ETH zürich

Pricing carbon in a multi-sector economy with social discounting

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Motivation

- **Carbon neutrality** requires **large-scale transformation**
- Firms need to **substitute away** from ***dirty*** fossil fuels to ***green*** capital use in production
- **Capital accumulation** is linked to capital market participants **private discount rate**
- Problematic in this context is **that capital market participants** might be too **impatient** and invest to little resources in green capital
- **Society** might place a **higher welfare weight** on **future generations** and would prefer more **investments than observed** on the market

- This motivates to use the concept of **differential social discounting**: **private** market participants apply **a higher discount rate** than the **social** planner

With this paper, we…

… ask: **Is a uniform carbon price - as put forward by the economics discipline - really optimal under differential social discounting?**

Differential social discounting: HH apply a different concept of discounting than a planner.

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… ask: **Is a uniform carbon price - as put forward by the economics discipline - really optimal under differential social discounting?**

Differential social discounting: HH apply a different concept of discounting than a planner.

… find a very surprising result: **Uniform Carbon pricing** ✗

Non-Uniform Carbon pricing ✓

… investigate the economic driver behind this result.

Agenda

Literature

Social discounting

Optimal environmental policies under social discounting

- Barrage (2018), von Below (2012), Belfiori (2017), van der Ploeg and Rezai (2019)

Motives for Non-Uniform Carbon Prices

Imperfectly competitive markets (e.g. pre-existing tax distortions):

- Sandmo (1975), Markusen (1975), Hoel (1996), Krutilla (1991), Rauscher (1994)

Social equity concerns over heterogeneous households:

- Bovenberg, Goulder and Gurney (2005), Bento et al. (2009), Rausch et al. (2005), Fullerton and Monti (2013), Landis, Rausch and Kosch (2018), Abrell, Rausch and Schwarz (2018)

The decentralized economy

The decentralized economy: The HH side

- Household maximizes $$U = \sum_{t=0}^{\infty} \frac{1}{(1+\zeta)^t} u(C_t)$$
- s.t. the intertemp. budget constraint $$C_t + \bar{K}_{t+1} \leq w_t \bar{L} + [1 + R_t(1 - \Xi_t)]\bar{K}_t + \Pi_t + \Lambda_t$$
- capital accumulates with $$\sum_{j=1}^{J} \bar{K}_{jt+1} = \sum_{j=1}^{J} (1 - \delta_j)\bar{K}_{jt} + I_t$$
- Optimality requires: $$U_{Ct} = \frac{1}{1+\zeta} U_{Ct+1} \left(1 + R_{t+1}(1 - \Xi_{t+1})\right)$$

The decentralized economy: The Firm side

- Sector j produces with $$Y_{jt} = L_{jt}^{\alpha_j} \left[\beta_{Kj}(H_{Kj}K_{jt})^{\rho_j} + \beta_{Ej}(H_{Ej}E_{jt})^{\rho_j}\right]^{\frac{1-\alpha_j}{\rho_j}}$$
- under perfect competition $$r_{jt} = p_{jt}\frac{\partial Y_{jt}}{\partial K_{jt}},\ w_t = p_{jt}\frac{\partial Y_{jt}}{\partial L_{jt}},\ \tau_{jt} = p_{jt}\frac{\partial Y_{jt}}{\partial E_{jt}},\ p_{jt} = \hat{p}_t\frac{\partial \hat{Y}_t}{\partial Y_{jt}}$$
- Final output produces with $$\hat{Y}_t = \prod_{j=1}^{J} Y_{jt}^{\gamma_j}$$

Definition: Heterogenous production technologies

Definition 1: **Sectors** are said to be **heterogeneous** if

- share parameters β_{Kj},
- **substitution parameters ρ_j,**
- input factor-specific productivities (H_{Kj}, H_{Ej}), or
- sector-specific depreciation rates δ_j,
- or a combination of these parameters, differ across sectors.

Sectors are **identical if** these parameters take on the **same respective values** or **if $\rho_j = 0$** across all sectors.

The Planner's Problem: First-Best Policy

First-Best Policy

The social planner solves

$$W = \sum_{t=0}^{\infty} \frac{1}{(1+\zeta_S)^t} u(C_t) \quad \text{s.t.} \quad \sum_{j=1}^{J} \bar{E}_{jt} = \bar{E}_t$$

s.t. the equilibrium conditions of the economy.

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Capital income is **subsidized** addressing that private actors discount the future too much.

Carbon emission is priced **uniformly**.

BUT: A capital income **subsidy is not feasible in the real-world** because

i. climate policies decisions are made separately from fiscal policy decisions,
ii. countries tax capital income.

The Planner's Problem: Second-Best Policy

The planner's problem: we constrain the planner to obey the HH's Euler equation

The social planner solves

$$W = \sum_{t=0}^{\infty} \frac{1}{(1+\zeta_S)^t} u(C_t) \quad \text{s.t.} \quad \sum_{j=1}^{J} \bar{E}_{jt} = \bar{E}_t$$

s.t. the equilibrium conditions of the economy

$$\text{s.t.} \quad \frac{U_{Ct}(1+\zeta)}{U_{Ct+1}} \leq (1+R_{t+1})) \,, \quad R_{t+1} = MPK_{jt+1} - \delta_j, \quad \forall j, \text{ and } t > 0$$

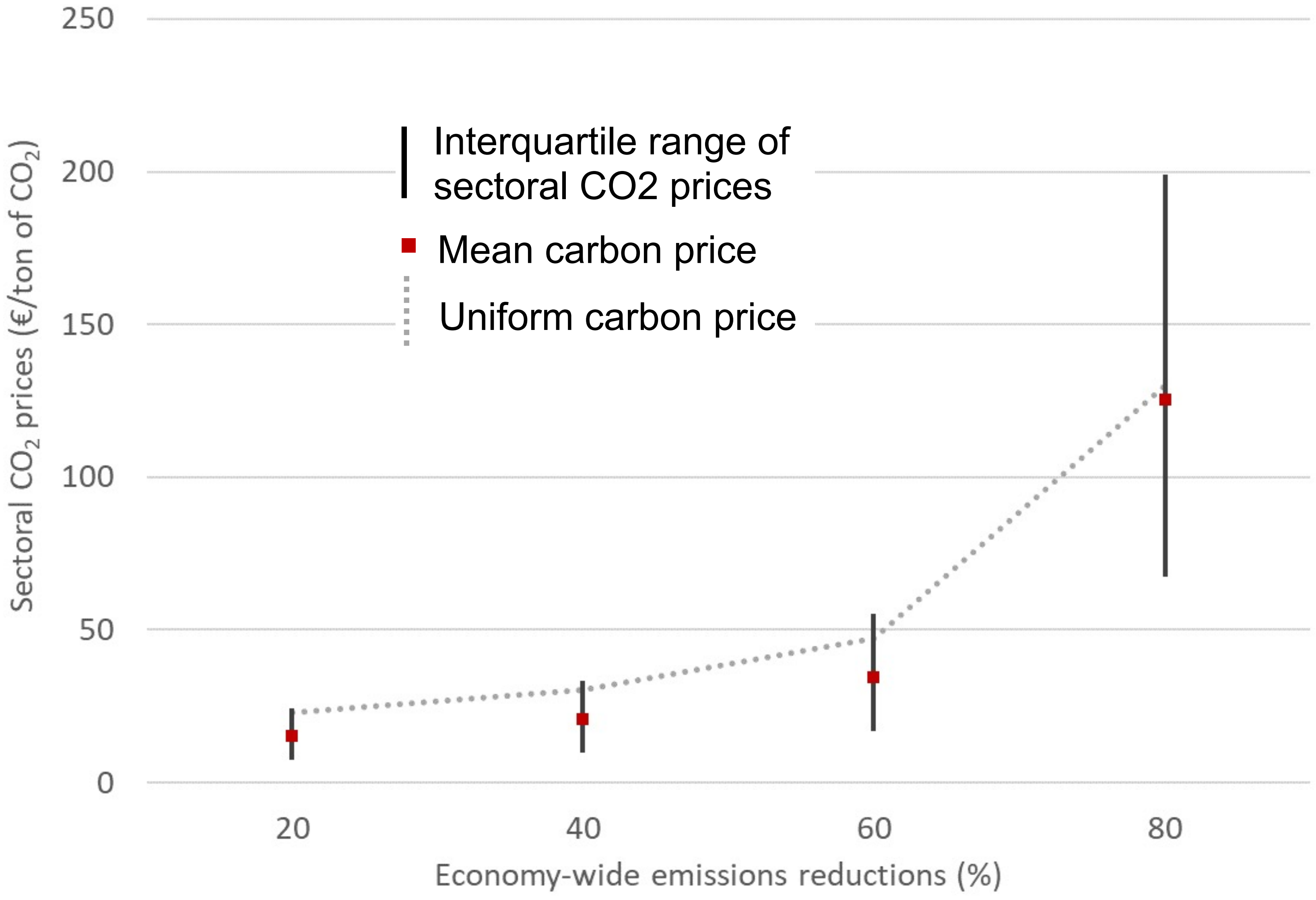
Let‘s look at this numerically: Calibration of the EU-28

- All data on sectoral level.
- Data on capital, labor and output from **World-Input-Output-Data** (socio-economic account).[1] We adjust for **exchange rates**.[2]
- Data on carbon emission from **European commission**.[3]
- Carbon prices reflect current policy and differentiate between EU-ETS and non EU-ETS sectors.
- **Substitution elasticities** are taken from the literature, but are highly uncertain**.**

1.http://wiod.org/database/seas16
2.https://fxtop.com/en/historical-exchange-rates.php?MA=1,
3.https://edgar.jrc.ec.europa.eu/overview.php?v=50_ GHG

The distribution of sectoral CO2 prices, for different CO2 reduction targets

The differences amount up to 100%



Under zero-social discounting: Non-Uniform CO2 prices steer capital demand upwards

PROPOSITION 1: If sectoral production technologies are **heterogeneous**, the constrained optimal carbon prices **differ across sectors:** $\boldsymbol{\tau_j \neq \tau_k, \forall j, k}$. In particular, $\boldsymbol{\tau_j > \tau_k}$ **if** ceteris paribus capital is a better substitute for emissions in sector *j* relative to sector *k* $(\boldsymbol{\rho_j > \rho_k})$.

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We assume **zero social discounting**: the planner treats all generations equally, so the planner **maximizes** household consumption in **steady-state**

Intuition: Optimality requires to **increase** the steady-state **capital stock.**

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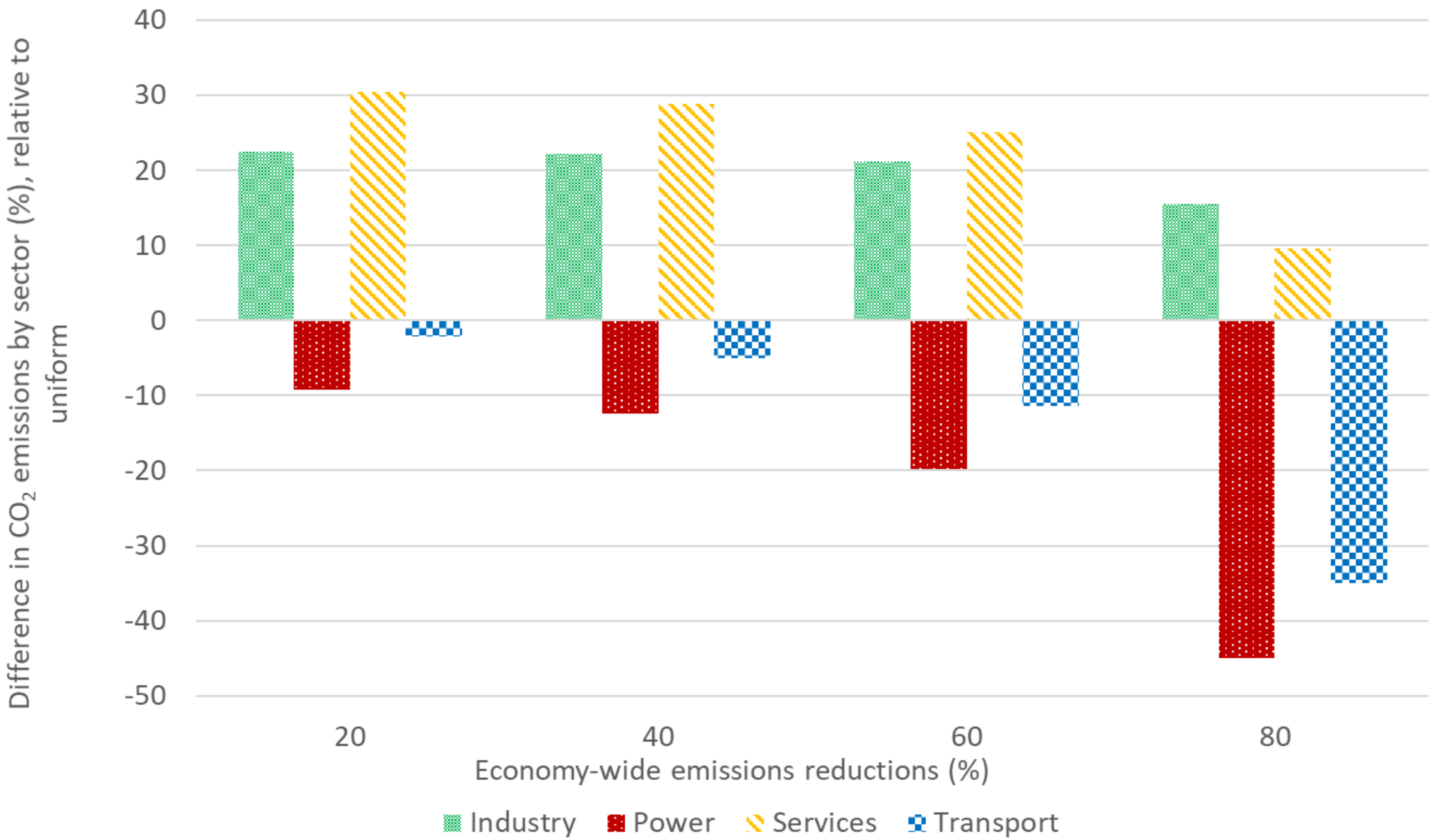


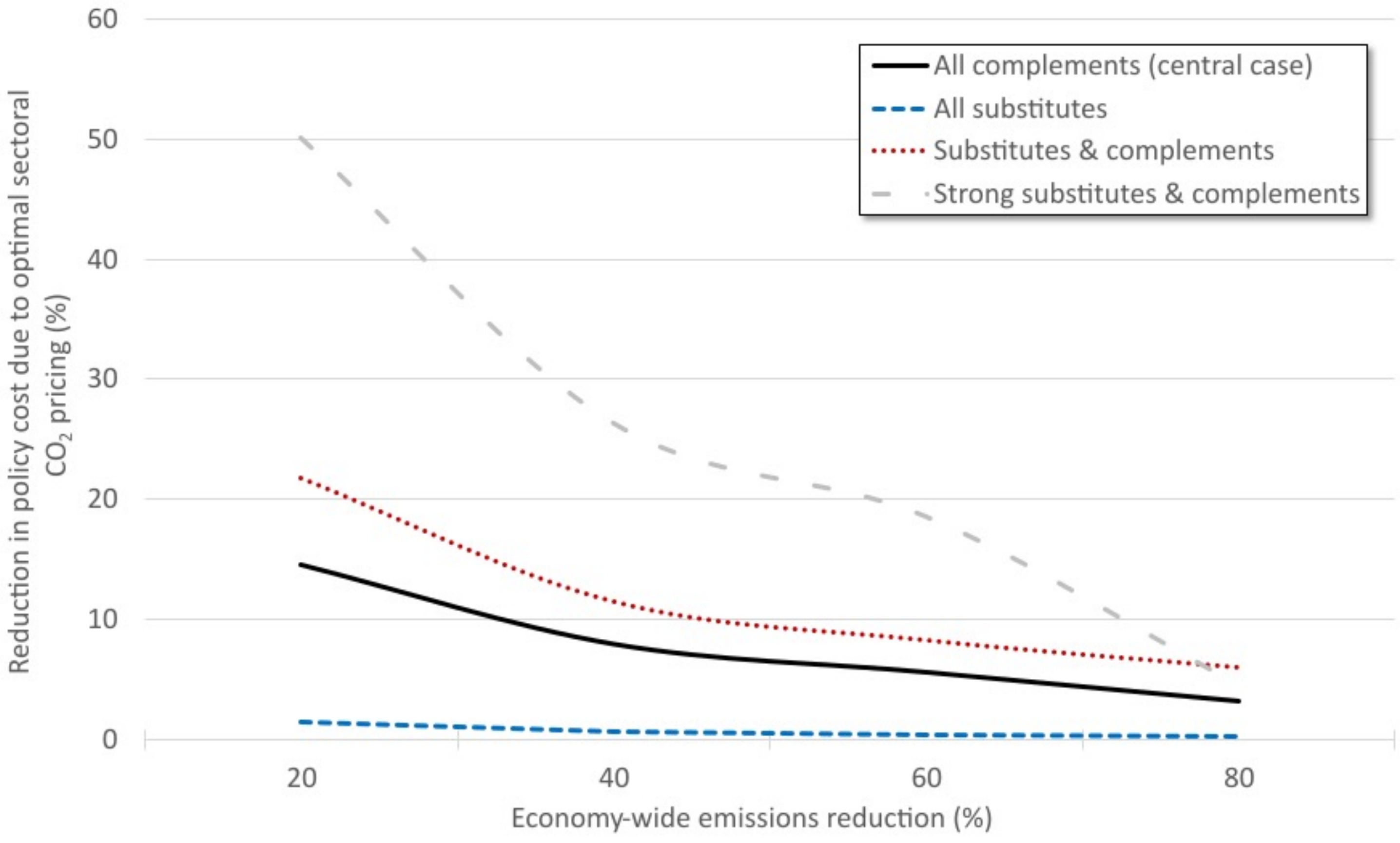
- **Industry** and **Services** produce with **inflexible technologies**.
- I and S **receive more CO2** to increase capital demand.

- **Power** and **Transport** produce with **flexible technologies**.
- P and T **abate additional CO2**.

- Total capital demand increases, leading to more output/consumption.

Large welfare gains from optimally differentiated carbon prices

Less consumption losses under optimally differentiated than uniform carbon prices, relative to the baseline



- **Central Case** calibration: significant **lower policy costs** with **optimal** carbon prices
- **Cost-advantage increases** if sectors produce with **more heterogenous** production technologies
- **Welfare implication** of *optimal vs. uniform* **decrease** with the policy stringency

Conclusion

Conclusion

- We ask: **What is the optimal carbon pricing rule in light of differential social discounting?**

- Differential social discounting calls for a **capital income subsidy.**
- Fiscal instruments to address capital market inefficiencies are not available because (i) countries tax capital income and (ii) climate policies decisions are made seperably from fiscal policy decisions.

- Optimal **prices are non-uniform** if sectors produce with more heterogenous production technologies. HH under-accumulate under differential social discounting. Carbon prices incentivse capital demand and stimulate capital investments.

- **CO2 price differentiation** and **welfare gains** are **significant**.

Backup

Private vs. Social Discounting: not a novel discussion

Nordhaus applies a **positive** argument: he is in favor of a ***"high"*** discount rate that reflects ***real-world preferences*** as observed in markets.

Real-world HH preferences:
HH discounts with a **private discount rate (ξ):**

$$U = \sum_{t=0}^{\infty} \frac{1}{(1+\zeta)^t} u(C_t)$$

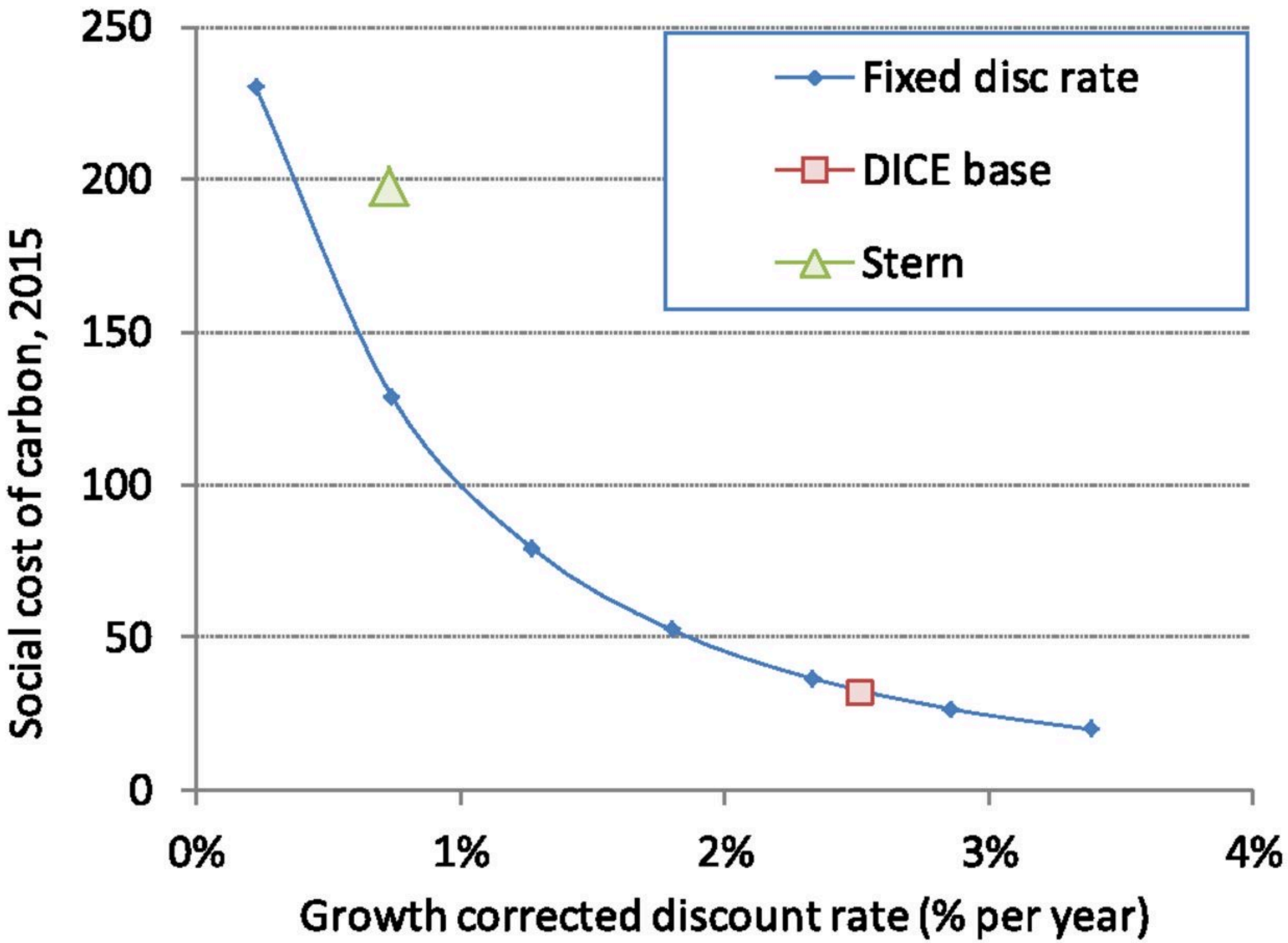
Stern applies a **normative** argument: he is in favor of a **"*low*"** discount rate. Only low, potentially (near) zero, rates are ***socially justifiable***. (See also Ramsey, 1928)

Socially justifiable planner preferences:
The social planner discounts with a **social discount rate (ξ_S):**

$$W = \sum_{t=0}^{\infty} \frac{1}{(1+\zeta_S)^t} u(C_t)$$

Climate change is an inter-generational problem

How shall we discount future climate damages? How stringent should our policy be?



William D. Nordhaus, 2017, PNAS, Revisiting the social cost of carbon, 1518-1523

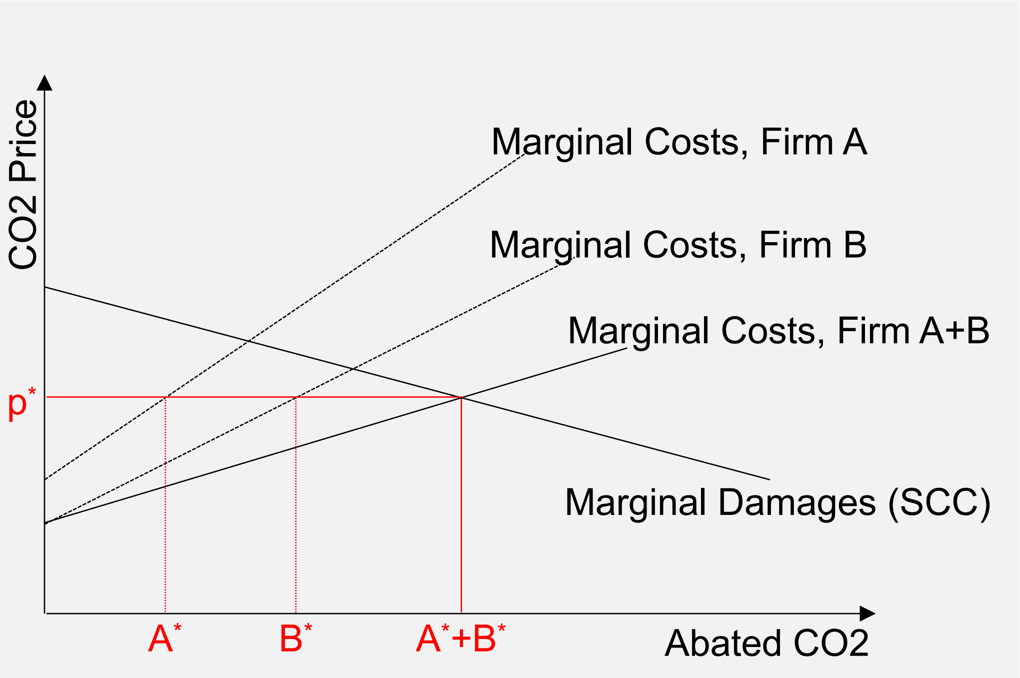
… based on these analyses, I conclude with:

If valueing future climate damages is *normative*, we open the door for social discounting.

If we accept that capital income subsidies are not possible, **we should discuss the possibility of non-uniform carbon prices**.

Environmental Economics on Efficient Carbon Pricing

- *„Conventional wisdom" – that the first-best carbon price is globally uniform, applying to all sectors, in all countries and at all times. (*Hepburn, Stiglitz and Stern)[1]
- The Economists' Statement on Carbon Pricing *encourage(s) the emergence of a global carbon price.*[2]



Textbook example:

- A uniform carbon price equalizes the marginal costs of CO2 abatement.
- An optimal, uniform CO2 is set equal to the SCC.
- **Here:** SCC does not capture fully capture inter-generational equity concerns.

1. Hepburn, Stiglitz, Stern, 2020: "Carbon Pricing" Special Issue in the European Economic Review
2. EAERE 2019, Economists' Statement on Carbon Pricing

Climate change is an inter-generational problem

Inherent to climate change mitigation is that

benefits of emitting CO_2 are **today**, but

costs of emitting CO_2 lie **in the future**.

How shall we discount climate damages? How stringent should our policy be?

More formally,

private HH maximizes

$$U = \sum_{t=0}^{\infty} \frac{1}{(1+\zeta)^t} u(C_t)$$

and the social planner maximizes

$$W = \sum_{t=0}^{\infty} \frac{1}{(1+\zeta_S)^t} u(C_t)$$

where $\xi > \xi_S \geq 0$.

Is zero social discounting ($\xi_S = 0$) a good way to think about climate change?
Under $\xi_S = 0$, every generation receives the same weight. The planner treats every generation equally.

Definition: Heterogenous production technologies

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First-Best Policy: The optimal capital income subsidy

The Planner's Problem

$$U_{Ct} = \frac{1}{1+\zeta_S} U_{Ct+1} \left(1 + R_{t+1}\right)$$

The HH's Problem

$$U_{Ct} = \frac{1}{1+\zeta} U_{Ct+1} \left(1 + R_{t+1}(1 - \Xi_{t+1})\right)$$

$$\Xi_{t+1} = \frac{\zeta_s - \zeta}{1+\zeta_S} \frac{1 + R_{t+1}}{R_{t+1}}$$

First-Best Policy: The optimal pricing of CO2

The Planner's Problem

$$\underbrace{\mu_{jt}}_{\substack{\text{marginal value}\\ \text{of sectoral output}}} \underbrace{\frac{\partial Y_{jt}}{\partial E_{jt}}}_{\substack{\text{marginal product of}\\ \text{sectoral emissions}}} = \underbrace{\lambda_t^E}_{\substack{\text{marginal social cost of}\\ \text{economy-wide emissions}}}$$

The Firms' Problem

$$\underbrace{p_{jt}}_{\substack{\text{price of}\\ \text{sectoral output}}} \underbrace{\frac{\partial Y_{jt}}{\partial E_{jt}}}_{\substack{\text{marginal product of}\\ \text{sectoral emissions}}} = \tau_{jt} = \underbrace{\tau_t}_{\substack{\text{marginal social cost of}\\ \text{economy-wide emissions}}}$$

When is a uniform carbon price optimal?

PROPOSITION 2: Constrained-optimal sectoral carbon prices **are uniform if** the economy displays one or more of the **following** characteristics:

i. sectoral production technologies are identical,
ii. the capital stock is exogenously given and fixed, or
iii. there is no social discounting, i.e. social and private discount rates coincide ($\xi = \xi_S$).

When are non-uniform carbon prices optimal?

PROPOSITION 1: In a **second-best setting** when **capital income subsidies are not feasible**, the constrained-**optimal allocation** can be decentralized by **sector specific carbon taxes** which are implicitly defined by equating the marginal benefits of emissions use with the marginal social cost of emissions which comprise a Pigouvian and a social discounting externality-correcting term

$$\underbrace{p_{jt}}_{\substack{\text{price of}\\ \text{sectoral output}}} \underbrace{\frac{\partial Y_{jt}}{\partial E_{jt}}}_{\substack{\text{marginal product of}\\ \text{sectoral emissions}}} = \underbrace{\tau_t}_{\substack{\text{social cost of}\\ \text{carbon emissions}}} - \underbrace{(1+\zeta_S)\tilde{\phi}^K_{jt}\frac{\partial MPK_{jt}}{\partial E_{jt}}}_{\substack{\text{marginal sectoral emissions' impact}\\ \text{on sectoral marginal product of capital}}}$$

where $\tilde{\phi}^K_{jt} = \phi^K_{jt}/U_{Ct}$ denotes the social costs of constrained capital prices that are governed by the private Euler equation.

A closer look at sectoral heterogeneity and carbon prices

PROPOSITION 3: **If sectoral production technologies** are **heterogeneous**, the constrained optimal carbon prices **differ across sectors: $\tau_j \neq \tau_k, \forall j, k$.** In particular, $\tau_j > \tau_k$ **if ceteris paribus**:

(i) capital is a better substitute for emissions in sector *j* relative to sector *k* ($\rho_j > \rho_k$),

(ii) the capital share is higher in sector *j* relative to sector *k* ($\beta_{Kj} > \beta_{Kk}$) of both sectors are substitutes ($\rho_j = \rho_k > 0$) and vice versa if both sectors are complements ($\rho_j = \rho_k < 0$),

(iii) capital is more productive ($H_{Kj} > H_{Kk}$), or emissions are less productive ($H_{Ej} < H_{Ek}$), in sector *j* relative to sector *k*, if both sectors are complements ($\rho_j = \rho_k < 0$), and vice versa if both sectors are substitutes ($\rho_j = \rho_k > 0$) ,or

(iv) the capital depreciation rate is lower in sector *j* relative to sector *k* ($\delta_j < \delta_k$) if both sectors are substitutes ($\rho_j = \rho_k > 0$) and vice versa if both sectors are complements ($\rho_j = \rho_k < 0$).

The economic intuition

Assume $\xi > \boldsymbol{\xi_S = 0}$: only the longrun steady state matters, the social optimum requires a greater capital stock.

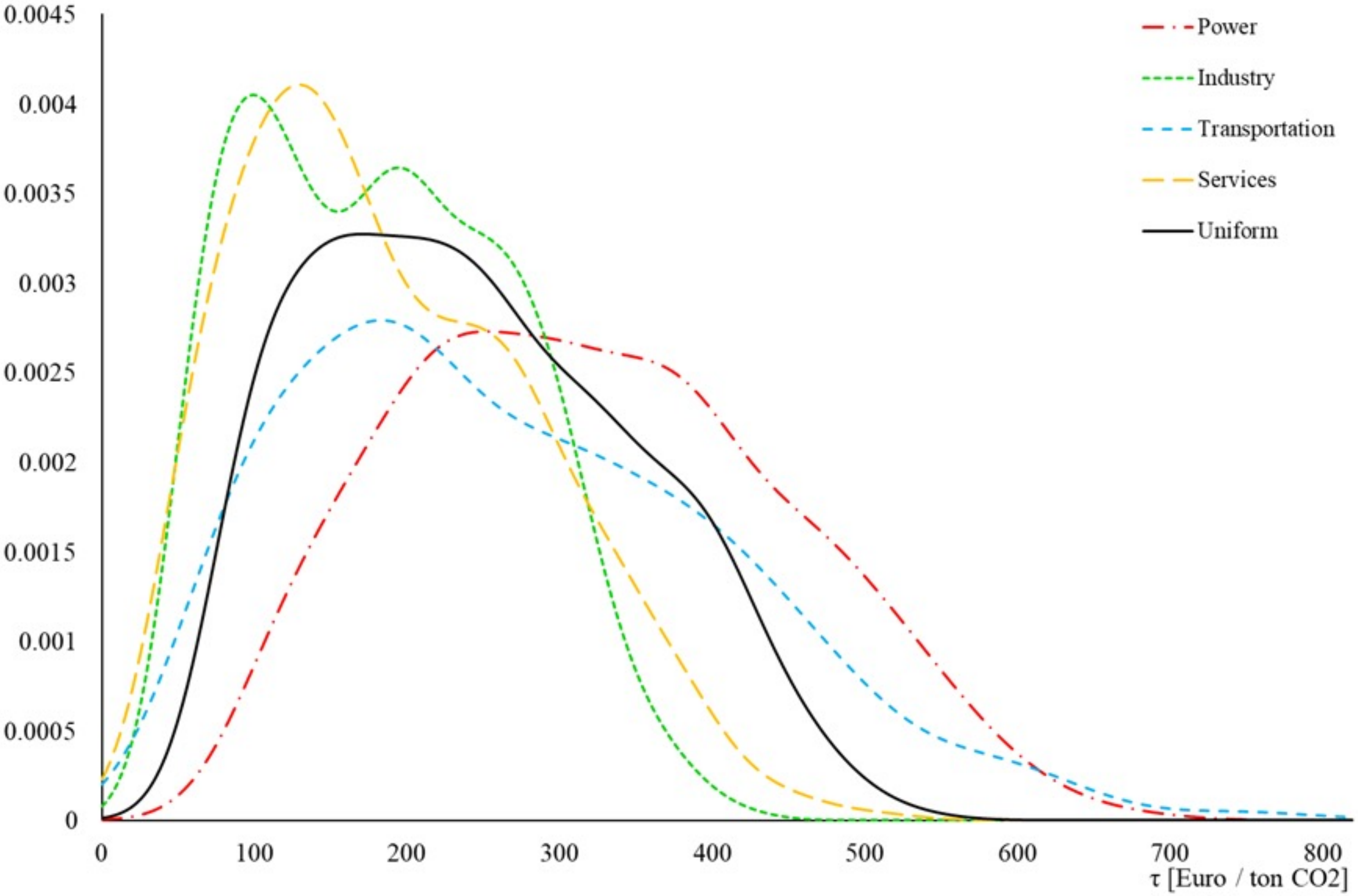
	j=1: Perfect Complement	**j=2: Cobb-Douglas**
Response to carbon price	• No input factor substitution. • Capital and emission decrease equally in response to a higher carbon price. • Output decreases significantly.	• Better input factor substitution. • Capital decreases, but less, in response to a higher carbon price. • Output decreases less.
Optimal price adjustment	• Decrease sectoral carbon price to allow for more emission. • **Greater capital demand and output**.	• Increase sectoral carbon price to abate additional emission. • **Less capital demand, but total capital demand increases**.

Economy produces with **more capital** under the **same CO2 budget**. **Deviation from** a **uniform** CO2 price yields **welfare gains.**

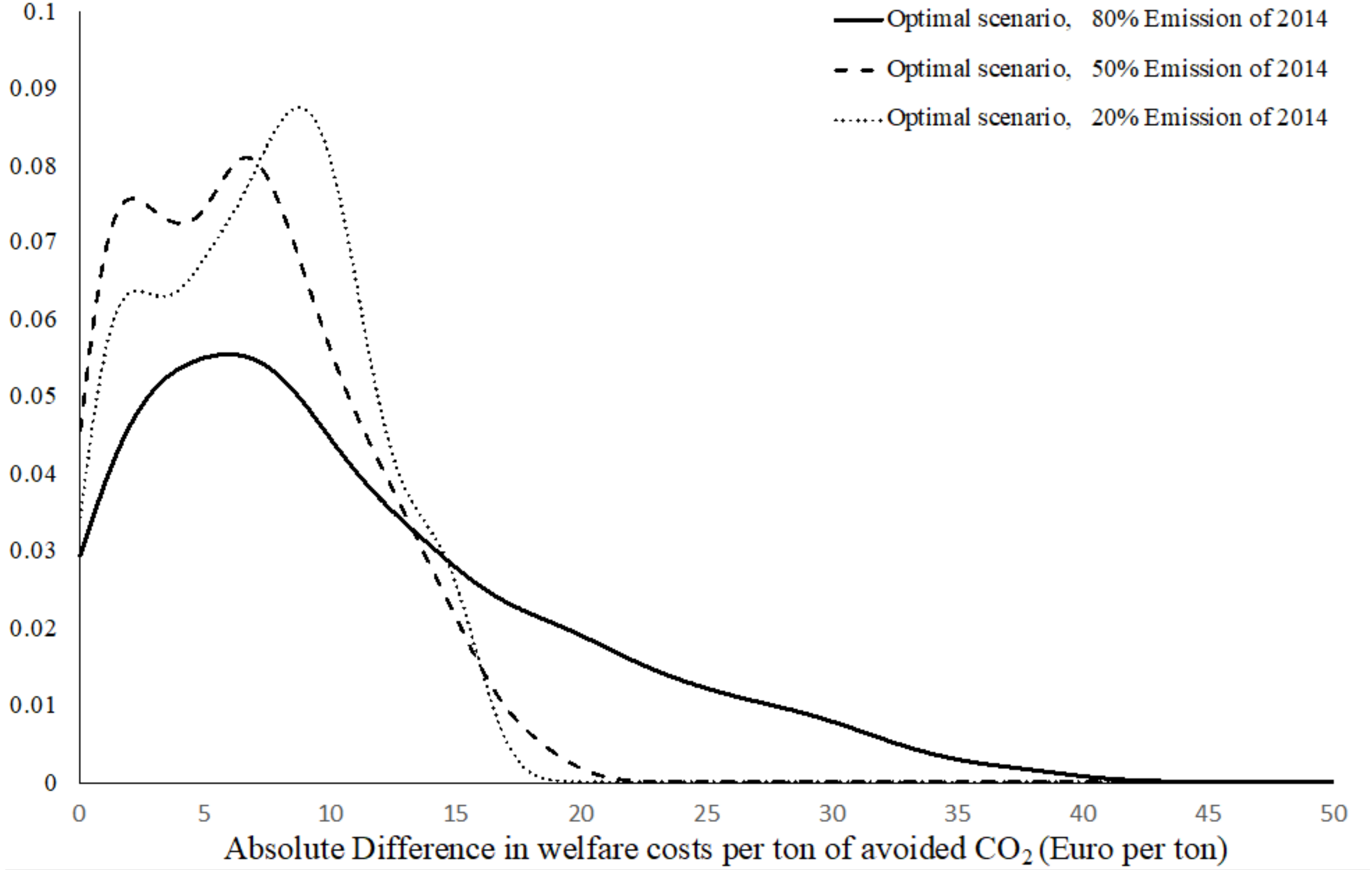
Elasticity estimates between Capital and CO_2 (energy)

	Koesler	Okagawa	van der Werf	Costantini	Dissou	Papageorgiou
ρ_P^{min}	-1.38	-1.52				0.42
ρ_P^{max}	-1.17	-0.87				0.65
ρ_I^{min}	-5.66	-19	-0.041	-6.69	-2.33	
ρ_I^{max}	0.01	-1.56	0.002	-1.22	-0.51	
ρ_T^{min}	-1.70	-1.22			-1.23	
ρ_T^{max}	0.21	-1.22			-1.23	
ρ_S^{min}	-6.69	-2.70				
ρ_S^{max}	-0.47	-0.53				

Monte-Carlo Simulation: Distribution of sectoral carbon prices



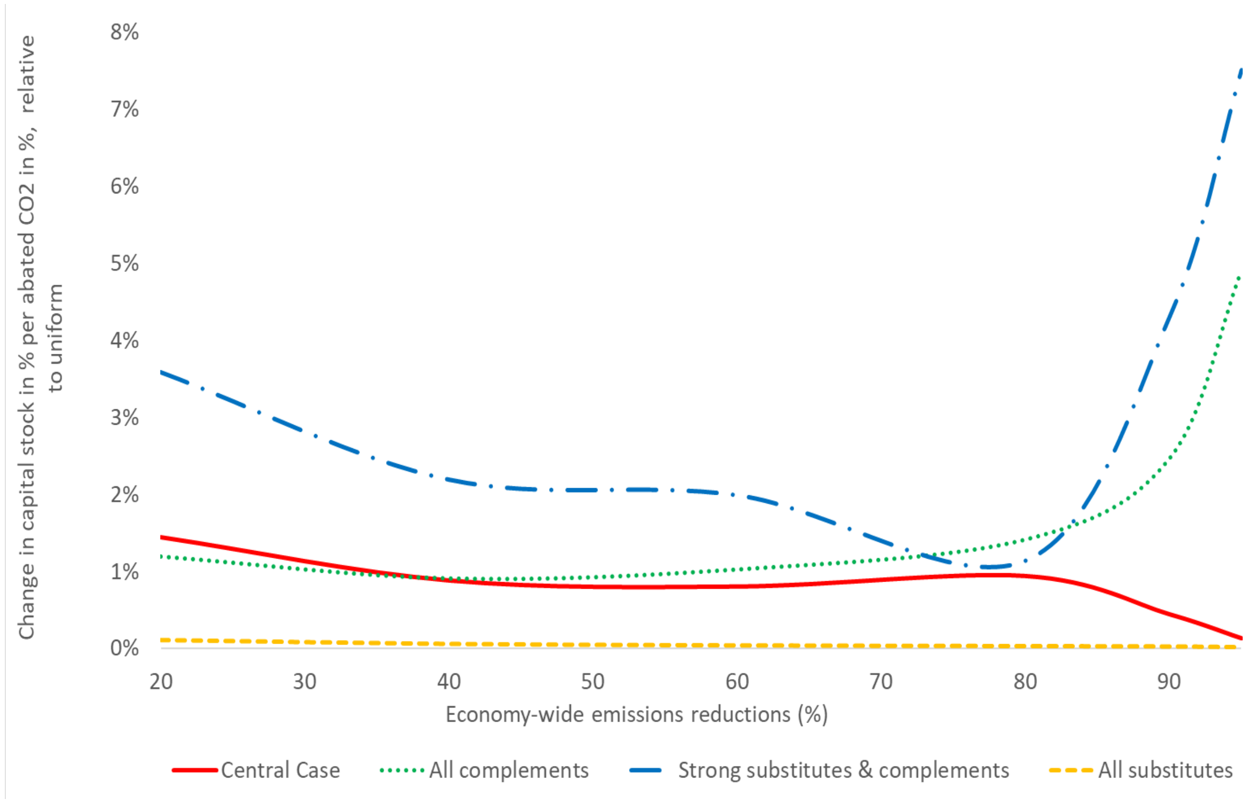
Monte-Carlo Simulation: Welfare gains under optimal to uniform



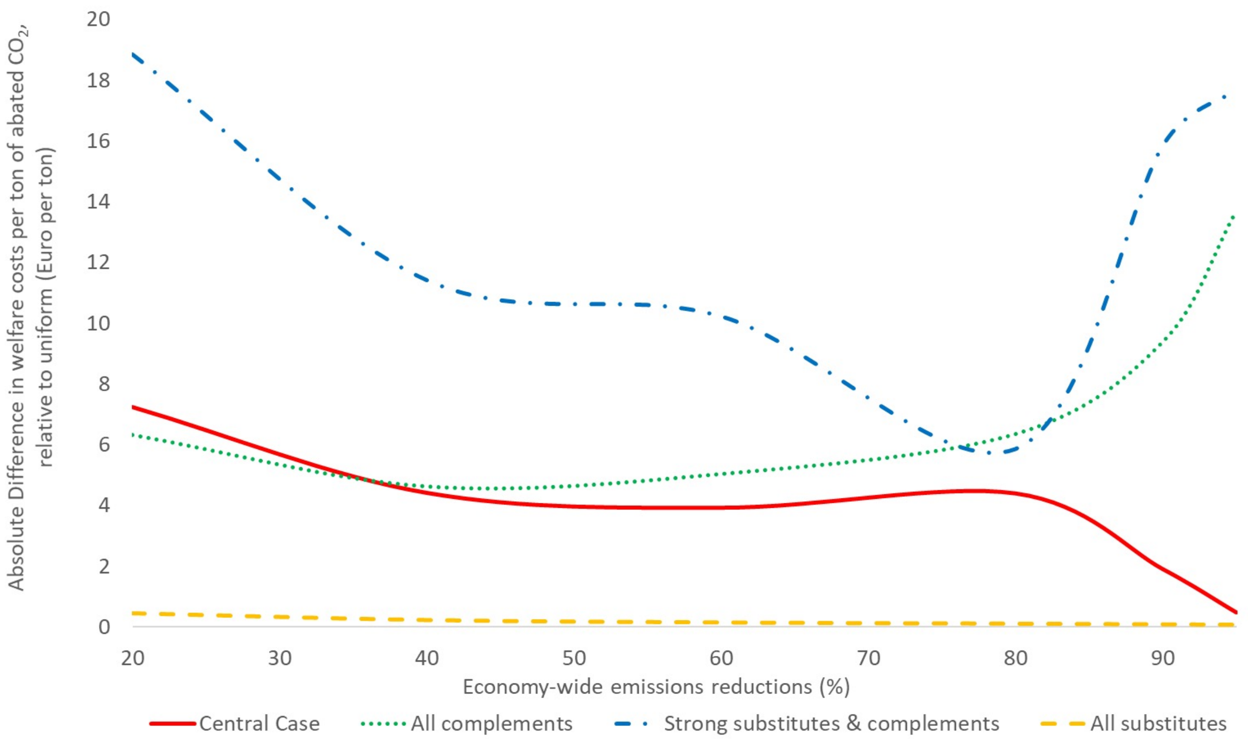
Welfare gains are driven by „how well CO2 prices can steer the capital accumulation“

- Capital stock changes explain welfare gains. Both follow the same pattern.
- Difference in substitution pattern between capital and CO2 among sectors determine welfare gains at high reduction targets.

Change in capital stock in % per abated CO2 in %



Change in consumption in Euro per abated ton of CO2



The Key-takeaways from this paper

- Social discounting calls for a **capital income subsidy.**
- A capital income **subsidy is not available** because (i) countries tax capital income and (ii) climate policies decisions are made seperably from fiscal policy decisions.

- Fiscal instruments to address capital market inefficiencies are not available.
- Optimal **prices are non-uniform** and address the capital market inefficiencies.

- Under **social discounting**, we care more about **the long-run.** The economy should produce with **more capital.** Welfare increases because non-uniform carbon prices increase the capital demand.