A new damage function for the Nested-Inequalities Climate Economy (NICE) Model

Based on Bilal & Känzig (2024) estimations

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September 30, 2024

Plan

Climate Change and Economic Impacts

- Global temperature increase of 1.09°C from 1850-1900 to 2011-2020
- Macroeconomic **damages from climate change are 6 times higher than previously estimated** (Kotz, Levermann, Wenz (2024) and Bilal & Känzig (2024))

⇒ Need for better representations of climate damages in economic models

Limitations of traditional Cost-Benefits Analysis Integrated Assessment Models (CBA-IAMs)

- **Market damages** are quadratic with respect to **temperature increase**:

$$\Omega(\Delta T) = \beta_1 \Delta T + \beta_2 \Delta T^2$$

  $\rightarrow$ **Level effect**: immediate impact on GDP value
  $\rightarrow$ **Deterministic approach**

NICE Model Overview

- Builds on RICE model
- 179 countries (i) & within-country inequalities (*via* consumption quantiles (q))
- Social Welfare Function:

$$W(cpc(t,i,q)) = \sum_{t=2020}^{2300} \frac{1}{(1+\rho)^t} \sum_{i=1}^{179} \frac{L(t,i)}{n_{quantiles}} \sum_{q=1}^{10} \frac{cpc(t,i,q)^{1-\eta}}{1-\eta}$$

$\Rightarrow$ Optimal mitigation depends on:

- the rate of pure preference ρ (see Nordhaus v. Stern debate)
- the inequality aversion parameter η (see Budolfson et al. (2017))
- the demographic evolution $L(t,i)$ (exogenous, given by the SSP2-4.5 scenario)
- the **consumption per capita** $cpc(t,i,q)$, **directly affected by damages on GDP**

NICE Main Equations

Neoclassical Growth Model (Ramsey-Cass-Koopmans):

$$Y_{\text{gross}}(t,i) = A(t,i) \cdot K(t,i)^{\alpha} \cdot L(t,i)^{1-\alpha}$$

$$\mu(t,i) = \left(\frac{\text{Tax}(t,i)}{\textit{Backstop price}(t)}\right)^{\frac{1}{\theta_2 - 1}}$$

$$E_{\text{gtco2}}(t,i) = Y_{\text{gross}}(t,i) \cdot \sigma(t,i) \cdot (1 - \mu(t,i))$$

$$\Delta T_{\text{local}}(t,i) = \beta_{\text{temp}}(i) \cdot \Delta T_{\text{global}}(t) = T(t,i) - T_0(i)$$

$$\Omega_{KW}(\Delta T_{\text{local}}(t,i)) = \beta_{1,KW}(i) \cdot \Delta T_{\text{local}}(t,i) + \beta_{2,KW} \cdot \Delta T^2_{\text{local}}(t,i)$$

$$\Lambda(t,i) = \theta_1(t,i) \cdot \mu(t,i)^{\theta_2}$$

$$\delta_{\text{NICE}}(\Omega(\Delta T)) = \frac{1}{1 + \Omega(\Delta T)}$$

$$Y_{\text{net}}(t,i) = \delta_{\text{NICE}}(\Omega_{KW}(\Delta T_{\text{local}})) \cdot (1 - \Lambda) \cdot Y_{\text{gross}}$$

$$CPC(t,i) = \frac{1 - s(t,i)}{L(t,i)} \cdot Y_{\text{net}}(t,i)$$

Exogenous | *Engodenous*

Carbon taxes

Exponential growth carbon tax trajectory:
$Tax(t) = Tax(0)(1 + g_{Tax})^{t-2020}$

1. Global uniform carbon tax:
    - From a range of $Tax_G(0)$ and g_{Tax_G}, choose the path that satisfy:
        - $\Delta T_{\text{global}}(t) \leq 2$°C for $t \in [2020, 2120]$
        - $E_{\text{gtco2}}(t, i) = 0$ for $t \geq 2050$ and $i \in$ EU countries.
        - $\Rightarrow$ max $W(CPC)$ for $t \in [2020, 2100]$, $\rho = 0.015$, $\eta = 1.5$
    - Result: $\forall i$, $Tax_G(t, i) = Tax_G(t)$
2. Differentiated:

Carbon taxes

1. Global uniform carbon tax:
   - Result: $\forall i$, $Tax_G(t,i) = Tax_G(t)$
2. Differentiated:
   - Select a reference country i_{ref} (*e.g.* USA). The country-specific tax is:

$$Tax_D(t,i) = Tax_D(t,i_{ref}) \cdot \frac{(1-s(t,i_{ref}))}{(1-s(t,i))} \left(\frac{Y_{gross}(t,i) \cdot L^{-1}(t,i)}{Y_{gross}(t,i_{ref}) \cdot L^{-1} L(t,i_{ref})} \right)^{\eta}$$

   - From a range of $Tax_D(0)$ and g_{Tax_D}, choose the path that satisfy:
     - $\min \sum_t \left[\sum_i \left(E_{\mathrm{gtco2}_D}(t,i) - E_{\mathrm{gtco2}_G}(t,i) \right)^2 \right]$

Revenue Recycling, Distribution Across Deciles, Consumption

$Revenue_{tax}(t,i) = E_{\text{gtco2}}(t,i) \cdot Tax(t,i)$

- Deciles: estimated from country income Gini projections in the SSP2-4.5 scenario
- Distribution of damages, mitigation costs and carbon tax burdens across deciles:
  - CO_2-income elasticity $\omega = 3.22 - 0.2 \ln(\frac{Y(t,i)}{L(t,i)})$
  - Damage elasticity $\xi = 0.85 < 1$: the poor bear a relatively higher share of the climate damages
- Consumption per quantile per capita:

$$cpc(t,i,q) = \text{Gross consumption} - \text{Damages} - \text{Abatement} \\ - \ (Tax - Refund)$$

$$\begin{cases} Tax \propto Revenue_{tax}(t,i) \\ Refund \propto share_{recycle}(i,q) \cdot Dividend_{tax}(t,i) \end{cases}$$

Revenue Recycling, Distribution Across Deciles, Consumption

- Consumption per quantile per capita:

$$cpc(t, i, q) = \text{Gross consumption} - \text{Damages} - \text{Abatement} \\ - \ (Tax - Refund)$$

- No recycling: $Tax = Refund$
- Recycling:
  - Within country: equal per capita refund, $Dividend_{tax}(t, i) = \frac{Revenue_{tax}(t,i)}{L(t,i)}$
  - Global per capita: $share_{recycle} = 100\%$, $Dividend_{tax}(t) = \sum_i \frac{Revenue_{tax}(t,i)}{L(t,i)}$
  - Loss and Damages (L&D) fund: $share_{recycle}(LLMICs, q) = 5\%$

Focus on Damages

- $cpc(t, i, q) =$ Gross consumption − **Damages** − Abatement − $(Tax - Refund)$
- $Y_{\text{net}}(t, i) = \delta_{\text{NICE}}(\boldsymbol{\Omega_{KW}}(\Delta T_{\text{local}})) \cdot (1 - \Lambda) \cdot Y_{\text{gross}}$
- Under a certainty-equivalent approach, market damages are quadratic with respect to temperature increase:
  1. $\Omega_{KW}(\Delta T_{\text{local}}(t, i)) = \beta_{1,KW}\boldsymbol{(i)} \cdot \Delta T_{\text{local}}(t, i) + \beta_{2,KW} \cdot \Delta T^2_{\text{local}}(t, i)$
  2. $\delta_{\text{NICE}}(\boldsymbol{\Omega_{KW}}(\Delta T)) = \frac{1}{1+\Omega(\Delta T)}$
  3. **Level effect → "Growth" effect**: impact on GDP growth rate

Coefficients Update

$$\beta_1(i) = \kappa + 2 \cdot \beta_2 \cdot T_0(i)$$

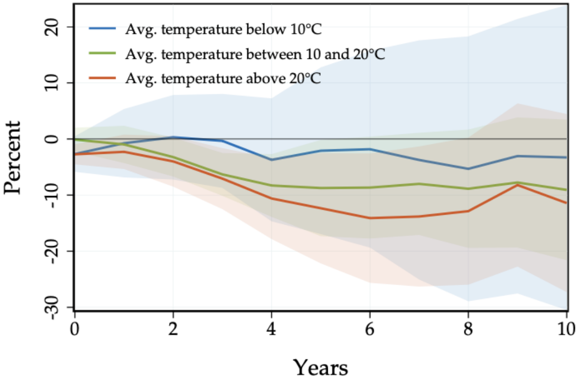


Figure: Impulse responses of real GDP per capita to a global temperature shock, from Bilal & Känzig (2024)

$\{\kappa_{KW} = -11.28 \cdot 10^{-3}; \beta_{2,KW} = 9.2 \cdot 10^{-4}\}$
$\rightarrow \{\kappa_{BK} = -57.9 \cdot 10^{-3}; \beta_{2,BK} = 43.478 \cdot 10^{-4}\}$

Damage Function's Shape Update

M. Young-Brun *et al.* (2024): $1 - \exp^{-\Omega(\Delta T)} \approx \Omega(\Delta T)$ (1-st order Taylor expansion around 0).

1. NICE: $\delta_{\text{NICE}}(\Omega(\Delta T)) = \frac{1}{1+\Omega(\Delta T)}$
2. DICE 2023 ("MYB_approx") : $\delta_{\text{DICE}}(\Omega(\Delta T)) = 1 - \Omega(\Delta T)$
3. Exact form of Young-Brun's assumption in a DICE 2023 shape: $\delta_{\text{MYB}}(\Omega(\Delta T)) = \exp^{-\Omega(\Delta T)}$
4. F. Murtin's suggestion: $\delta_{\tanh}(\Omega(\Delta T)) = \tanh(0.5 \cdot \Omega(\Delta T))$

Towards a Growth Effect

Bilal & Känzig (2024) : use of lags to capture the extent of impact persistence over 10 years for temperature effects.

How to take a lag into account in the damage function?

1. To account for temperature increase between 1850 and $\{2020 + timelag\}$, we use $\delta_{\text{DICE}}(\Omega_{KW}(\Delta T_{local}(t,i)))$
2. Then, we set:
   - $\beta_1^{GE}(t,i) = \kappa + 2 \cdot \beta_2 \cdot \big(T_0(i) + \Delta T_{local}(t - timelag, i)\big)$
   - $$\begin{aligned}\Delta_T^{GE}(t,i) &= \Delta T_{local}(t,i) - \Delta T_{local}(t - timelag, i)\\ &= T(t,i) - T(t - timelag, i)\end{aligned}$$
   - $\Omega^{GE}(\Delta T^{GE}) = \beta_1^{GE}(t,i) \cdot \Delta T^{GE}(t,i) + \beta_2(i) \cdot (\Delta T^{GE}(t,i))^2$
3. $\delta^{GE}(\Omega^{GE}(\Delta T^{GE}(t,i))) = \prod_{\tau=2020+timelag-1}^{t} \delta(\Omega^{GE}(\Delta T^{GE}(\tau,i)))$

Towards a Growth Effect

How to take a lag into account in the damage function?

- $\delta^{GE}(\Omega^{GE}(\Delta T^{GE}(t,i))) = \prod_{\tau=2020+timelag-1}^{t} \delta(\Omega^{GE}(\Delta T^{GE}(\tau,i)))$

- Before:

$$\frac{Y_{net}(t+1,i)}{Y_{net}(t,i)} = \frac{\delta_{NICE}(\Omega(\Delta T(t+1,i)))}{\delta_{NICE}(\Omega(\Delta T(t,i)))} \cdot \left(\frac{Y_{gross}(t+1,i)}{Y_{gross}(t,i)}\right) \cdot \left(\frac{1-\Lambda(t+1,i)}{1-\Lambda(t,i)}\right)$$

$$= \left(\frac{1+\beta_1(i)\Delta T(t,i)+\beta_2(i)\Delta T^2(t,i)}{1+\beta_1(i)\Delta T(t+1,i)+\beta_2(i)\Delta T^2(t+1,i)}\right) \cdot \left(\frac{Y_{gross}(t+1,i)}{Y_{gross}(t,i)}\right) \cdot \left(\frac{1-\Lambda(t+1,i)}{1-\Lambda(t,i)}\right)$$

- with Growth Effect:

$$\frac{Y_{net}(t+1,i)}{Y_{net}(t,i)} = \frac{\prod_{\tau=2020+timelag-1}^{t+1} \delta(\Omega^{GE}(\Delta T^{GE}(\tau,i)))}{\prod_{\tau=2020+timelag-1}^{t} \delta(\Omega^{GE}(\Delta T^{GE}(\tau,i)))} \cdot \left(\frac{Y_{gross}(t+1,i)}{Y_{gross}(t,i)}\right) \cdot \left(\frac{1-\Lambda(t+1,i)}{1-\Lambda(t,i)}\right)$$

$$= \delta(\Omega^{GE}(\Delta T^{GE}(t+1,i))) \cdot \left(\frac{Y_{gross}(t+1,i)}{Y_{gross}(t,i)}\right) \cdot \left(\frac{1-\Lambda(t+1,i)}{1-\Lambda(t,i)}\right)$$

On the Importance of Calibration and function's Shape on Damages...

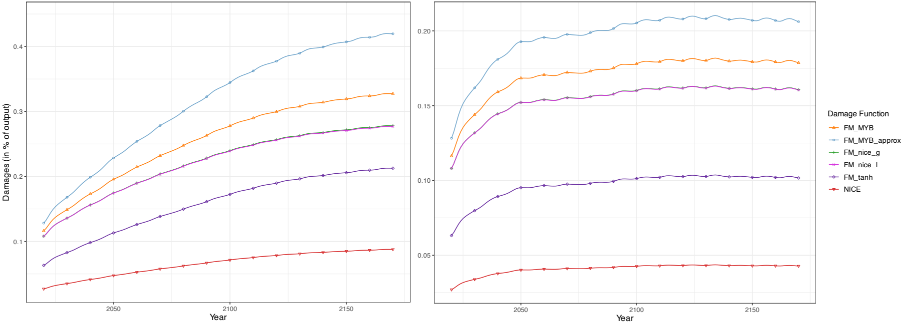
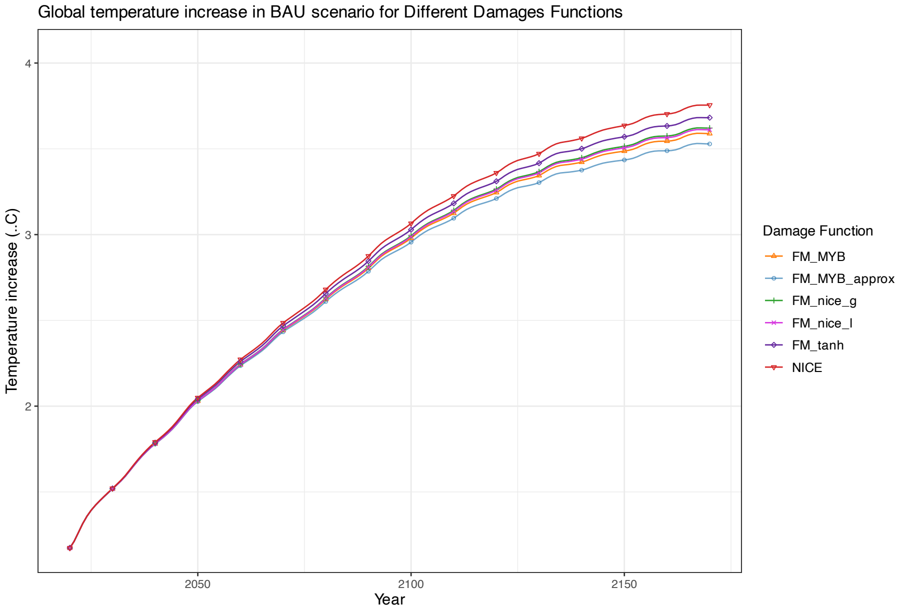


Figure: Average damage-output ratio in BAU scenario (left) and under a 2°C scenario (right) for different damage functions

Barrage & Nordhaus (2024): Damages are estimated to be 4.4% of output by 2100.

...But not on Temperature Trajectories



What about the Growth Effect?

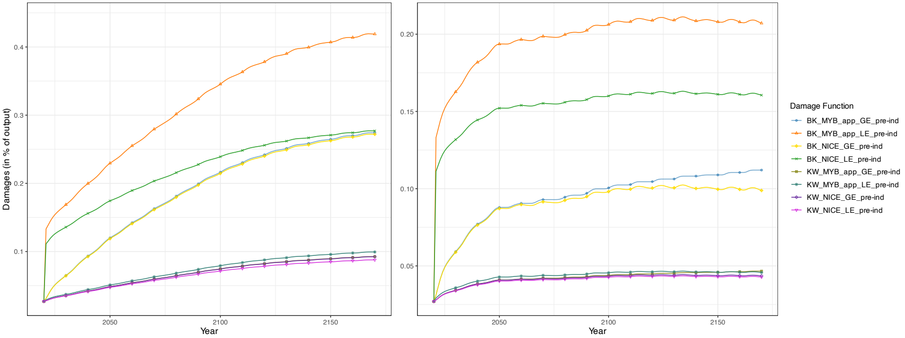


Figure: Average damage-output ratio in BAU scenario (left) and under a 2°C scenario (right) for different damage functions

Burke *et al.* (2015): unmitigated warming is expected to reshape the global economy by reducing average global incomes roughly 23% by 2100

Zoom on $\delta^{GE}_{DICE}(\Omega^{GE}_{BK})$ vs. $\delta_{NICE}(\Omega_{KW})$: Regional Damages

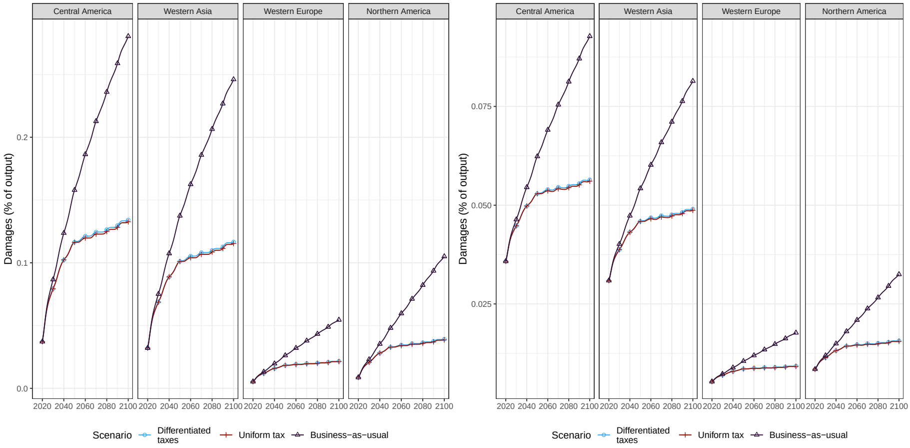


Figure: Regional damage-output ratio with $\delta^{GE}_{DICE}(\Omega^{GE}_{BK})$ (left) and with $\delta_{NICE}(\Omega_{KW})$ (right)

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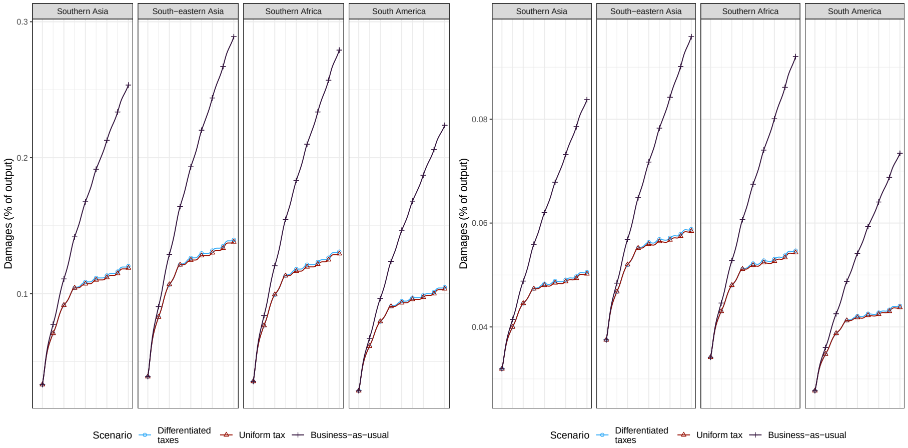

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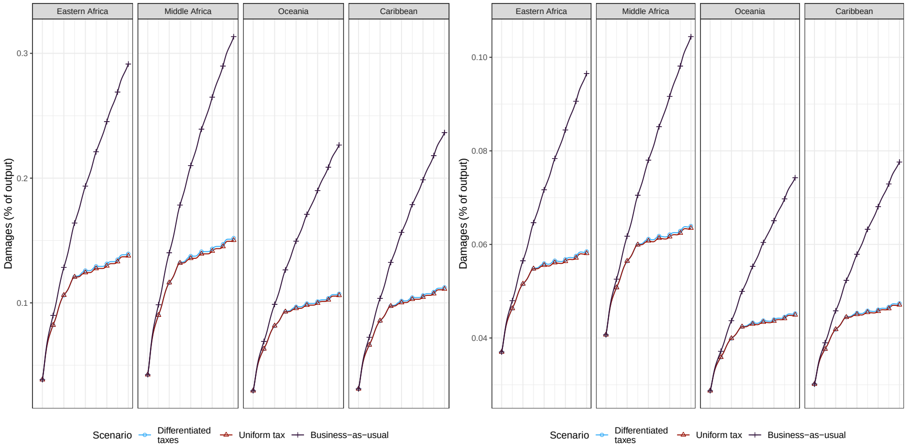

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Zoom on $\delta^{GE}_{DICE}(\Omega^{GE}_{BK})$ vs. $\delta_{NICE}(\Omega_{KW})$: Inequalities

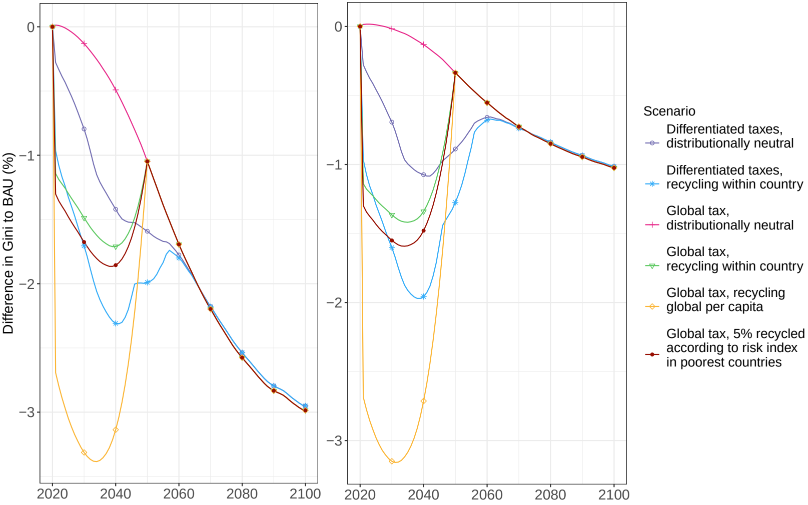
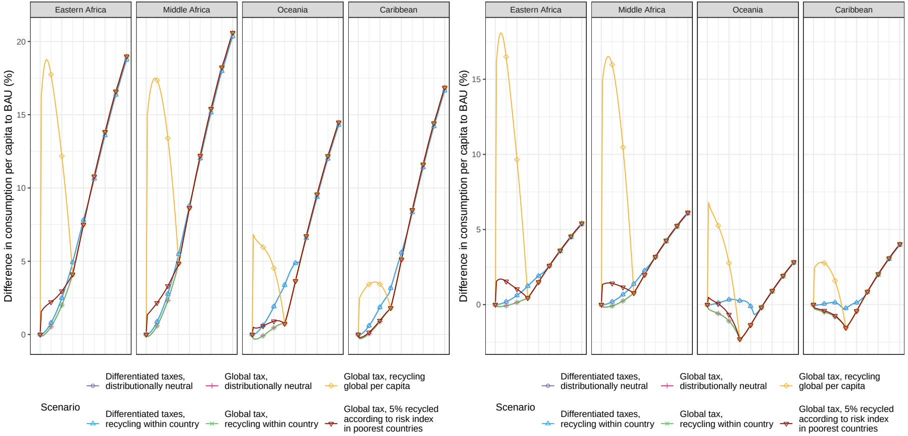


Figure: Change in Gini compared to BAU with $\delta^{GE}_{DICE}(\Omega^{GE}_{BK})$ (left) and with $\delta_{NICE}(\Omega_{KW})$ (right)

Zoom on $\delta^{GE}_{DICE}(\Omega^{GE}_{BK})$ vs. $\delta_{NICE}(\Omega_{KW})$: Regional Consumption



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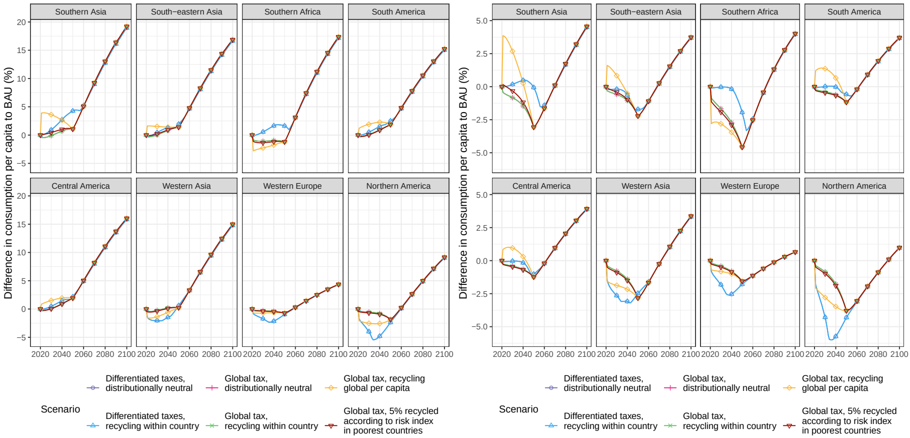
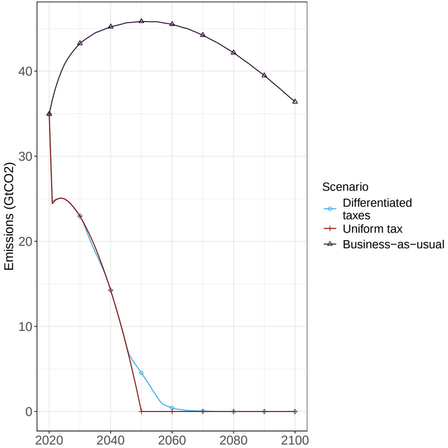


Figure: Regional damage-output ratio with $\delta^{GE}_{DICE}(\Omega^{GE}_{BK})$ (left) and with $\delta_{NICE}(\Omega_{KW})$ (right)

Carbon taxes under net-zero 2050: policy implications



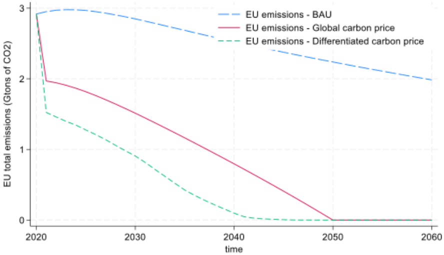


Figure: Global emissions (left) and EU emissions (right) under different taxes scenario

Carbon taxes under net-zero 2050: policy implications

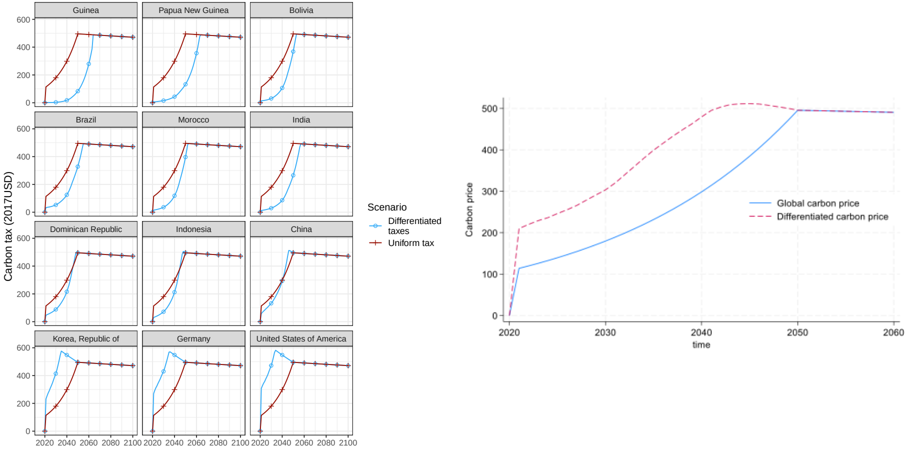


Figure: Carbon tax for various countries (left) and in average for EU countries (right) under different taxes scenario

Barrage & Nordhaus (2024): \$200/tCO_2 in 2050 in a 2 °C scenario

Limits

- Kotz *et al.* (2024): income reduction of 19% within 2050, independent of future emission choices
- Bilal & Känzig (2024): output and consumption reduction over 50% by 2100 back to damages
- Calibration over a single dataset, which may be questioned
- Use of $timelag = 1$ year, but calibration for a 5-year lag
- Issue in 2020 temperature data:
  - underestation of the temperature increase (-3 °C in France, -5 °C in Australia and -6.8 °C in Algeria)
  - over-estimation of the temperature increase (+4 °C in the USA, +5.8 °C in Russia, +7.6 °C in China and +10 °C in Canada)
- Traditional criticism of CBA-IAMs: quadratic damages, no tipping points, no uncertainty, based on past data, existence of a backstop technology, etc.

Take-Home Messages

Do not ontologize results!

- The shape of the normalization function doesn't matter for small damage values
- The transition from the coefficients derived by Kalkuhl and Wenz to those of Bilal and Känzig underlines the importance of precise knowledge of the effects of climate change on the economy
- Damages : $\delta_{DICE}^{GE}(\Omega_{BK}^{GE}) \approx 3 \times \delta_{NICE}(\Omega_{KW})$, coherent regional distribution according to Kotz *et al.* (2024) and Bilal & Känzig (2024)
- Trade-off between cost-efficiency, equity and political feasibility: Differentiated taxes lead to more consumption everywhere but in the three wealthies regions until the net-zero 2050 target

What's next?

- Fix technical issues
- What about per quantile consumption and well-being effects?
- What are the Social Costs of Carbon associated with $\delta_{NICE}(\Omega_{KW})$ and $\delta^{GE}_{DICE}(\Omega^{GE}_{BK})$?