The role of *warm-glow* in the prevention of climate change

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Motivation

Is there a risk of an environmental disaster?

Energy consumption

Ever growing global energy consumption at a lower rate of growth

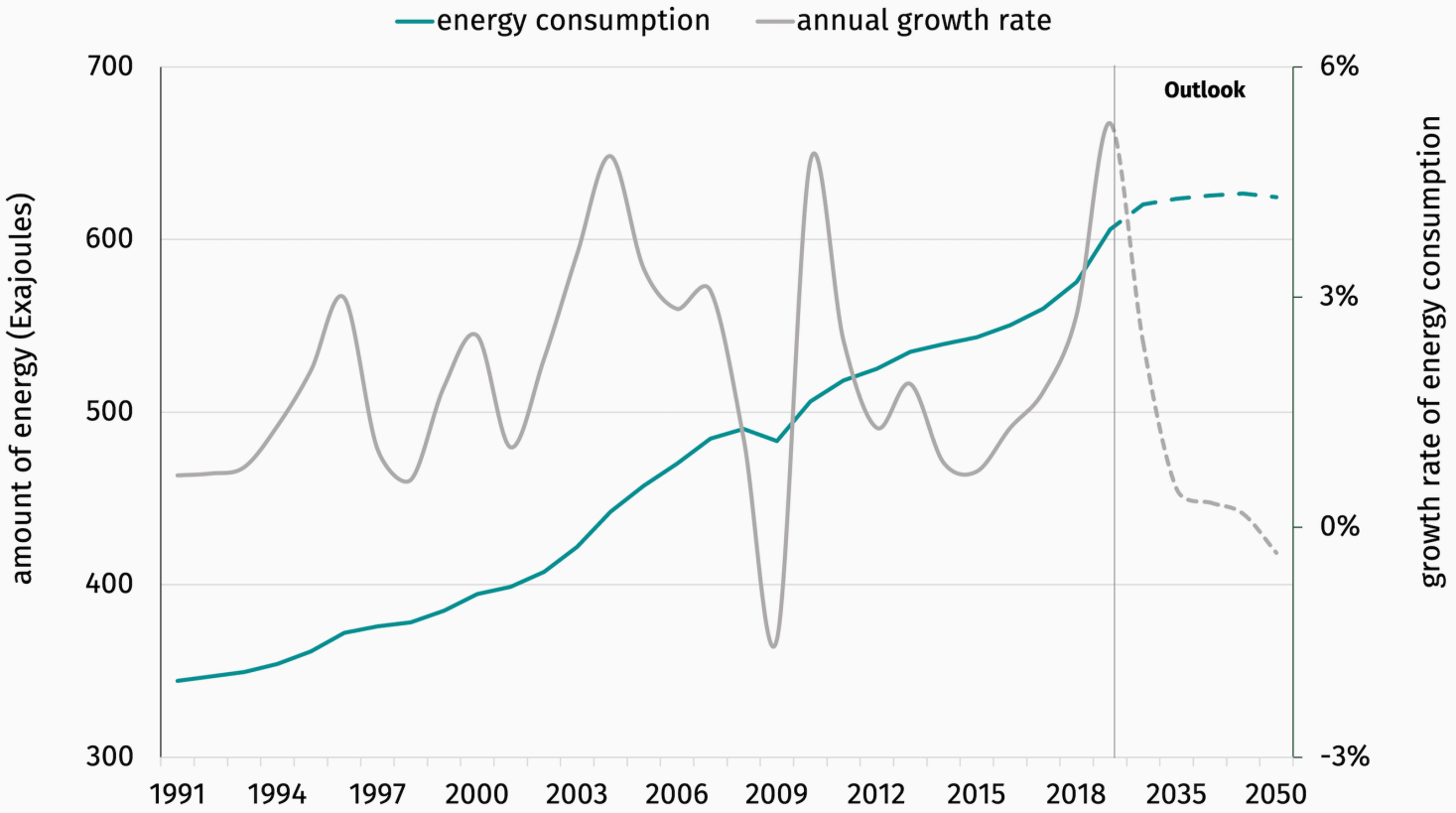


Figure 1: Global primary energy consumption. Source: BP Energy Outlook 2020

Environmental disaster

The flow of emissions related to energy consumption keeps us heading towards an environmental disaster

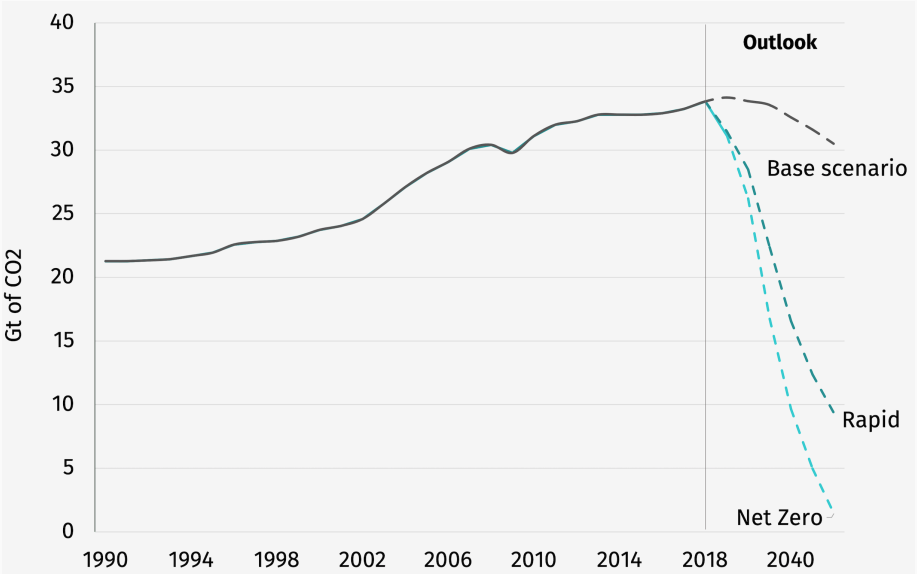


Figure 2: CO2 emissions scenarios
Source: BP Energy Outlook 2020

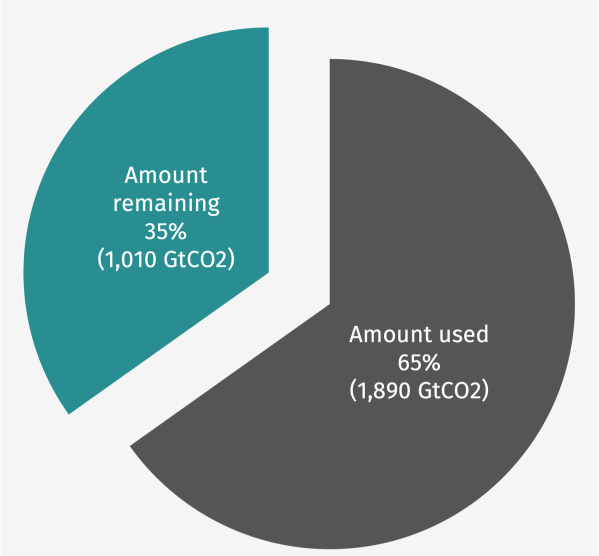


Figure 3: 2°C total carbon budget.
Source: IPCC-2018

Changes in behaviours and preferences are key to mitigating the problem

Warm-glow

Warm-glow giving: Individuals contribute to public goods for the simple joy of giving [Andreoni, 1990]

- *Payoff* received for taking actions socially believed as virtuous [Feddersen and Sandroni, 2009]
- People take action for the environment:
  - Purchase fair-trade goods
  - People's willingness to pay higher prices for cleaner energy
- Paris Agreement goal requires warm-glow giving to be achieved

Outline

1. Brief literature review
2. The Model
3. Optimal Policy
4. Numerical simulations
5. Conclusions and discussion

1. Brief literature review

1. Brief literature review

- [Nordhaus, 1991] proposes the first Integrated Assessment Models (IAM) to explain and measure the economic impacts of climate change over welfare
- [Nordhaus, 1993] extends the Ramsey Model to include climate constraints and estimate the social cost of carbon
- [Popp, 2004] and [Edenhofer et al., 2005] introduce endogenous technical change in an IAM
- [Acemoglu et al., 2012], [Acemoglu et al., 2014], and [Hémous, 2016] link directed technical change theory with environmental degradation
- Willingness to pay for sustainable items: [Perfecto et al., 2005], [Arnot et al., 2006], [Carlson, 2009],[Murakami et al., 2015],

2. The Model

2. The Model: General structure

- An extension of a growth model with directed technical change and environmental constraint developed by [Acemoglu et al., 2012]
- Preferences reflect the warm-glow received when individuals choose to consume the clean energy option
- Assuming the whole world as a single economy which produces a consumption good, using clean, c_{ct}, and dirty, c_{dt}, energy
- Two opposing forces: market size and price
- Initially, dirty sector is more technologically advanced than clean

2.1 Preferences

Workers, scientists and entrepreneurs are grouped into a continuum of households, each one with homothetic preferences

$$u_t = \sum_{t=0}^{\infty} \beta^t \frac{(C_t E_t)^{1-\theta}}{1-\theta} \tag{1}$$

- $u(C_t, E_t)$ increasing in all variables and holds standard properties
- $\theta > 0$ is the intertemporal elasticity of substitution

2.1 Preferences

CES aggregate consumption is defined by:

$$C_t = \left((1+\phi)c_{ct}^{\frac{\epsilon-1}{\epsilon}} + c_{dt}^{\frac{\epsilon-1}{\epsilon}}\right)^{\frac{\epsilon}{\epsilon-1}} \tag{2}$$

- $\epsilon > 0$ is the elasticity of substitution between two energy sources
- Warm-glow is modelled here through the parameter ϕ, $\phi \geqslant 0$
- Budget constraint:

$$p_{ct}c_{ct} + p_{dt}c_{dt} = w_t + \pi_{ct} + \pi_{dt} \tag{3}$$

- Relative prices:

$$\frac{p_{ct}}{p_{dt}} = (1+\phi)\left(\frac{c_{dt}}{c_{ct}}\right)^{\frac{1}{\epsilon}} \tag{4}$$

2.2 The environment

Quality of the environment, E_t, is defined:

$$E_{t+1} = \max\{ \min \{\bar{E}, -\xi c_{dt} + (1+\delta)E_t\}, 0\} \tag{5}$$

- $E_t \in [0 ; \bar{E}]$ with $E_t < \infty$
- ξ is the environmental degradation rate and δ is the regeneration rate.
- Environmental disaster: $E_t = 0$

2.3 Production side

1. Consumption good producer (Competitive market)

c_{jt} is produced by combining a continuum of sector-specific machines:

$$c_{jt} = \Big(\int_0^1 \left(A_{jit} x_{jit}\right)^{\alpha} di \Big)^{\frac{1}{\alpha}} \quad j \in (d, c) \tag{6}$$

- $\alpha \in (0, 1)$ is the capital intensity (machines) degree.
- A_{jit} is the productivity of the machine i and x_{jit} the quantity of that machine (full depreciation)

2. Entrepreneurs

Machines in sector *j* are supplied by monopolistically competitive firms which produces one unit of output per unit of labour.

2.3 Production side

The solution of the energy generators and intermediate producers problems result in:

- Demand for intermediate goods $j \in \{c, d\}$:

$$x_{jit} = \left(\alpha p_{jt}\right)^{\frac{1}{1-\alpha}} c_{jt} A_{jit}^{\frac{\alpha}{1-\alpha}} \tag{7}$$

- Relative price of clean consumption:

$$\frac{p_{ct}}{p_{dt}} = \left(\frac{A_{dt}}{A_{ct}}\right)^{\frac{1-\alpha}{\alpha}} \quad \Longrightarrow \quad A_{jt} = \left(\int_0^1 A_{jit}^{\frac{\alpha}{1-\alpha}} di\right) \tag{8}$$

2.4 Innovation possibilities frontier

Innovation drives growth by improving the quality A_{jt}, $j \in \{c, d\}$

Process of innovation:

- Scientists decide the sector to direct their research to guarantee $s_{ct} + s_{dt} = 1$.
- In each sector, scientists are randomly allocated to one of the intermediate inputs in the sector;
- η_j is the probability of being successful on improving the quality of x_{jit} and γ the rate of increasing quality:

$$A_{jt} = \begin{cases} (1+\gamma)A_{jt-1} & \text{with probability } \eta_j \\ A_{jt-1} & \text{with probability } 1-\eta_j \end{cases} \implies A_{jt} = (1+\gamma\eta_j s_{jt})A_{jt-1} \quad (9)$$

Successful scientists $\implies$ 1-period patent $\implies$ entrepreneur

2.4 Equilibrium

Considering that the expected return to entrepreneurial activities in each sector is given by:

$$\Pi_{jt} = \eta_j \frac{1-\alpha}{\alpha} c_{jt} A_{jt}^{\frac{\alpha-1}{\alpha}} \tag{10}$$

A scientist takes her research decisions based on clean relative return:

$$\frac{\Pi_{ct}}{\Pi_{dt}} = (1+\phi)^{\epsilon} \underbrace{\frac{\eta_c}{\eta_d}\left(\frac{(1+\gamma\eta_c s_{ct})}{(1+\gamma\eta_d(1-s_{ct}))}\right)^{\frac{(1-\alpha)\epsilon-1}{\alpha}}}_{=\frac{1}{\Gamma(s_{ct})}} \underbrace{\left(\frac{A_{ct-1}}{A_{dt-1}}\right)^{\frac{-\varphi}{\alpha}}}_{\frac{1}{a_{t-1}}} \tag{11}$$

Where $\varphi = (1-\alpha)(1-\epsilon)$

- Two possible corner solutions under substitutability between both inputs
- Balance growth path achieved only under the complementarity case (interior solution)

2.4 Corner solutions

When clean and dirty inputs are gross substitutes, economy assigns:

- All scientists to the clean sector if

$$a_t^{\frac{\varphi}{\alpha}} > (1+\phi)^{-\epsilon} \quad \Gamma(s_{ct} = 1)$$

- All scientists to the dirty sector if

$$a^{\frac{\varphi}{\alpha}} < (1+\phi)_t^{-\epsilon} \quad \Gamma(s_{ct} = 0)$$

If one of these conditions holds at the initial time, it will hold forever

2.4 Interior solution

Scientists are indifferent between researching in any sectors if and only if

$$a_t = \left(\hat{\eta}(1+\phi)^{\epsilon}\right)^{\frac{\alpha}{(1-\alpha)\epsilon-1}} a_{t-1}^{-\frac{\alpha}{(1-\alpha)\epsilon-1}} \tag{12}$$

The dynamics of a_t has a unique stationary interior solution:

$$a^* = \left((1+\phi)^{\epsilon}\hat{\eta}\right)^{\frac{-\alpha}{\varphi}} \tag{13}$$

- Warm-glow will not solve the un-sustainability problem, but by reducing a_t the economy will survive longer before reaching the point of no return.

3. Optimal Policy

3.1 Central planner problem

$$Max \quad \sum_{t=0}^{\infty} \beta^t \frac{(C_t E_t)^{1-\theta}}{1-\theta} \tag{14}$$

Subject to

$$(1) \quad C_t = \left((1+\phi) c_{ct}^{\frac{\epsilon-1}{\epsilon}} + c_{dt}^{\frac{\epsilon-1}{\epsilon}} \right)^{\frac{\epsilon}{\epsilon-1}}$$

$$(2) \quad c_{ct} = \left(\int_0^1 (A_{cit} x_{cit})^{\alpha} di \right)^{\frac{1}{\alpha}} \quad \text{and} \quad (3) \quad c_{dt} = \left(\int_0^1 (A_{dit} x_{dit})^{\alpha} di \right)^{\frac{1}{\alpha}}$$

$$(4) \quad A_{ct} = (1+\gamma\eta_c s_{ct}) A_{ct-1} \quad \text{and} \quad (5) \quad A_{dt} = (1+\gamma\eta_d s_{dt}) A_{dt-1}$$

$$(6) \quad E_t = max\Big\{ min\{\bar{E}, -\xi c_{dt-1} + (1+\delta) E_{t-1}\}, 0 \Big\}$$

$$(7) \quad \int_0^1 x_{cit} di + \int_0^1 x_{dit} di = 1 \quad \text{and} \quad (8) \quad s_{ct} + s_{dt} = 1$$

3.2 Central planner solution

Shadow value of input j relative to shadow value of consumption: $\hat{p}_{jt} = \frac{\lambda_{jt}}{\lambda_{1t}}$

$$\hat{p}_{ct} = (1+\phi)\left(\frac{C_t}{c_{ct}}\right)^{\frac{1}{\epsilon}} \tag{15}$$

The CP introduces a different wedge to represent the cost of environmental degradation (Carbon Tax)

$$(1+\tau_t)\hat{p}_{dt} = \left(\frac{C_t}{c_{dt}}\right)^{\frac{1}{\epsilon}} \quad \Longrightarrow \quad \tau_t = \frac{\lambda_{6t+1}\xi}{\lambda_{1t}\hat{p}_{dt}} \tag{16}$$

Relative shadow value

$$\frac{\hat{p}_{ct}}{\hat{p}_{dt}} = (1+\phi)(1+\tau_t)\left(\frac{c_{dt}}{c_{ct}}\right)^{\frac{1}{\epsilon}} \tag{17}$$

3.2 Central planner solution

CP guarantees more intensive use of machines and zero profits in producing machines:

$$x_{cit} = \hat{p}_{ct}^{\frac{1}{1-\alpha}} c_{ct} A_{cit}^{\frac{\alpha}{1-\alpha}} \quad \text{and} \quad x_{dit} = \hat{p}_{dt}^{\frac{1}{1-\alpha}} c_{dt} A_{dit}^{\frac{\alpha}{1-\alpha}}$$

As in the DC case, it is possible express relative prices and technology as:

$$\frac{\hat{p}_{ct}}{\hat{p}_{dt}} = \left(\frac{A_{dt}}{A_{ct}}\right)^{\frac{1-\alpha}{\alpha}} \quad \text{and} \quad A_{jt} = \left(\int_0^1 A_{jit}^{\frac{\alpha}{1-\alpha}} di\right) \quad j \in (c, d) \tag{18}$$

3.2 Central planner solution

Socially optimal allocation of scientists:

$$\frac{\eta_c(1+\gamma\eta_d(1-s_{ct}))}{\eta_d(1+\gamma\eta_c s_{ct})} \underbrace{\frac{\sum_{v=0}^{\infty}\beta^{t+v}C_{t+v}^{-\theta}E_{t+v}^{1-\theta}\left[\hat{p}_{ct+v}^{\frac{1}{1-\alpha}}c_{ct+v}A_{ct+v}\right]}{\sum_{v=0}^{\infty}\beta^{t+v}C_{t+v}^{-\theta}E_{t+v}^{1-\theta}\left[\hat{p}_{dt+v}^{\frac{1}{1-\alpha}}c_{dt+v}A_{dt+v}\right]}}_{\textit{New Term}} \tag{19}$$

The implementations of the optimal policy would imply:

$$\frac{\Pi_{ct}}{\Pi_{dt}} = (1+\phi)^{\epsilon}(1+\tau_t)^{\epsilon}(1+q_t)\underbrace{\frac{\eta_c}{\eta_d}\left(\frac{1+\gamma\eta_c s_{ct}}{1+\gamma\eta_d(1-s_{ct})}\right)^{\frac{(1-\alpha)\epsilon-1}{\alpha}}}_{=\frac{1}{\Gamma(s_{ct})}} a_{t-1}^{\frac{\varphi}{\alpha}} \tag{20}$$

- CP chooses $s_{ct} > s_{dt}$ due to greater **net present value** of clean energy
- **Pigovian-tax** on the consumption and production of dirty input
- Clean **R&D subsidy** to capture the standing-on-shoulder effect of research

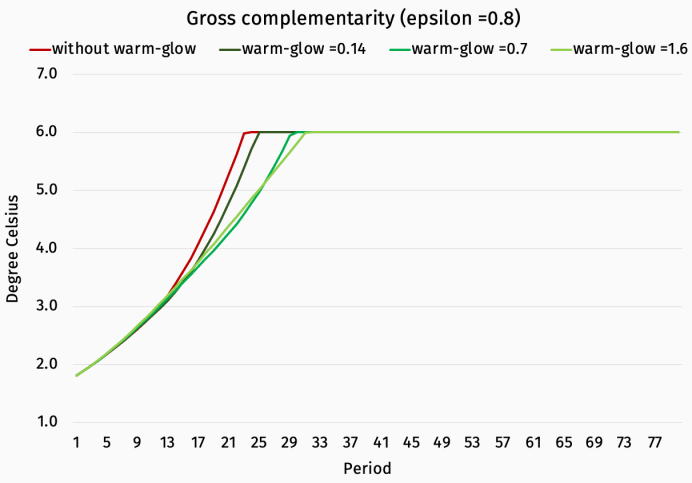
4. Numerical simulations

4.1 Calibration values

- Calibration mainly follows [Acemoglu et al., 2012]
- Each period corresponds to five years (model calibrated over 400 years)
- Share of machines is set $\alpha = 1/3$ and the probability of successful innovation per year is $\eta_j = 0.002 \in$ (c,d).
- Initial levels for both technologies match the implied values of world renewable and fossil energy consumption in 2016.
- 2 scenarios for ϵ : (i) assuming complementary, $\epsilon = 0.8$; (ii) assuming substitutability, $\epsilon = 5$.
- Warm-glow parameter calibrated [Ma et al., 2015] under 3 scenarios: 14%, 70% and 1.6 times the average value of electricity from non-renewable sources.
- 2 scenarios for discount rate: $\rho = 0,001$ (Nordhaus's research) and $\rho = 0.015$ (Sterm's research).
- Environmental disaster occurs when temperature increase exceeds 6°

4.2 Decentralised Equilibrium

High warm-glow + substitutability = environmental disaster delayed but not avoided



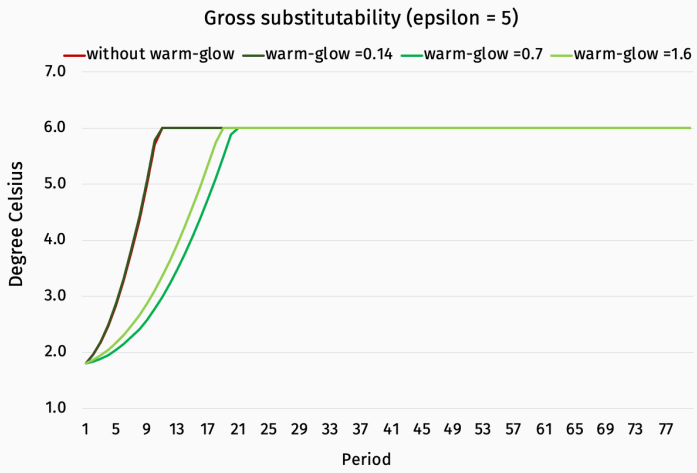


Figure 4: Decentralised equilibrium: Temperature increase (degree Celsius)

4.2 Decentralised Equilibrium

High warm-glow + complementary $\Longrightarrow$ $\uparrow$ scientists to clean energy sector

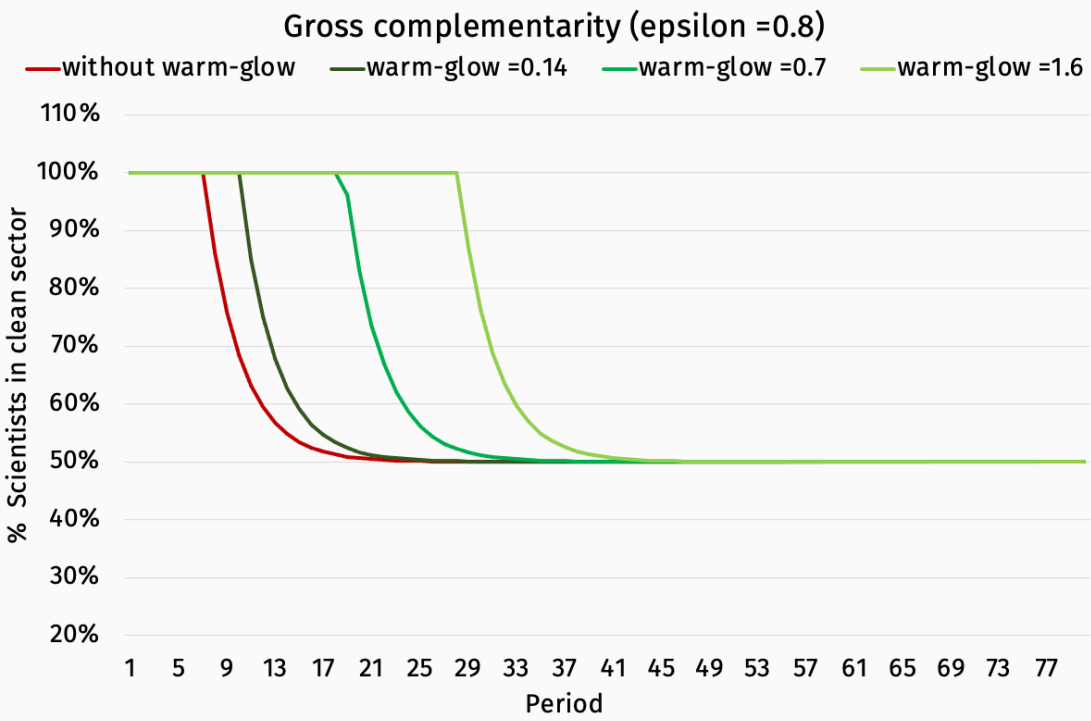
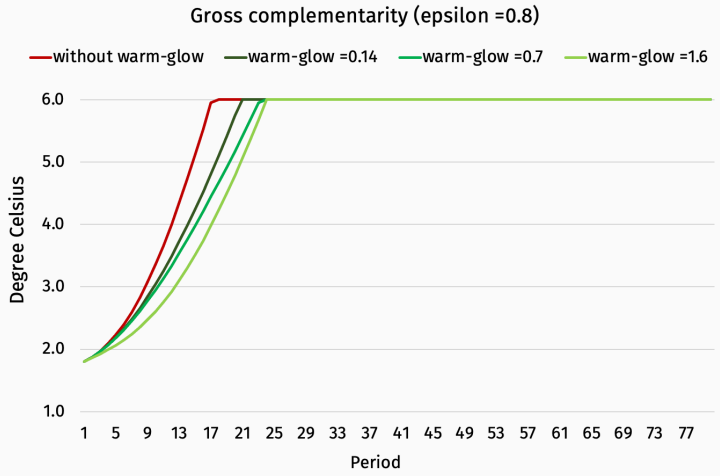


Figure 5: Decentralised equilibrium: Scientists allocation in clean sector

Assuming substitutability any scientist is allocated to clean sector since the beginning

4.3 Optimal Policy

Only substitutability can avoid an environmental disaster and warm-glow makes that process quicker



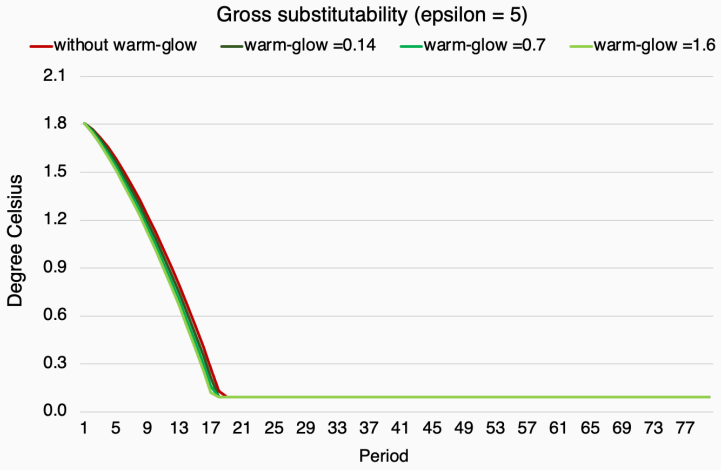
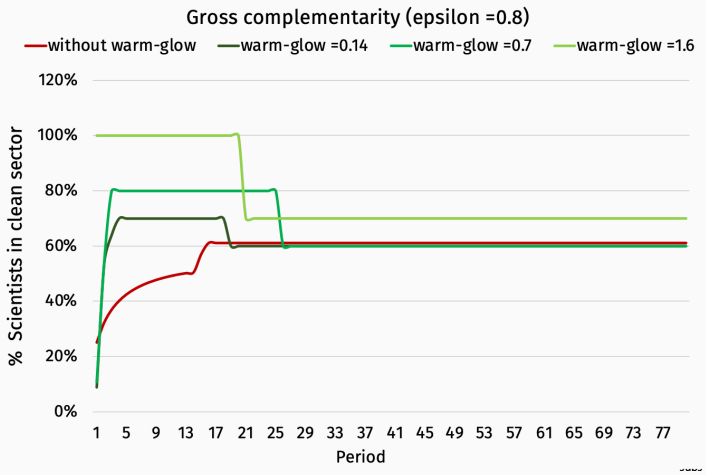


Figure 6: Optimal policy: Temperature increase vs pre-industrial era

Warm-glow increases clean scientists allocation



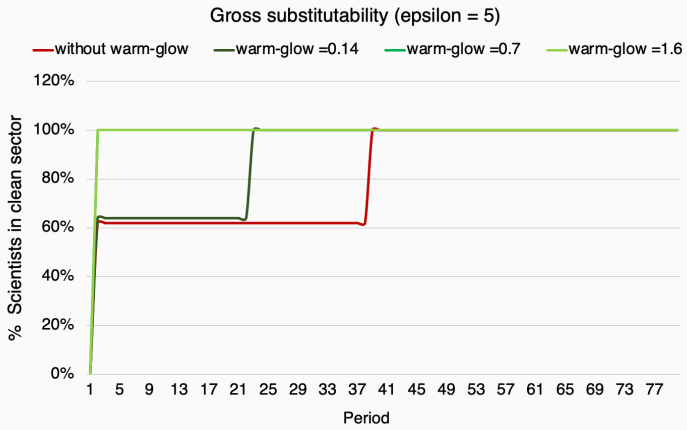
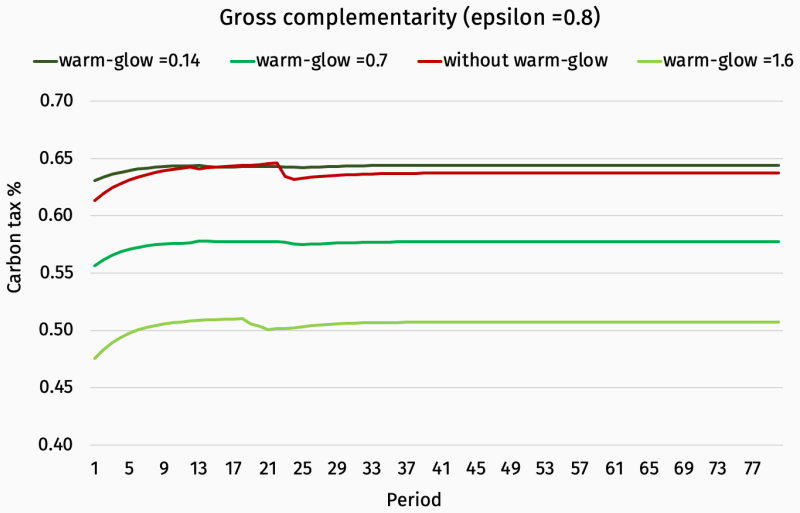


Figure 7: Optimal policy: Scientist allocation in clean sector

4.3 Optimal Policy

Gross substitutability + high warm-glow $\Longrightarrow$ low carbon tax



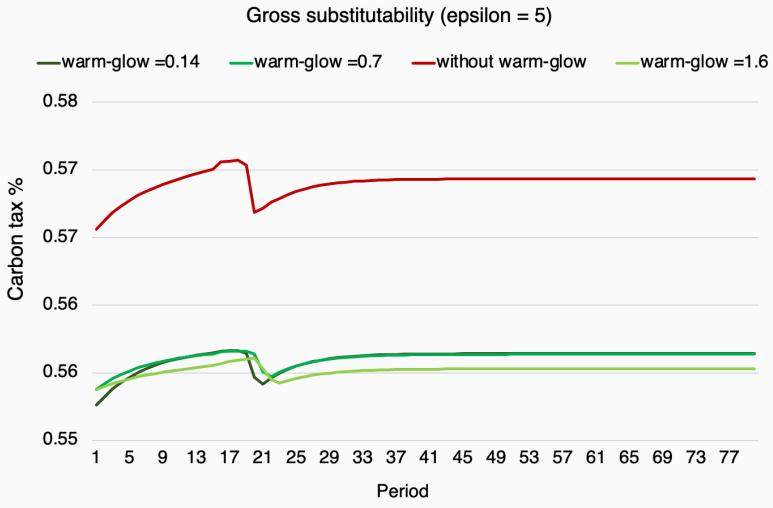
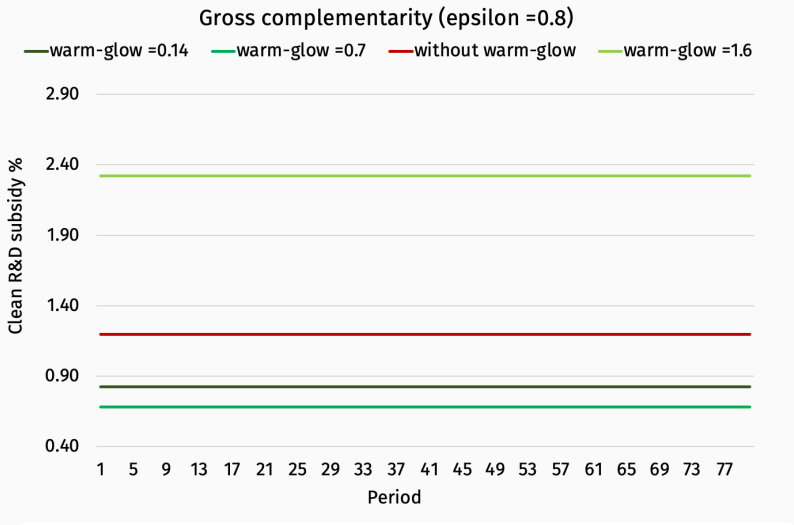


Figure 8: Carbon tax

4.3 Optimal Policy

Gross substitutability + high warm-glow $\Longrightarrow$ low clean R&D subsidy



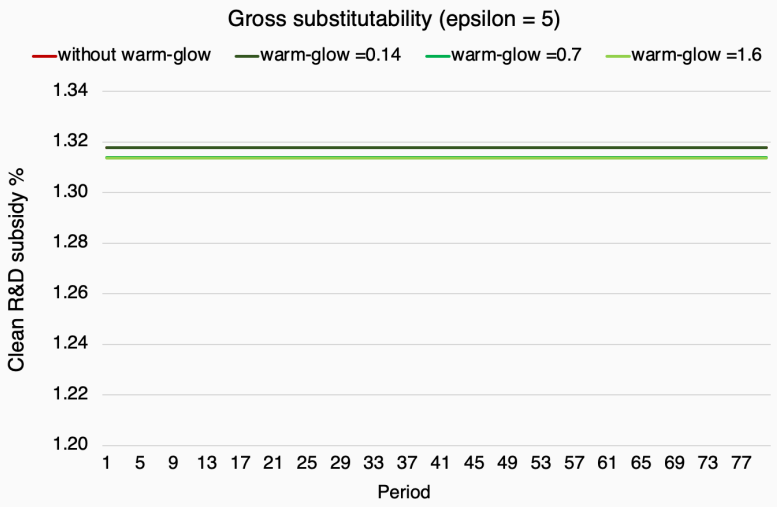


Figure 9: Clean R&D subsidy

5. Conclusions and discussion

5. Conclusions and discussion

- Ever growing energy consumption without sustainable energy will cause an environmental disaster .
- The introduction of warm-glow giving reflects the increasing public concern for voluntarily mitigating climate change
- Substitutability level between renewable and non-renewable energy is the main factor in the impact of warm-glow on the environment
- Decentralised equilibrium and substitutability with warm-glow will delay but not avoid an environmental disaster
- Optimal policy avoids an environmental disaster using carbon taxes and clean R&D subsidies, and warm-glow reduces the distortion .
- There is a warm-glow threshold

Thank You

Muchas Gracias!

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