Climate Economics for the Age of President Trump

The Agnostic's Response to Climate Scepticism

Climate Policies under Climate Model Uncertainty

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Climate Sceptics on the Helm!

- Trump: “Global warming is a hoax invented by the Chinese”.
- The Trump administration’s first budget proposal cuts funding for the EPA by 31%.
- Vice President Michael Spence: big advocate of the coal industry (as is Trump of course).
- Scott Druitt (Head of EPA):“[…] I think that measuring with precision human activity on the climate is something very challenging to do and there's tremendous disagreement about the degree of impact. So no, I would not agree that it's a primary contributor to the global warming that we see.”
- Stephen K. Bannon (key strategist): regularly publishes climate denier articles such as “Global Temperature Plunges. Icy Silence from Climate Alarmists” or “Climate Change: The Greatest-Ever Conspiracy Against the Tax Payer”.

Model uncertainty vs. statistical uncertainty

- Interactions between the Earth‘s climate (and its change) and the economy are highly complex and subject to ongoing research.
- Much effort has gone into identifying uncertainties in our understanding but these have focused on *statistical* uncertainties, mostly key parameters (such as the climate sensitivity, positive feedback loops, and catastrophic shocks).
- However, *scientific* uncertainty about which particular climate model (with all the scientific uncertainties that are associated with it) is correct maybe more relevant with the growth in the number of climate sceptics.
- We study the effect of climate model uncertainty on the optimal climate policies and optimal energy transition and suggest suitable ways of dealing with these uncertainties.
- We focus on DICE, FUND, PAGE and a climate-denier model.

Additional fourth “climate model”: **TRUMP** (Temperature Response Unimportant for Macroeconomic Performance) or **DENIER** model

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We Have All the Best Climates, Really, They’re Great

Iwas A. Scientistonce *

* and now I have all my research approved by a public relations office

Abstract

The research presented in this paper is really the best research that you will ever see. We have methods, the best methods, and we used them to study climate. As you may already know, the Earth, led by America, has all the best climates. In this paper we refute prior work by out-of-touch scientists who insist that the climate is changing – why would it change, when it’s so great already? It is not getting warmer. In fact, our findings show that you were cold at least one day last year. Our (really fantastic) data also reveals that America has all the best CO2 levels, really great levels. In our discussion, we reveal that there is no reason to believe a bunch of scientists who spent all their time learning and studying “facts” instead of being out in the real world making jobs. Our alternative facts definitively prove that scientists are losers. Finally, we had peer reviews, by all the best people, our people, because politicians know the most about science, the very best things about science.

Keywords: climate, “data”, “facts”, #makeclimategreatagain, “science”

Aim

- How should policy makers take account of fundamental climate model uncertainty?
- The climate deniers view of global warming not being caused by human being is called the TRUMP or DENIER model.
- 2 climate modules (DICE or SCIENTIFIC and DENIER model) to project $SCCi$ and optimal energy transitions with common model of world economy and energy use.
- Maximising expected utility, $E[U(SCCi), i = 1,2,3]$ is a start if one can assign prior probabilities for each of these climate modules being the correct one. For simplicity, we will ignore all forms of statistical uncertainties.
- Our aim is to introduce robustness in decision making:
  (1) ***Max-Min*** (Wald, 1945; Gilboa and Schmeidler, 1989);
  (2) ***Min-Max Regret*** or ***Better Safe than Sorry*** (Savage, 1954);
  (3) ***Smooth Ambiguity Aversion*** provided one can assign subjective priors (Klibanoff, Marinacci and Mukerji, 2005).

“Scientists versus Climate Deniers”:

- Two climate modules: DICE2013-R and climate deniers.
- Different common economic module: DICE2013-R instead of Ramsey growth model with energy use, so now abundant fossil fuel and no scarcity rents. Also, no learning by doing in production of renewable energy.
- One economic policy only: the carbon price.
- Continuous range of policy options.
- Expected utility defines subjective prior probabilities for each climate model being correct and uses these to maximise expected utility
- To allow for robustness in decision making, policy makers can in addition be ambiguity averse to uncertainty about the right type of climate model.

"To believe or not to believe": what if we don't know whether God exists?

Blaise Pascal's Wager (*Pensées*, 1670)

Pay-offs	Believe in God	Do not believe in God
God exists with probability 1 - π	+ $\propto$ (infinity)	– $\propto$ (minus infinity)
God does not exist with probability π	– 1 (finite loss)	0 (benchmark)

$(1 - \pi) \times \propto + \pi \times (-1) = + \propto$ always exceeds
$(1 - \pi) \times (-\propto) + \pi \times (0) = - \propto$ as long as $\pi < 1$.

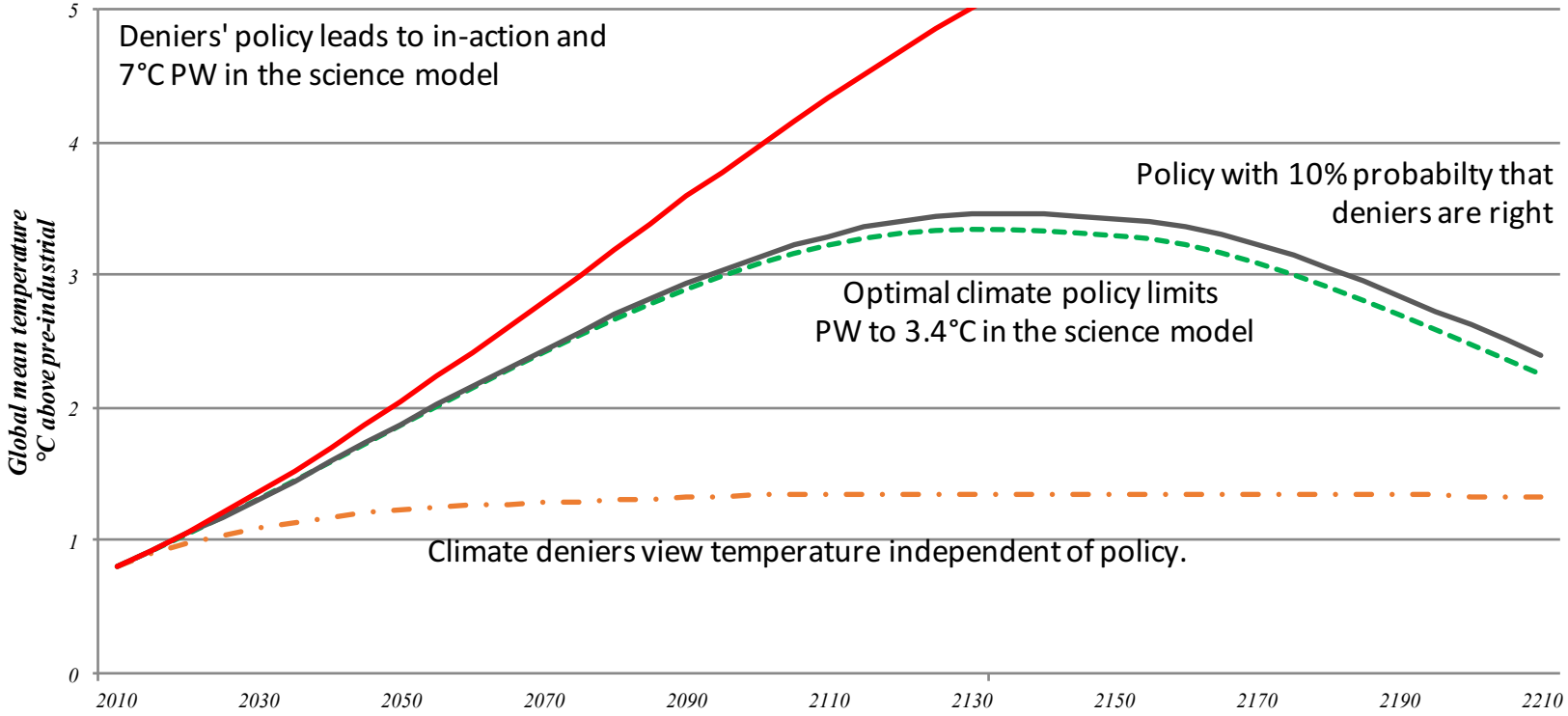
- Agnostics should believe in God as long as $1 - \pi > 0$. This is also the case if Paradise only leads a finite utility *or* Hell a finite disutility.
- Atheists, who know $\pi = 0$, should not believe in God.

Pascal's climate wager:

(% of 2015 world GDP)	Tax carbon	Don't tax carbon
Science	17%	0%
Denier	34%	41%
min	17%	0%

- Max-Min climate policy is to price carbon.
- Min-Max regret policy is to price carbon, since regret under Science view (17%) exceeds regret under Denier view (7%).
- Expected utility: if $17\ (1-\pi) + 34\ \pi > 41\ \pi$ or if $\pi < 70\%$, one taxes carbon. So only if one assigns a probability of deniers being right, π, bigger than 70%, does one not price carbon. This seems highly unlikely.

Temperature under Science and Deniers view of global warming



- The Climate Deniers model is independent of anthropogenic emissions has temperature peaking at 1.3 degrees (dashed-dotted brown line).
- In the Science model temperature peaks at 3.4 degrees (dashed green line).
- Policy inaction favoured by deniers leads to temperature rising to 7 degrees (red line).
- Optimal expected utility policy with continuous policy space is very close to the scientific non-denialist policy if probability that deniers are right is not 3% but 10% (solid black line).

Formally: Dealing with Ambiguity Aversion

- Under ambiguity aversion (*AA*), one maximises:

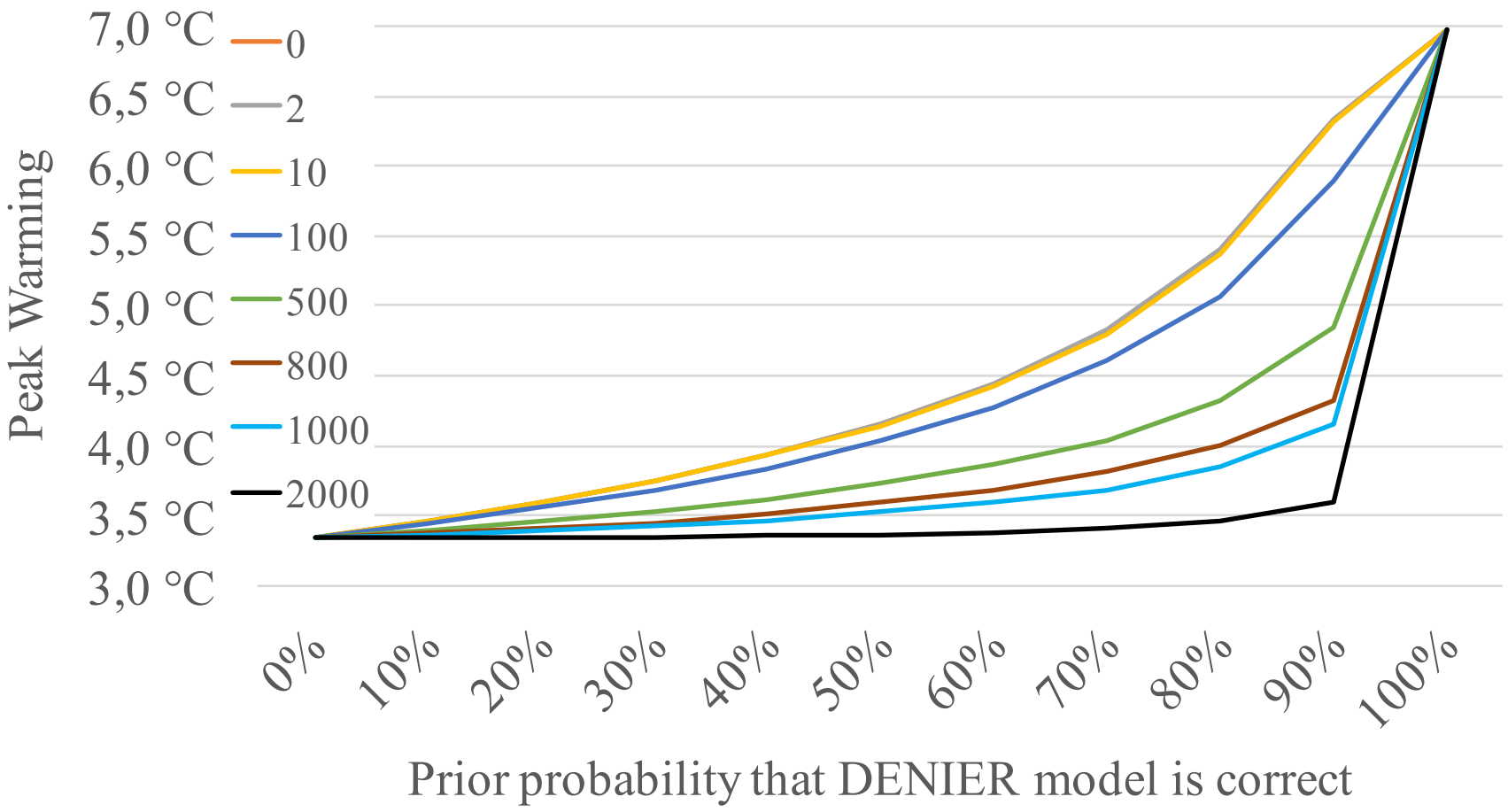
$$\left(\pi W_D(p)^{1-AA} + (1-\pi)W_S(p)^{1-AA}\right)^{1/(1-AA)} =$$

$$\pi^* W^T(p) + (1-\pi^*)W^S(p), \text{ where}$$

$$\pi^* \equiv \pi / \left(\pi + (1-\pi)\left(W_D(p)/W_S(p)\right)^{AA}\right) \leq \pi.$$

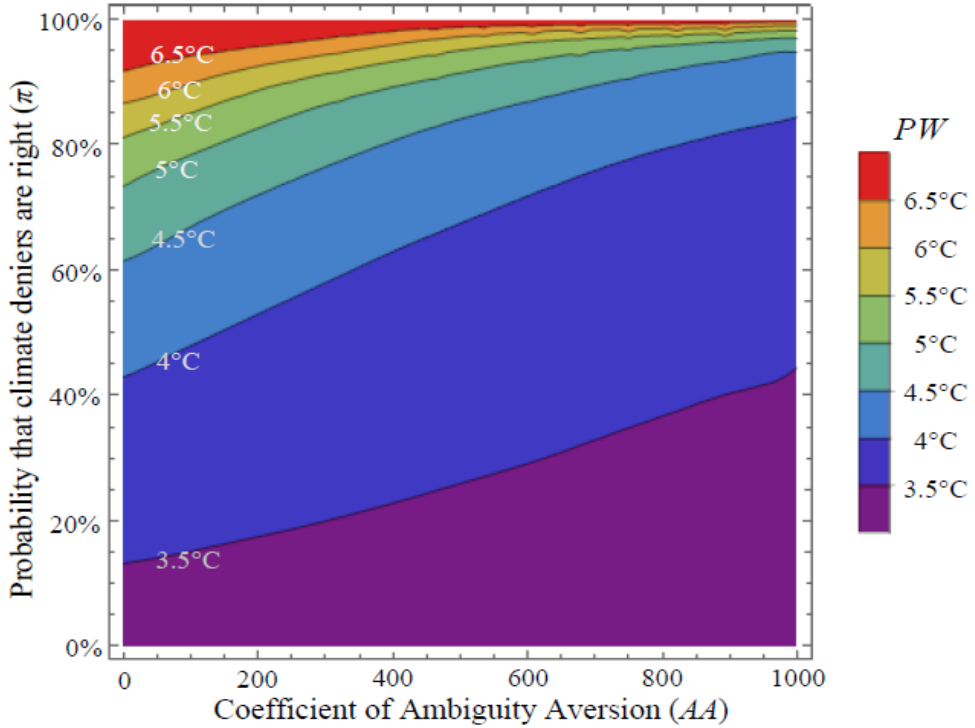
- Hence, if *AA* = 0, one has expected utility with $\pi^* = \pi$.
- But in general, *AA* > 0, and probability that deniers are right is biased downwards: $\pi^* < \pi$. As a consequence, climate policy will be more ambitious.
- As *AA* goes to infinity, one get the Max-Min policy which is independent of prior probabilities and thus much liked.

Climate agnostic's answer to climate scepticism? Tax carbon!



Optimal policy is insensitive to reasonable levels of skepticism.

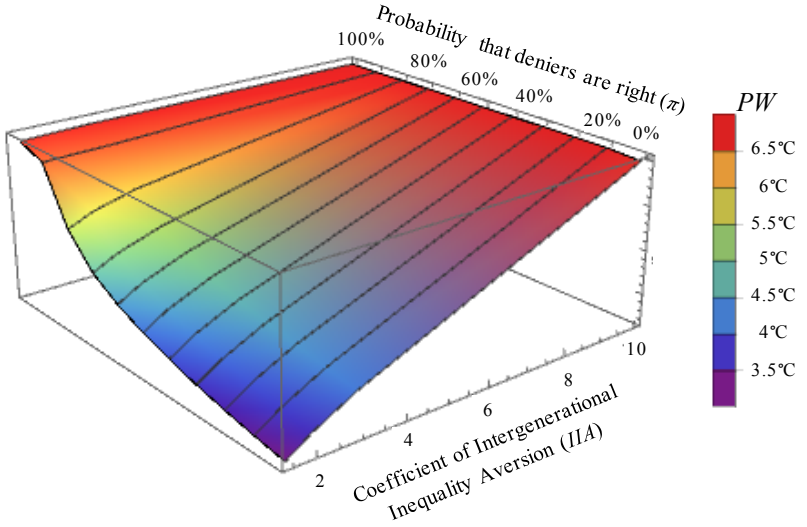
Peak warming versus prior that Deniers are right and versus Ambiguity Aversion



- Peak warming rises in probability that Deniers are right from 3.4 to 7 degrees (right axis).
- Aversion to ambiguity (AA) about climate model uncertainty (horizontal axis) lowers willingness to increase peak warming. As AA goes to infinity, peak warming falls to 3.4 degrees regardless of prior probability that Deniers are right: Max-Min policy.

- If *AA* = 0, peak warming increases by more than 0.5°C only for priors that deniers are right greater than one third.
- If *AA* = 800, this cut-off for the prior rises to 70%.
- Aversion to ambiguity about what the right climate model is, biases priors toward the non-sceptic scientist and encourages more ambitious climate policy. This effect is small for low *AA*, but large for high *AA*.
- Even if policy makers assign a 50% (or 90%) probability to climate deniers being right, allowing for a high degree of robustness but less than for the max-min policy biases this probability down to 20% if *AA* = 800 (or 2000).
- Typical, macro estimate of *AA* = 60. Then, if prior is 61% *PW* is 4.5 degrees if *AA* = 0 but 4.3 degrees if *AA* = 60.
- This implies an initial price of carbon of $11.9/tCO2 and peak global warming of 3.6°C.

Peak warming against prior that Deniers are right & Intergenerational Inequality Aversion



- If IIA is low, today's climate policy is more ambitious and peak warming lower. If the willingness to make sacrifices is low (high IIA), climate policy is severely delayed. Peak warming increases from 2 to 7 degrees.
- A higher probability that Deniers are right also boosts peak warming.

Robust Stochastic Control

- Builds on risk-sensitive control developed in books by Jacobson (1973), Whittle (1990) and in economics by van der Ploeg (1993, RES) and Bommier (2006, IER). Time inconsistency unless discount rate is zero, so either set risk sensitivity parameter as in standard discounted utility model or discount rate to zero for risk-sensitive approach. Both can capture the data, but with very different policy implications.
- Bommier, Lanz and Zuber (2015, JEEM) compare these two approaches to catastrophic environmental disaster.
- Main modern reference for "fear of misspecification", robust filtering and estimation, and Max-Min under macroeconomists is the book *Robustness* by Hansen and Sargent (2007).
- In macro different schools of thought: involuntary unemployment with people willing to work at the going wage a la Keynes *vs* voluntary unemployment (holiday, leisure) a la Lucas-Rapping. Or: post-Keynesian *vs* neoclassical models.
- Li, Narajabad and Temzelides (2016, QE) apply robust control to GHKT (2014, Ectra) model: coal use will be much less and optimal use of oil and gas edges down with robust policies.

Conclusions

- The differences in SCC estimates are large, persistent, and become larger as they are projected further into the future.
- Climate economics should draw on decision theory to study model uncertainty and come up with robust policies.
- Model uncertainty allows addressing rising climate scepticism.
- We derive the robust policy under fundamental uncertainty of IAM climate models as well as under the climate deniers' model.
- Even if there is a chance of 1:3 that TRUMP is right, robust policy taxes carbon and PW increases by less than 0.5°C.
- With a 1:2 chance the end of the transition to the carbon-free economy is only delayed by 30 years under expected utility.
- Max-Min, Min-Max and Safe (with high degrees of ambiguity aversion) policies shorten this and all point to policies very close to what a non-denialist scientist would set: price carbon anyway!
- Trump also seems to favour the current generations due to high intergenerational inequality aversion. Furthermore, the "just managing" are most hit by carbon taxes. And, of course, the far right is under the spell of the coal and shale gas lobbies. These make for very lacklustre climate policies, at least in the US.

Need more information for the general public on global warming

- Doran and Zimmerman (2009) finds that 97.4% of climate specialists (those that have published half their peer-reviewed papers during the last ten years on this topic) say that human activity is a significant contributing factor in changing mean global temperature.
- This figure drops to 58% for the general public!
- Two lessons. First, this is in both cases well below the 70% cut-off and thus suggests that the max-min policy of pricing carbon should be chosen. Second, it is important to educate the general public on anthropogenic causes of global warming.

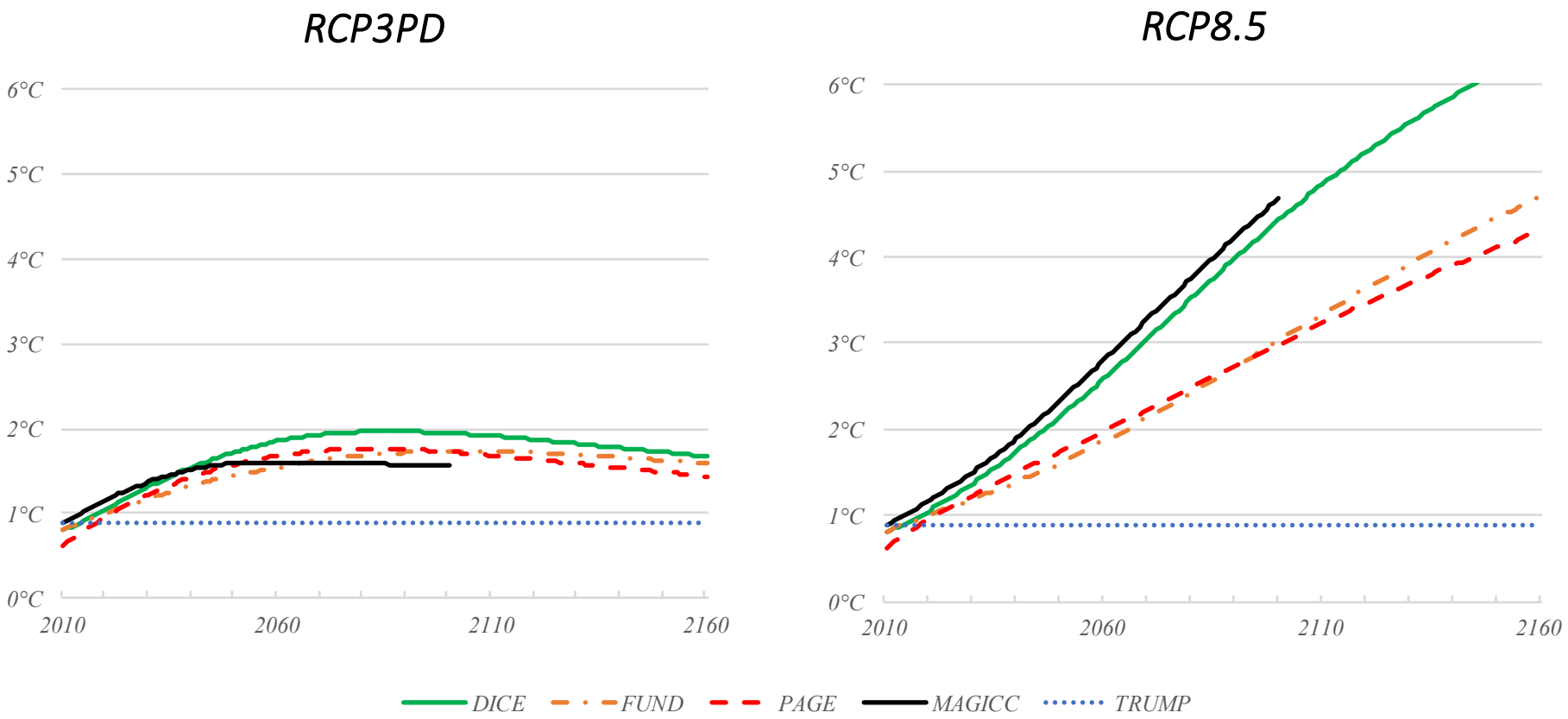
BACKGROUND MATERIAL

Climate models in 3 prominent IAMs

- **DICE** (Dynamic Integrated model of Climate and the Economy; Nordhaus, 2014)
  - 3 stocks of carbon (5% permanent)
  - Non-carbon GHGs modelled via exogenous forcing
  - 2 stocks of temperature
- **FUND** (Framework for Uncertainty, Negotiation and Distribution; Anthoff and Tol, 2013)
  - 5 stocks of carbon (13% permanent)
  - 3 stocks of non-carbon GHGs (CH_4, N_2O, SF_6) and SO_2 as a flow
  - Temperature adjusts to radiative forcing with a lag
- **PAGE** (Policy Analysis model of the Greenhouse Effect; Hope, 2006, 2011).
  - 2 stocks of carbon (30% permanent)
  - 3 stocks of non-carbon GHGs (CH_4, N_2O, SF_6+)
  - 7 regional temperatures adjust to radiative forcing with a lag.
  - Global mean temperature is a weighted mean of regional temperature.
- Note: FUND and PAGE have positive feedback from temperature/cumulative CO_2 to emissions.

Temperature responses to RCP scenarios

RCP3PD: radioactive forcing reaches 3 W/m^2 before 2100 and then falls.
RCP8.5: radioactive forcing reaches 8.5 W/m^2 in 2100 and then continues to rise.



Common model of the economy

- We consider various models of global warming and climate change, but use only one Ramsey model of economic growth and energy use.
- Exhaustible stock of fossil fuel (coal, oil and gas):
  - Stock-dependent extraction costs
  - Positive scarcity rent and stranded assets
- Renewable energy
  - Learning by doing in past cumulative use
  - Renewable subsidy as second policy instrument next to the carbon price
- Two energy sources are perfect substitutes in production of final goods, but only fossil energy is dirty in that its use leads to carbon emissions.
- Elasticity of substitution between energy, labour and capital is 0.5.
- We set discount rate to 1% per year and *IIA* = 2. Technical progress 2% per year.
- Convex global warming damages: $Z = 1/[1+0.00245\ T^2 + 5.021\ 10^{-6}\ T^6]$
- For comparability, we annualised the climate models of DICE and PAGE.
- We have not modelled non-carbon emissions (e.g., CH4), which are assumed zero.

Decentralised Equilibrium Conditions

- A competitive equilibrium is defined by the following equilibrium conditions.
- Keynes-Ramsey rule or Euler equation (Households):

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

- Fossil fuel and renewable use (Final goods firms):

$$Z_t A_t H_{F_t+R_t}(K_t, L_t, F_t + R_t) = p_t \leq G(S_t) + \theta_t^S + \tau_t, \; F_t \geq 0, \text{ c.s.}$$

$$Z_t A_t H_{F_t+R_t}(K_t, L_t, F_t + R_t) = q_t \leq b(B_t) - \nu_t, \qquad R_t \geq 0, \text{ c.s.}$$

- Scarcity rent on fossil fuel = PV[future increases in extraction cost from extracting one tC today]:

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

First-best policy for social optimum

- With the compound discount factors:

$$\Delta_{t+s} \equiv \prod_{s'=0}^{s} (1 + r_{t+1+s'})^{-1}, s \geq 0.$$

- Social benefit of learning by doing SBL = PDV[future benefits from producing unit of renewable energy extra today]:

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

- SCC = PDV[future damages from burning 1tC today]:

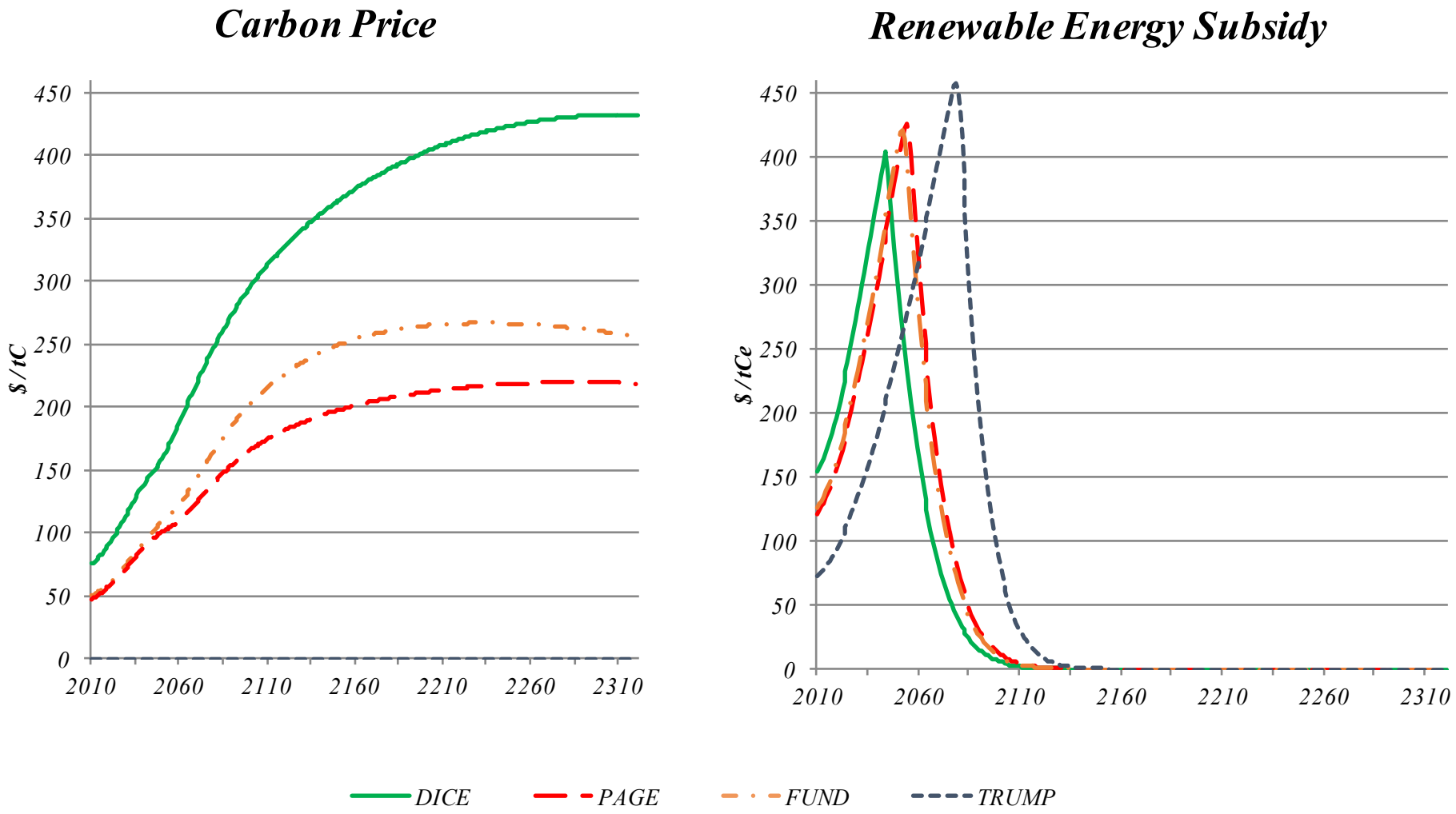
$$\theta_{t}^{E} = -\sum_{s=0}^{\infty} \left[\left\{ \varphi_L + \varphi_0(1-\varphi_L)(1-\varphi)^{s} \right\} \Delta_{t+s} Z'(E_{t+1+s}^{P} + E_{t+1+s}^{P}) H_{t+1+s} \right].$$

- The government implements the social optimum by setting carbon tax to SCC and renewable energy subsidy to SBL,

$$\tau_t = \theta_t^E \quad \text{and} \quad \nu_t = \theta_t^B,$$

and rebating the net revenues in lump-sum fashion.

Optimal carbon price and renewable subsidies for each climate module



Optimal climate policies for each climate model

Climate Model	Carbon price, τ_t		Renewable subsidy, v_t		End of Fossil Era	Carbon Budget	Peak Warming
	Initial	max.	Initial	max.			
DICE	76 $/tC	432 $/tC	154 $/tCe	403 $/tCe	2045	401 GtC	2.2 °C
PAGE	47 $/tC	125 $/tC	122 $/tCe	426 $/tCe	2056	581 GtC	2.1 °C
FUND	51 $/tC	146 $/tC	127 $/tCe	423 $/tCe	2054	546 GtC	2.0 °C
DENIER	0 $/tC	0 $/tC	72 $/tCe	408 $/tCe	2082	1094 GtC	0.9 °C

ROBUST CLIMATE POLICIES: Min-Max policies for peak warming

Peak Global Warming (PW)	DICE policies	PAGE Policies	FUND Policies	TRUMP policies	BAU
DICE model	2.2°C	2.5°C	2.4°C	3.2°C	4.8°C
PAGE model	1.9°C	2.1°C	2.1°C	2.6°C	3.8°C
FUND model	1.8°C	2.1°C	2.0°C	2.7°C	4.3°C
DENIER model	0.8°C	0.8°C	0.8°C	0.8°C	0.8°C
Maximum	**2.2°C**	2.5°C	2.4°C	3.2°C	4.8°C

- So the DICE policy is the Min-Max policy in terms of peak warming.

ROBUST CLIMATE POLICIES: Maximise welfare under worst outcome

Welfare gains (utils)	DICE policies	PAGE policies	FUND Policies	TRUMP policies	BAU
DICE model	5134	5080	5095	4518	207
PAGE model	5345	5387	5385	5202	3693
FUND model	5394	5425	5426	5186	3980
DENIER model	5712	5853	5837	5985	5451
Minimum	**5134**	580	5095	4518	207
0.5 Max-min	5423	**5467**	5466	5252	2829

- So the DICE climate policy in terms of welfare is the Max-Min policy (Wald, 1945; Gilboa and Schmeidler, 1989).
- PAGE climate policy is the 0.5-Max-Min policy (Arrow and Hurwicz, 1979).

ROBUST CLIMATE POLICIES: Minimise the maximum regret

Regret (utils)	DICE Policies	PAGE policies	FUND Policies	TRUMP policies	BAU
DICE model	0	54	39	616	4927
PAGE model	42	0	2	185	1694
FUND model	32	1	0	240	2446
DENIER model	273	132	148	0	534
Maximum	273	**132**	148	616	4927
Excluding TRUMP	42	54	**39**	616	4927

- The PAGE policy is the Min-Max regret or ”better safe than sorry” policy, but this is the FUND policy if the TRUMP climate denier model is excluded (Savage, 1954).