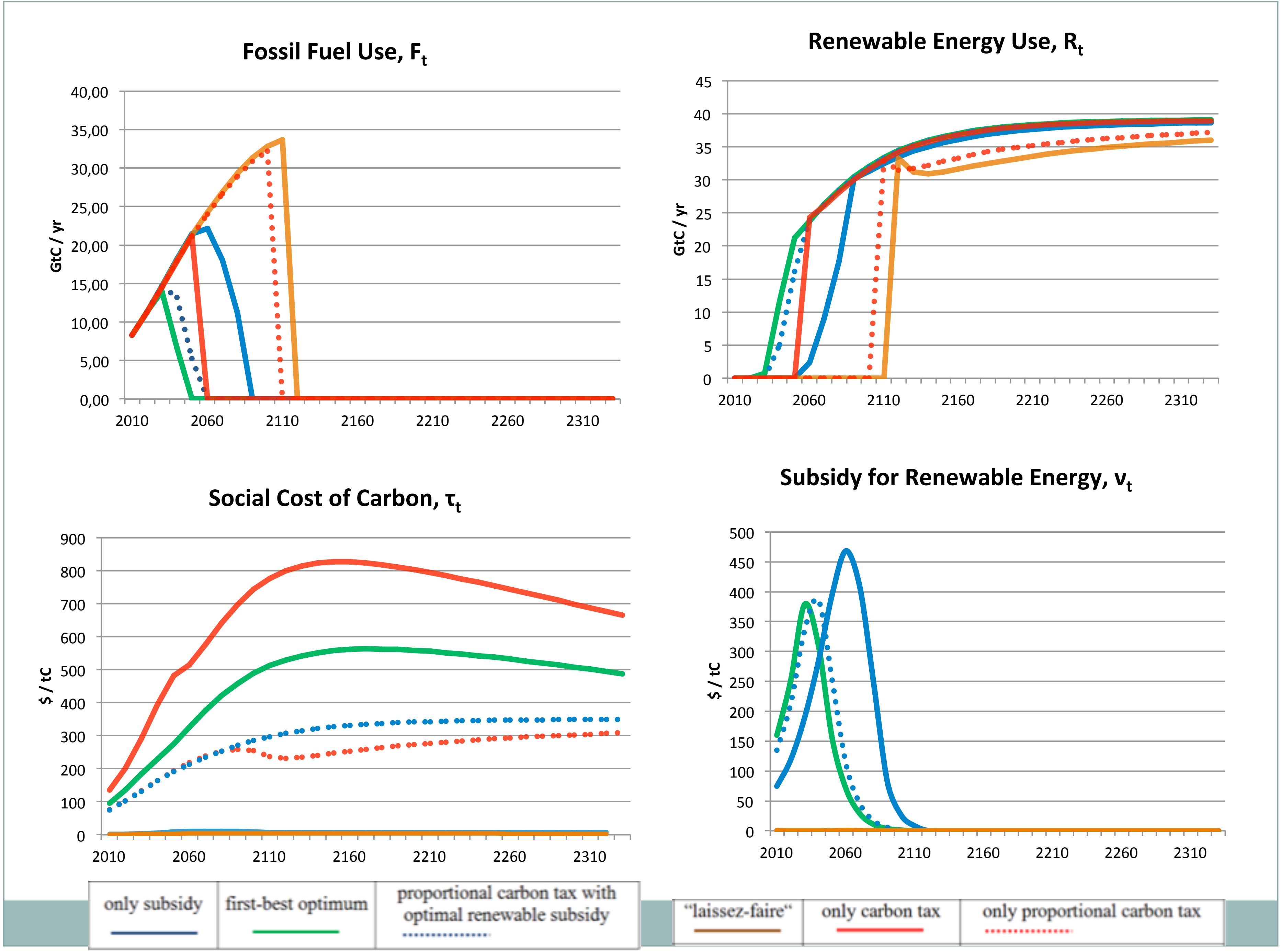
- Use 2010 GDP = 63 trillion \$ to back out $A = 34.67$.
- With Leontief 2010 carbon input is $F_0 = \sigma Z_0 H_0 = 8.36$ GtC, which gives $\sigma = 8.36/(2.13 \times 63) = 0.062$.
- Let $b(B_t) = \chi_1 + \chi_2 \exp(-\chi_3 B_t)$ as cost of producing with only carbon-free energy is $\sigma b(0) = 5.6\%$ (Nordhaus' cost of decarbonising economy) + 6.44% (cost of producing conventional energy) = 0.124 and thus $b(0) = 0.124/0.062 = 2 = \chi_1 + \chi_2$. Thru' learning by doing this cost can be reduced by 60% to a lower limit of 5% of GDP, so we set $b(\infty) = \chi_2 = 0.6 \times 2 = 1.2$. Cost of energy drops by 20% in a decade if all energy is renewable, so we set $\chi_3 = 0.008$.

Policy simulations

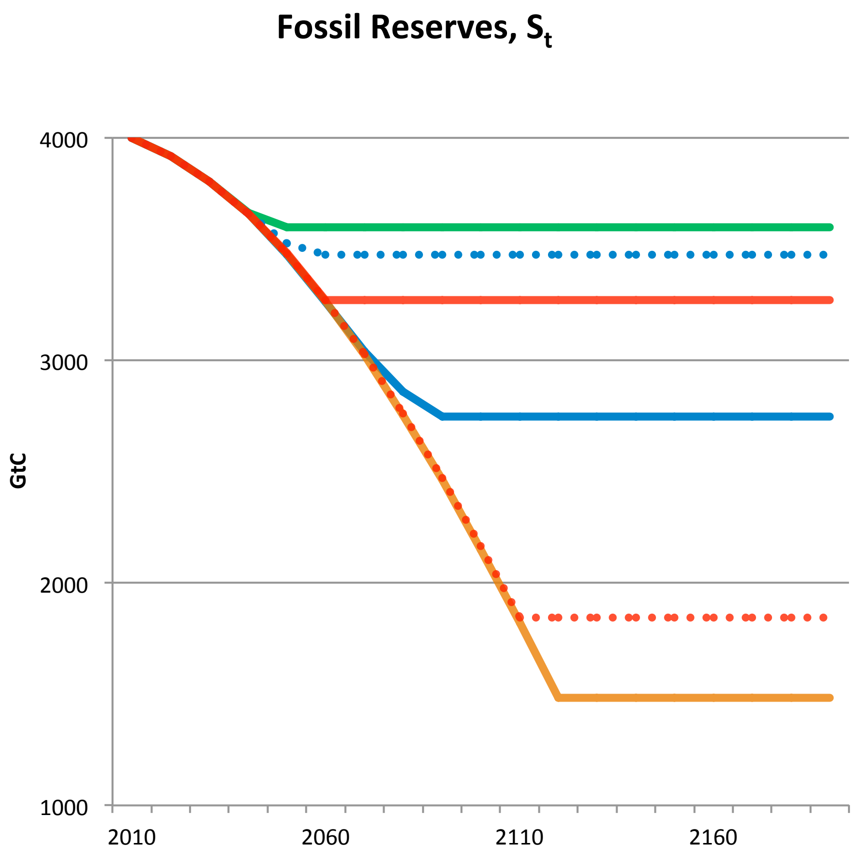
- Solution decade by decade from 2010 to 2600: t = 1 is 2010-2020, .., t = 60 is 2600-2610.
- 4 policy scenarios: 'laissez-faire', 'only tax', 'only subsidy', and 'optimal' (solid lines).
  2 scenarios for the proportional carbon tax of Golosov et al. (2013) with and without subsidy.
- Coding of figures:

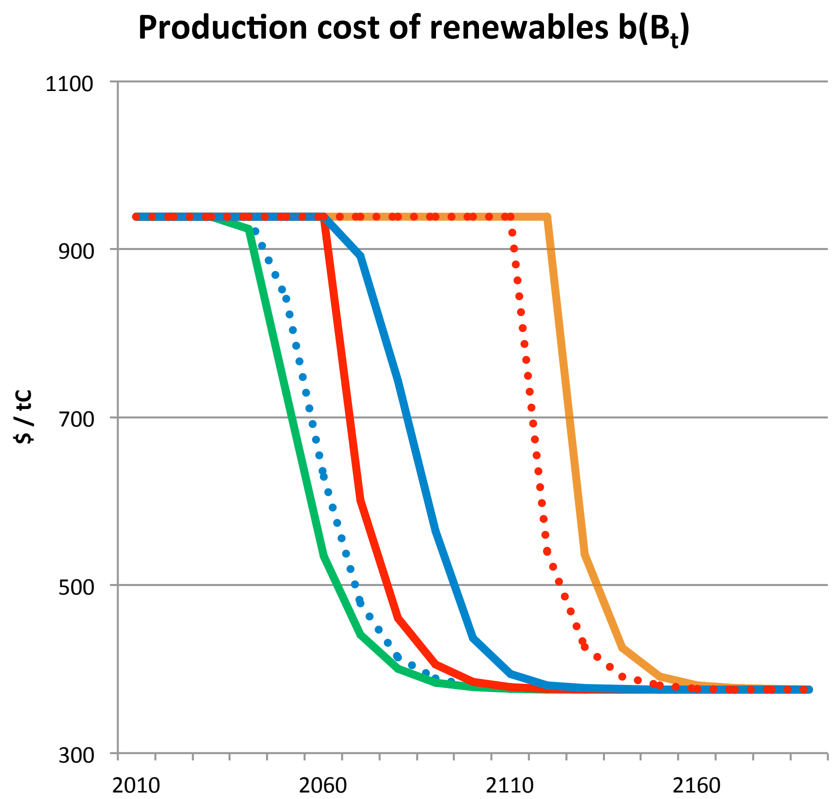
Renewable subsidy, υ_t \ Carbon tax, τ_t	0	θ_t^E	Proportional to GDP
0	"laissez-faire"	only carbon tax	only proportional carbon tax
θ_t^B	only subsidy	first-best optimum	proportional carbon tax with optimal renewable subsidy


Consumption, C_t
$trillions / decade
Output after Damage, Y_t
$trillions / decade
Capital Stock, K_t
$trillions (2010)
Mean Global Temperature, T_t
°C (above pre-industrial)
only subsidy
first-best optimum
proportional carbon tax with optimal renewable subsidy
"laissez-faire"
only carbon tax
only proportional carbon tax



Fossil Fuel Use, F_t
GtC / yr
40,00
35,00
30,00
25,00
20,00
15,00
10,00
5,00
0,00
2010
2060
2110
2160
2210
2260
2310
Renewable Energy Use, R_t
GtC / yr
45
40
35
30
25
20
15
10
5
0
Social Cost of Carbon, τ_t
$ / tC
900
800
700
600
500
400
300
200
100
0
Subsidy for Renewable Energy, ν_t
$ / tC
500
450
400
350
300
250
200
150
100
50
0
only subsidy
first-best optimum
proportional carbon tax with optimal renewable subsidy
“laissez-faire“
only carbon tax
only proportional carbon tax





Carbon tax, τ_t

Renewable subsidy, υ_t	0	θ_t^E	Proportional to GDP
0	"laissez-faire"	only carbon tax	only proportional carbon tax
θ_t^B	only subsidy	first-best optimum	proportional carbon tax with optimal renewable subsidy

Interpretation

- The optimal policy mix combines a persistent carbon tax with a transitory renewable subsidy and limits warming to 2.3°C.
- Under laissez-faire, global temperature rises to 5.3°C. Missing markets lead to a transitory capital over-accumulation, inducing severe climate damage and a fall in capital stock. Rising extraction costs drive transition.
- If the second policy instrument is not available, the one available increases beyond its optimal level.
- Simultaneous use occurs only under a renewable subsidy.
- The Golosov et al. (2013) formula attains the first-best level of consumption, capital and GDP provided the renewable subsidy is implemented alongside it, but without the subsidy consumption , capital and GDP are much lower and temperature much higher. Without subsidy economy uses fossil fuel for too long and waits too long before renewable is phased in.

Transition times and carbon budget

	Only fossil fuel	Simultaneous use	Renewable Only	Carbon used
Social optimum	2010-2020	2030-2040	2050 –	400 GtC
Carbon tax only	2010-2050	N.A.	2060 –	730 GtC
Renewable subsidy only	2010-2050	2060-2080	2090 –	1250 GtC
No policy	2010-2110	N.A.	2120 –	2510 GtC

Welfare losses, SCCs, renewable subsidies and global warming

	Welfare Loss (% of GDP)	Maximum carbon tax τ ($/tC)	Maximum renewable subsidy ($/tC)	max T (°C)
Social optimum		560 $/tC	380 $/tC	2.3 °C
Carbon tax only	-3%	830 $/tC		2.9 °C
Renewable subsidy only	-10%		550 $/tC	3.7 °C
No policy	-73%			5.3 °C

Summing up: global first best

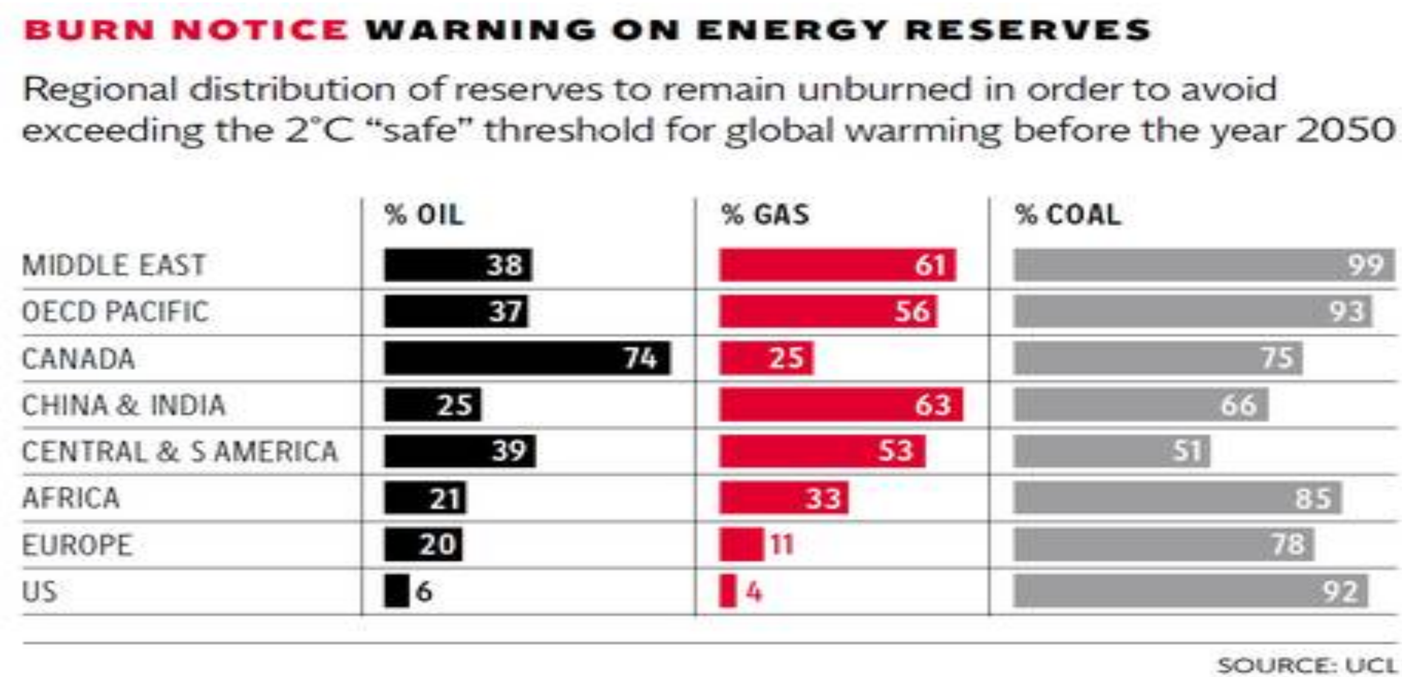
- Need global carbon tax which rises from 100$/tC in 2010 to 275$/tC in 2050 and a renewable subsidy which starts with 160$/tCe, rises rapidly to 380$/tCe in 2030 and then tapers off to zero quickly.
- So quickly make renewable energy competitive and a gradually rising carbon tax to price fossil fuel out of the market.
- Only 400 GtC is burnt in contrast with 2500 GtC under "laissez faire". Hence, temperature is limited to 2.3° C instead of 5.3° C. No policy ⇒ welfare loss is 73% of today's global GDP.

Summing up: national second best

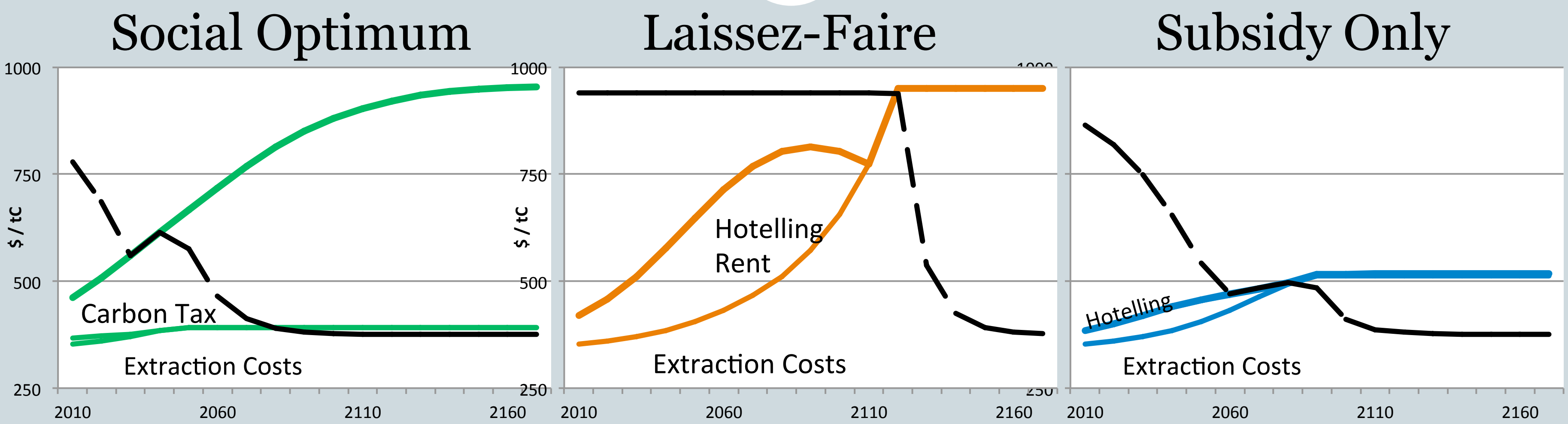
- 30 years of climate negotiations have utterly failed. How about national renewable subsidies?
- Level and duration of subsidy increases compared with first best to compensate for lack of carbon tax.
- Temperature is limited to 3.7^{o} C and the welfare loss is only 10% of GDP compared to first best.
- If only a carbon tax is in place, the welfare loss is only 3% of GDP compared to first best. Important to prioritize the carbon tax, but renewable subsidy is not such a bad second-best instrument to avert the worst of global warming.

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.

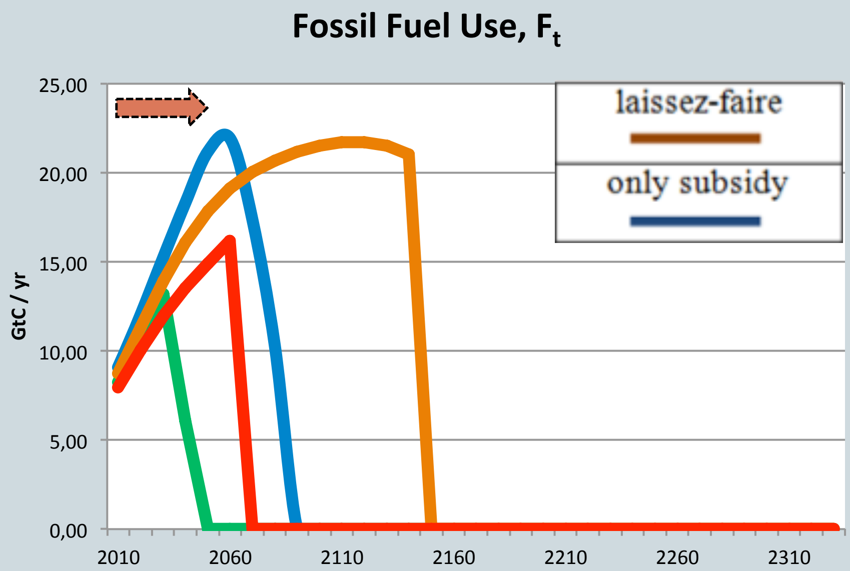


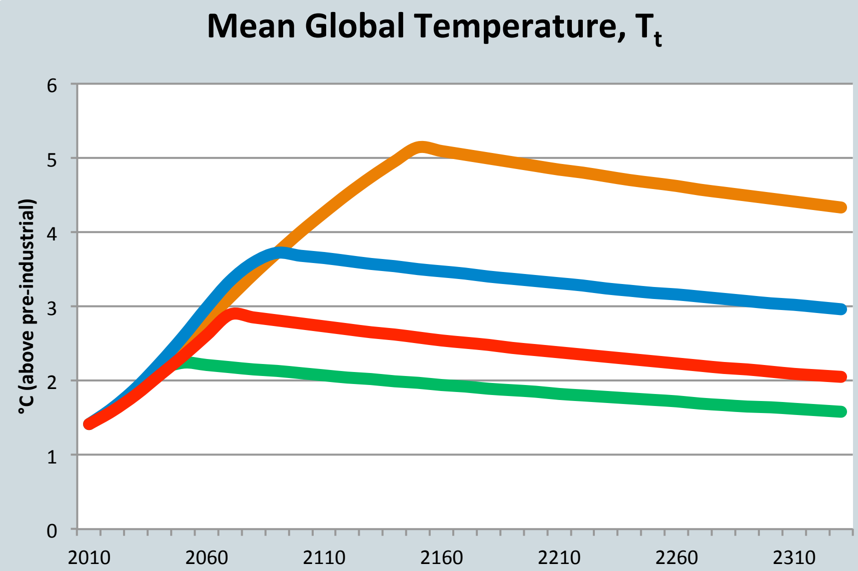
Decomposition of Fossil Energy Prices



- Market price of fossil energy highest under social optimum (due to carbon tax).
- Without a carbon tax, the Hotelling rent is large. Market price still lower than under optimum.
- Market price under 'subsidy only' lowest due to lower Hotelling rent ("Green Paradox" effect).

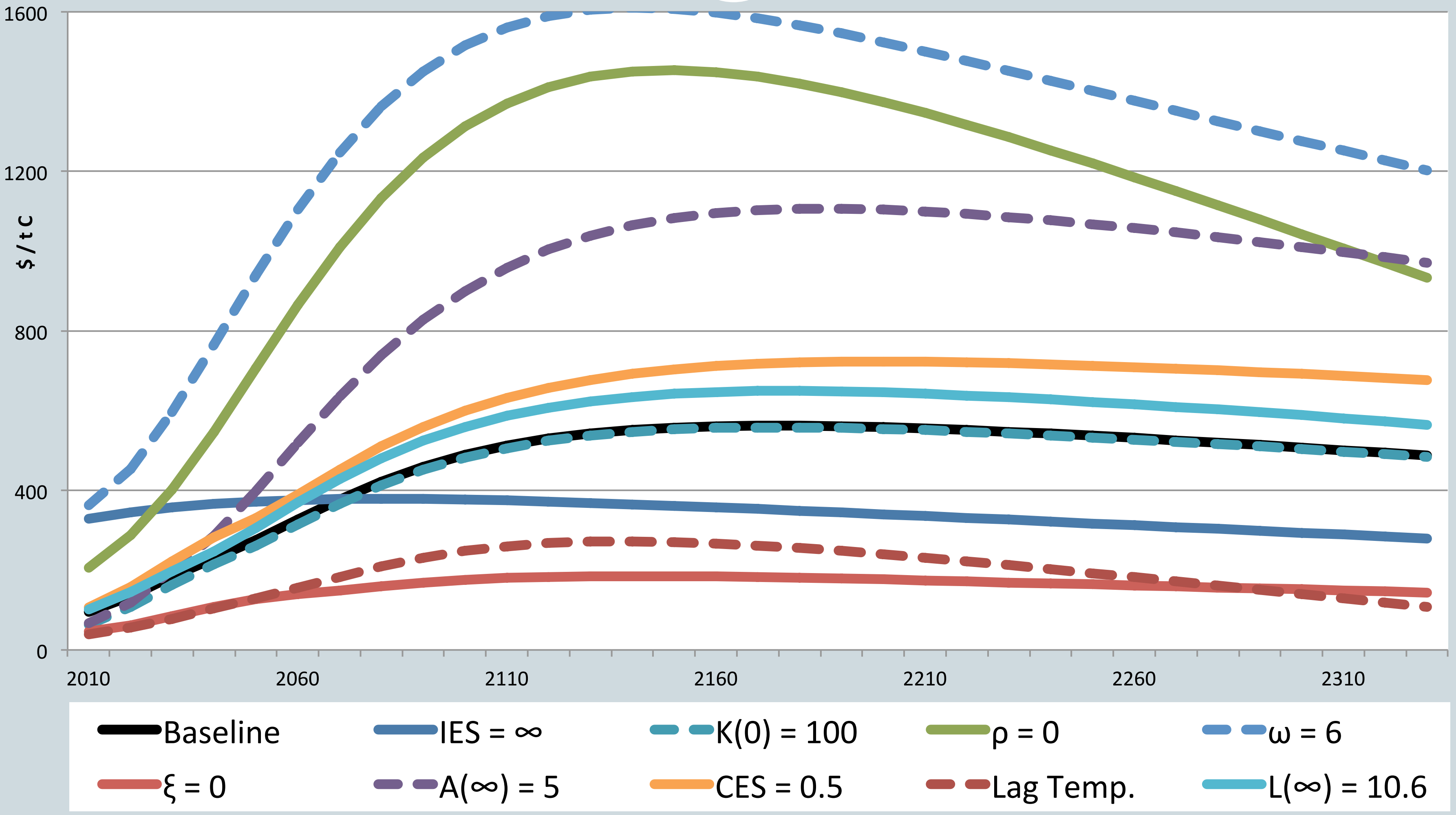
Factor substitution and Green Paradox (compare blue line with brown line)





- If technology permits the substitution of energy for capital (e.s. = 0.5), the demand for energy is price-elastic.
- The introduction of a subsidy lowers the benefit of in situ fossil energy (Hotelling rent), lowering its market price.
- More fossil energy is used (GP!) but temporary effect on temperature is small. In total, less fossil energy is burnt.

Social Cost of Carbon - Sensitivity



Sensitivity to economic and climate assumptions

- SCC is higher and climate policy is more aggressive requiring a higher carbon tax and renewable subsidy, leaving more fossil fuel unburned and thus using less fossil fuel if:
  - the equilibrium climate sensitivity ω is higher (6 not 3),
  - the discount rate ρ is lower (0 not 0.96%/year),
  - technological progress is more rapid ($A(\infty) = 5$ not 3),
  - elasticity of factor substitution ϑ is higher (0.5 not 0),
  - population explosion is more substantial ($L(\infty) = 10.6$ not 8.6 billion).
- But climate policy less aggressive if:
  - there is a lag between warming up and higher carbon concentration,
  - intergenerational inequality aversion is weaker,
  - global warming damages are additive ($\xi = 0$), not multiplicative ($\xi = 1$).
- SCC and carbon tax more upfront if EIS = ∞ and CRIIA = 0.
- Climate policy not much affected if:
  - the initial capital stock K_0 is half the size (100 not 200 trillion \$).

Robustness: 5 Climate Cycles (based on joint work with Armon Rezai)

- There exists large difference between estimates of the social cost of carbon.
- Many models… even more modelers.
- Systematic comparison of prominent climate cycles necessary to understand importance of economics and science for policy prescriptions
- Comparison of:
  - Oxford cycle (Allen et al., 2013)
  - FUND (Anthoff and Tol, 2009)
  - DICE (Nordhaus, 2014)
  - GL (Gerlagh and Liski, 2014)
  - GHKT (Golosov et al., 2014)

Robustness – Temperature