

Tax vs. Cap-and-Trade for Carbon Emissions

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Motivation

Mitigating climate risk \rightsquigarrow reduction of carbon emissions

- **Business-as-usual: bau**

Nothing is done

- **Carbon tax: tax**

Tax levied on each unit of carbon emitted

43+ carbon tax systems, 5% of global emissions

- **Emission markets: mar**

Carbon certificates traded on the market

37+ market schemes, 23% of global emissions

Question: Which performs “better”: **tax** or **mar**?

- **Tax scheme = market scheme**

Weitzman, 1974 ; Anand and Giraud-Carrier, 2020

Under idealized conditions: complete information, no uncertainty

- **Tax scheme**

Golosov et al., 2014; MacKay et al., 2015; Fan et al., 2023 ;
Ahmad et al., 2024

But for which tax level?

- **Market scheme**

Montgomery, 1972; Kosnik, 2018; Parry et al., 2022;
Xu et al., 2023

Cost-effective, minimize social costs

Involvement of **compliance companies** alongside various **economic actors** in the certificates market:

- **(Compliance) companies (bau, tax, mar)**: produce goods and pollute
- **Regulator (tax, mar)**: levy tax, issue certificates, design scheme
- **Financial Intermediaries (mar)**: buy and sell certificates
80% of auctioned certificates, 56% of trading volume
in the secondary-market in EU ETS, 2023
ESMA, 2025; *Cludius et al., 2022*; *Quemin and Pahle, 2023*;
Isah et al., 2024
- **Tech companies (tax, mar)**: produce green technologies

Question: How do financial intermediaries under the market scheme influence the redistribution of wealth among actors, and how these outcomes diverge from those under a tax scheme?

Model and General Results

Situation of a generic compliance company

- We consider a one-period, deterministic (first) model
- Produce q units of goods \rightsquigarrow q tons of emissions
- Get a raw wealth (ignoring any carbon-related factors)

$$\pi(q) = \pi^0 q - \frac{\pi^1}{2} q^2$$

Maximizing wealth: $q^{\text{bau}} = \arg \max \pi(q) = \frac{\pi^0}{\pi^1}$

GDP Contribution: $W_C^{\text{bau}} = \pi(q^{\text{bau}}) = \frac{1}{2} \frac{(\pi^0)^2}{\pi^1}$

Emissions: $E^{\text{bau}} = q^{\text{bau}}$

Generic company: Tax Scheme

- Green tech effort a reduces emissions $q \searrow e^{-a}q$ at cost
$$c(q, a) = \frac{\gamma}{2} [(1 - e^{-a})q]^2$$
- Tax τ levied per unit of emissions
↪ compliance cost $\tau e^{-a}q$

Maximize wealth: $q^{\text{tax}}, a^{\text{tax}} = \arg \max \{ \pi(q) - c(q, a) - \tau e^{-a}q \}$

GDP contribution: $W_C^{\text{tax}} = \pi(q^{\text{tax}}) - c(q^{\text{tax}}, a^{\text{tax}}) - \tau e^{-a^{\text{tax}}} q^{\text{tax}}$

Emissions: $E^{\text{tax}} = e^{-a^{\text{tax}}} q^{\text{tax}}$

Generic company: Market Scheme

- Green tech effort a reduces emissions $q \searrow e^{-a}q$ at cost
$$c(q, a) = \frac{\gamma}{2} [(1 - e^{-a})q]^2$$
- Buy δ carbon certificates at price P at **auction/via a financial intermediary**
- Pay penalty on excess emissions $\lambda(e^{-a}q - \delta)^+$

Maximize wealth:

$$q^{\text{mar}}, a^{\text{mar}}, \delta = \arg \max \left\{ \pi(q) - c(q, a) - \delta P - \lambda (e^{-a}q - \delta)^+ \right\}$$

GDP contribution:

$$\mathcal{W}_C^{\text{mar}} = \pi(q^{\text{mar}}) - c(q^{\text{mar}}, a^{\text{mar}}) - \delta P - \lambda \left(e^{-a^{\text{mar}}} q^{\text{mar}} - \delta \right)^+$$

Emissions: $E^{\text{mar}} = e^{-a^{\text{mar}}} q^{\text{mar}}$

Note: $\delta = \delta(P)$ for a given P

Generic company: GDP Contribution and Emissions

Theorem

Let $\varrho = \frac{1}{\pi^1} + \frac{1}{\gamma}$. For a given tax τ and certificate price P :

- **tax**: Production, emissions, GDP contribution

$$q^{\text{tax}} = q^{\text{bau}} - \frac{\tau}{\pi^1}$$

$$E^{\text{tax}} = E^{\text{bau}} - \tau \varrho$$

$$\mathcal{W}_C^{\text{tax}} = \mathcal{W}_C^{\text{bau}} - \tau \left(E^{\text{bau}} - \frac{\tau}{2} \varrho \right)$$

- **mar**: Production, certificates demand, emissions, GDP contribution

$$q^{\text{mar}} = q^{\text{bau}} - \frac{P}{\pi^1}$$

$$\delta(P) = E^{\text{mar}}$$

$$E^{\text{mar}} = E^{\text{bau}} - P \varrho$$

$$\mathcal{W}_C^{\text{mar}} = \mathcal{W}_C^{\text{bau}} - P \left(E^{\text{bau}} - \frac{P}{2} \varrho \right)$$

Companies Aggregation

Scheme	GDP contribution	Emission
bau	$\mathcal{W}_C^{\text{bau}} = \sum_i \mathcal{W}_{C,i}^{\text{bau}}$	$E^{\text{bau}} = \sum_i E_i^{\text{bau}}$
tax	$\mathcal{W}_C^{\text{tax}} = \mathcal{W}_C^{\text{bau}} - \tau \sum_i \left(E_i^{\text{bau}} - \frac{\tau}{2} \varrho_i \right)$	$E^{\text{tax}} = E^{\text{bau}} - \tau \sum_i \varrho_i$
mar	$\mathcal{W}_C^{\text{mar}} = \mathcal{W}_C^{\text{bau}} - \sum_i P_i \left(E_i^{\text{bau}} - \frac{P_i}{2} \varrho_i \right)$	$E^{\text{mar}} = E^{\text{bau}} - \sum_i P_i \varrho_i$

- Reduction of emissions and wealth in **tax** and **mar** relative to **bau**
- **tax**: emissions reductions factors ϱ_i are weighted by a uniform τ
- **mar**: reduction factors ϱ_i are weighted by a company-level price P_i

Question: Where does the price P_i comes from?

Market Scheme

Market Scheme

- The regulator issues A certificates \rightsquigarrow emissions cap = A
- Auction them for a price S
- Compliance company i purchases directly at a spot price S

$$P_i(S) = S$$

- Alternatively, a financial intermediary buys at price S and resells to company i at price

$$P_i(S) = \arg \max \{ \delta_i(P)(P - S) \}$$

- Equilibrium spot price (\mathbf{S}): market clearing condition

$$\sum_i \delta_i(P_i(\mathbf{S})) = A$$

- Equilibrium company-level certificate price

$$P_i = P_i(\mathbf{S})$$

Multi companies Market Schemes

- **Spot market scheme (competition)**: all companies participate to the auction

$$P_i = S \quad \forall i, \quad \sum_i \delta_i(S) = A$$

- **Purely intermediated market scheme (monopoly)**: financial intermediaries are counterparties

$$P_i = P_i(S) = \arg \max \{ \delta_i(P)(P - S) \} \quad \forall i, \quad \sum_i \delta_i(P_i(S)) = A$$

- **Hybrid**: Some companies participate to the auction

$$\underbrace{\sum \delta_b(P_b(S))}_{\text{demand from intermediated purchases}} + \underbrace{\sum \delta_c(S)}_{\text{demand from direct market participants}} = A$$

- $(S; (q_i^{\text{mar}})_i, (a_i^{\text{mar}})_i, (\delta_i)_i)$ forms a Radner equilibrium

Market Scheme: Equilibrium

Theorem (Extreme Schemes)

An equilibrium price S exists and is unique. Let $\varrho = \sum \varrho_i$.

- **If all companies participate to the auction** (competition)

$$S = \frac{1}{\varrho} (E^{\text{bau}} - A)$$

$$P_i = S$$

- **If all companies go through financial intermediaries** (monopoly)

$$S = \frac{1}{\varrho} (E^{\text{bau}} - 2A)$$

$$P_i(S) = \frac{1}{2} \left(S + \frac{E_i^{\text{bau}}}{\varrho_i} \right)$$

In general:

$$\underbrace{S}_{\text{Monopoly}} \leq \underbrace{S}_{\text{Hybrid}} \leq \underbrace{S}_{\text{Competition}}$$

Comparison of the Tax and Market Schemes

How to Compare Tax and Market Schemes?

- Given total number of certificates A (taken as 40% of E^{bau} in the numerics), fix a tax τ and a penalty λ such that

$$E^{\text{tax}}(\tau) = E^{\text{mar}}(\lambda, A)$$

↪ each scheme achieves identical aggregate carbon emissions

- Then compare the resulting economic outcomes:

GDP contributions \mathcal{W} ; emissions E

GDP Contributions

- **bau:**

$$\text{GDP}^{\text{bau}} = \mathcal{W}_C^{\text{bau}}$$

- **tax:**

$$\text{GDP}^{\text{tax}} = \mathcal{W}_C^{\text{tax}} + \mathcal{W}_R^{\text{tax}}$$

where $\mathcal{W}_R^{\text{tax}} = \tau A$

- **mar:**

$$\text{GDP}^{\text{mar}} = \mathcal{W}_C^{\text{mar}} + \mathcal{W}_R^{\text{mar}} + \mathcal{W}_F^{\text{mar}}$$

where $\mathcal{W}_R^{\text{mar}} = \mathbf{S}A$

$$\mathcal{W}_F^{\text{mar}} = \sum_i \delta_i (P_i - \mathbf{S})$$

Theorem (GDP for equal emission reduction objective)

- $\underbrace{\text{GDP}^{\text{mar}}}_{\text{monopoly}} \leq \underbrace{\text{GDP}^{\text{mar}}}_{\text{hybrid}} \leq \underbrace{\text{GDP}^{\text{mar}}}_{\text{competition}} = \text{GDP}^{\text{tax}}$
- **Companies:** $\underbrace{\mathcal{W}_C^{\text{mar}}}_{\text{monopoly}} \leq \underbrace{\mathcal{W}_C^{\text{mar}}}_{\text{hybrid}} \leq \underbrace{\mathcal{W}_C^{\text{mar}}}_{\text{competition}} = \mathcal{W}_C^{\text{tax}}$
- **Regulator:** $\underbrace{\mathcal{W}_R^{\text{mar}}}_{\text{monopoly}} < \underbrace{\mathcal{W}_R^{\text{mar}}}_{\text{hybrid}} < \underbrace{\mathcal{W}_R^{\text{mar}}}_{\text{competition}} = \mathcal{W}_R^{\text{tax}}$
- **Intermediaries:** $\underbrace{\mathcal{W}_F^{\text{mar}}}_{\text{competition}} = 0 < \underbrace{\mathcal{W}_F^{\text{mar}}}_{\text{hybrid}} < \underbrace{\mathcal{W}_F^{\text{mar}}}_{\text{monopoly}}$
- The inequality “C” **does not** hold in general at the individual company level
- The inequality “F” works for each financial intermediary

Numerical Case Study

- Six groups of companies with equal **ba** GDP contributions
- Companies classified by their **carbon intensity** $\kappa_i = \frac{E_i^{\text{bau}}}{W_{C,i}^{\text{bau}}} = \frac{2}{\pi_i^0}$
 - **Brown groups (B1–B3)**: most carbon intensive
 - **Green groups (G1–G3)**: least carbon intensive
- Heterogeneous technology costs (**B2** and **G2** are the most expensive)
- As **tax = mar (competition)** , we compare **tax** vs. **mar (monopoly)**

Summary of Parameter Values

Group	Parameters		
	π_i^0	π_i^1	γ_i
B1	475.65	1.13	10
B2	605.38	1.83	30
B3	665.91	2.22	5
G1	739.90	2.74	10
G2	832.39	3.46	30
G3	951.31	4.52	5

- linear wealth coefficients π_i^0 (€/ton)
- quadratic cost coefficients π_i^1 (10^6 €/ton²)
- technology quadratic cost coefficients γ_i (10^6 €/ton²)
- $A = 0.4E^{\text{bau}}$

Note that the wealth of the green technology provider associated with company i corresponds to $c_i(\mathbf{a}_i^{\text{tax}}, \mathbf{q}_i^{\text{tax}})$ under the tax scheme and $c_i(\mathbf{a}_i^{\text{mar}}, \mathbf{q}_i^{\text{mar}})$ under the market scheme.

In order to compare the level of investment in the green transition under each policy scheme, we include the wealth of tech providers

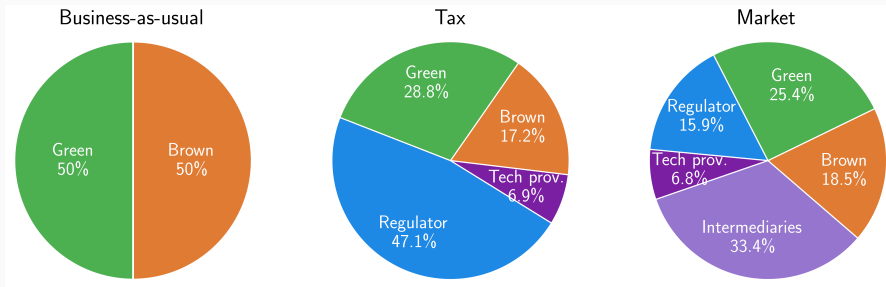
$\sum c_i(\mathbf{a}_i^{\text{tax}}, \mathbf{q}_i^{\text{tax}})$ vs. $\sum c_i(\mathbf{a}_i^{\text{mar}}, \mathbf{q}_i^{\text{mar}})$ in our numerical analysis.

GDP and Emissions Values

Group	GDP contributions (billions €)			Emission contributions (million tons)		
	bau	tax	mar	bau	tax	mar
Brown	300	80	86	1,051	363	411
B1	100	17	23	420	115	159
B2	100	25	22	330	150	135
B3	100	38	41	300	98	116
Green	300	134	117	721	345	298
G1	100	38	35	270	126	111
G2	100	41	27	240	140	103
G3	100	55	56	210	79	83
Regulator	—	220	73	—	—	—
Tech providers	—	32	31	—	—	—
Financial intermediaries	—	—	154	—	—	—
Total	600	467	462	1,772	709	709

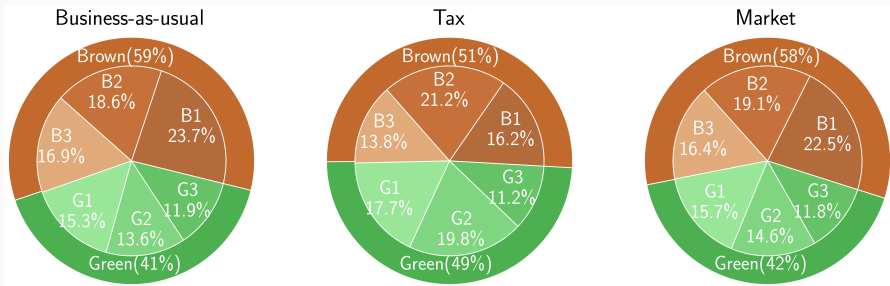
- **GDP:** **bau** → **tax**: -22%; **bau** → **mar**: -23% ; **tax** → **mar**: -1%
- **Emissions:** **bau** → **tax/ mar**: -60%

GDP Shares



The GDP shares of the different actors in the bau case and under the tax and purely intermediated market schemes

Emission Shares



The emissions shares of each company in the bau case and under the tax and purely intermediated market schemes

- Under **tax**, brown companies reduce more relative to green companies
- Emission share under **mar** and **bau** is almost similar

Random Emissions

Revisit the Model

- A generic compliance company produce q units of goods $\rightsquigarrow qX$ tons of emissions

X is positive random variable,

$$\mathbb{E}[X] = 1, \quad \sigma^2 := \mathbb{E}[X^2] = 1 + \text{Var}(X)$$

- Reduce emissions $qX \searrow e^{-a}qX$
- Generic company's expected wealth function:

$$\begin{aligned} \text{tax : } \pi(q) - \mathbb{E} \left[\frac{\gamma}{2} \left((1 - e^{-a})qX \right)^2 \right] - \tau \mathbb{E} [e^{-a}qX] \\ = \pi(q) - \underbrace{\frac{\gamma \sigma^2}{2} q^2 (1 - e^{-a})^2}_{=c(q,a)} - \tau e^{-a}q \end{aligned}$$

$$\begin{aligned} \text{mar : } \pi(q) - \mathbb{E} \left[\frac{\gamma}{2} \left((1 - e^{-a})qX \right)^2 \right] - \delta P - \lambda \mathbb{E} \left[(e^{-a}qX - \delta)^+ \right] \\ = \pi(q) - c(q,a) - \delta P - \lambda \mathbb{E} \left[(e^{-a}qX - \delta)^+ \right] \end{aligned}$$

Generic company: GDP Contribution and Emissions

Theorem

Let $\hat{\rho}_i = \frac{1}{\pi_i^1} + \frac{1}{\gamma_i \sigma^2}$. For a given tax τ and certificate price P :

- **tax**: Production, emissions, GDP contribution

$$q^{\text{tax}} = q^{\text{bau}} - \frac{\tau}{\pi^1}$$

$$E^{\text{tax}} = E^{\text{bau}} - \tau \hat{\rho}$$

$$W_C^{\text{tax}} = W_C^{\text{bau}} - \tau \left(E^{\text{bau}} - \frac{\tau}{2} \hat{\rho} \right)$$

- **mar**: Production, certificates demand, emissions, GDP contribution

$$q^{\text{mar}} = q^{\text{bau}} - \frac{P \text{ES}_{P/\lambda}(X)}{\pi^1}, \quad \delta(P) = \text{VQR}_{P/\lambda}(X) E^{\text{mar}}$$

$$E^{\text{mar}} = E^{\text{bau}} - P \text{ES}_{P/\lambda}(X) \hat{\rho}$$

$$W_C^{\text{mar}} = W_C^{\text{bau}} - P \text{ES}_{P/\lambda}(X) \left(E^{\text{bau}} - \frac{P \text{ES}_{P/\lambda}(X)}{2} \hat{\rho} \right)$$

where $\text{VQR}_\epsilon(X) = \inf\{y \in \mathbb{R} : \mathbb{P}[X \leq y] \geq 1 - \epsilon\}$, $\text{ES}_\epsilon(X) = \frac{1}{\epsilon} \int_0^\epsilon \text{VQR}_u(X) du$

Companies Aggregation

Scheme	GDP Contribution	Emission
bau	$W_C^{\text{bau}} = \sum_i W_{C,i}^{\text{bau}}$	$E^{\text{bau}} = \sum_i E_i^{\text{bau}}$
tax	$W_C^{\text{tax}} = W_C^{\text{bau}} - \tau \sum_i (E_i^{\text{bau}} - \frac{\tau}{2} \hat{\varrho}_i)$	$E^{\text{tax}} = E^{\text{bau}} - \tau \sum_i \hat{\varrho}_i$
mar	$W_C^{\text{mar}} = W_C^{\text{bau}} - \sum_i P_i \mathbb{E} S_{P_i/\lambda}(X) \times \left(E_i^{\text{bau}} - \frac{P_i \mathbb{E} S_{P_i/\lambda}(X)}{2} \hat{\varrho}_i \right)$	$E^{\text{mar}} = E^{\text{bau}} - \sum_i P_i \mathbb{E} S_{P_i/\lambda}(X) \hat{\varrho}_i$

- $\hat{\varrho}_i = \frac{1}{\pi_i} + \frac{1}{\gamma_i \sigma^2} < \varrho_i$
- **tax**: companies' emissions \nearrow and GDPs \searrow relative to deterministic case
- **mar**: demands in certificates $\delta_i(P_i) = \mathbb{V} @ \mathbb{R}_{P_i/\lambda}(X) E_i^{\text{mar}} \neq E_i^{\text{mar}}$

Comparing Tax and Market Schemes

- The regulatory authority does not expect emissions to be exactly equal to the total number of certificates A
- (Expected) emissions cap $\hat{A} > A$, so that $\hat{A} - A$ represents the expected excess emissions tolerated by the regulator.
- Given \hat{A} and A , fix a tax τ and a penalty λ such that

$$E^{\text{tax}}(\tau) = E^{\text{mar}}(A, \lambda) = \hat{A}$$

↪ each scheme achieves identical aggregate carbon emissions

- company-level certificate prices:

$$\begin{cases} P_b = P_b(\mathbf{S}) = \arg \max \{ \delta_i(P)(P - \mathbf{S}) \}, & b \text{ buys via intermediary} \\ P_c = \mathbf{S}, & c \text{ buys at auction} \end{cases}$$

- \mathbf{S} such that $\sum \delta_b(P_b(\mathbf{S})) + \sum \delta_c(\mathbf{S}) = A$

GDP Contributions

- **bau:**

$$\text{GDP}^{\text{bau}} = \mathcal{W}_C^{\text{bau}}$$

- **tax:**

$$\text{GDP}^{\text{tax}} = \mathcal{W}_C^{\text{tax}} + \mathcal{W}_R^{\text{tax}}$$

where $\mathcal{W}_R^{\text{tax}} = \tau \hat{A}$

- **mar:**

$$\text{GDP}^{\text{mar}} = \mathcal{W}_C^{\text{mar}} + \mathcal{W}_R^{\text{mar}} + \mathcal{W}_F^{\text{mar}}$$

where

$$\mathcal{W}_R^{\text{mar}} = \lambda \sum_i \mathbb{E} \left[\left(q_i^{\text{mar}} e^{-a_i^{\text{mar}}} X - \delta_i \right)^+ \right] + SA$$

$$\mathcal{W}_F^{\text{mar}} = \sum_i \delta_i (P_i - S)$$

Theorem (Tax vs. spot market scheme)

- $\underbrace{\text{GDP}^{\text{mar}}}_{\text{Competition}} = \text{GDP}^{\text{tax}}, \quad \text{tax} = \text{mar}$
- *company level outcomes are also identical under the tax and market schemes*

Tax versus Fully Intermediated Market: Numerical Case Study

- $\hat{A} = 1.05A$
- Other parameters are as in the deterministic case
- $X \sim \text{LogNormal}(-\frac{1}{2}, 1)$

- Survival function G and its derivative:

$$G(t) = \Phi\left(-\ln(t) - \frac{1}{2}\right), \quad G'(t) = -\frac{\Phi'\left(\ln t + \frac{1}{2}\right)}{t}, \quad t > 0$$

where Φ is the standard normal cdf

- $\sigma^2 = \mathbb{E}[X^2] = e$
- $V@R_\epsilon(X) = \exp\left(-\Phi^{-1}(\epsilon) - \frac{1}{2}\right)$

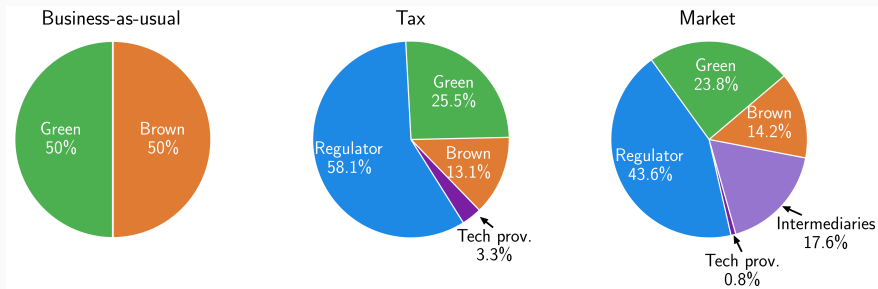
$$\mathbb{ES}_\epsilon(X) = \frac{\Phi(\Phi^{-1}(\epsilon)+1)}{\epsilon}$$

GDP and Emission Values

Group	GDP contributions (billions €)			Emission contributions (million tons)		
	bau	tax	mar	bau	tax	mar
Brown	300	58	61	1,051	367	394
B1	100	10	14	420	106	136
B2	100	20	19	330	140	137
B3	100	28	28	300	121	121
Green	300	112	102	721	380	354
G1	100	31	29	270	133	125
G2	100	36	31	240	138	127
G3	100	45	43	210	110	102
Regulator	—	255	186	—	—	—
Tech providers	—	14	3	—	—	—
Financial intermediaries	—	—	75	—	—	—
Total	600	440	428	1,772	748	748

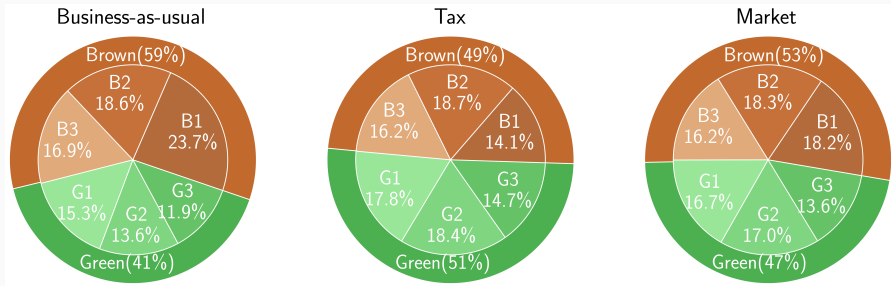
- **GDP:** **bau** → **tax**: -27%; **bau** → **mar**: -29% ; **tax** → **mar**: -2%
- **Emissions:** **bau** → **tax/ mar**: -58%

GDP Shares



The GDP shares of the different actors in the bau case and under the tax and purely intermediated market schemes

Emission Shares



The emissions shares of each company in the bau case and under the tax and purely intermediated market schemes

- Under **tax**, brown companies reduce more relative to green companies

Conclusion

Conclusion

- Comparison of carbon **tax** vs. **market** (ETS), focusing on financial intermediaries.
- Under perfect competition (direct, frictionless access to the central auction), the two schemes are **equivalent** for deterministic and stochastic emissions.
- **Intermediaries break parity:**
 - **Regulatory revenue:** intermediaries capture auction value \Rightarrow regulator revenue falls.
 - **Aggregate economic output:** total wealths (companies + intermediaries + regulator) are lower under an intermediated market.
 - **Distributional effects:** aggregate company wealths decline; individual outcomes depend on cost and production heterogeneity.
 - **Abatement incentives:** taxes incentivize high-intensity companies and green investment; intermediated market tends to induce production cuts under uncertainty.
- **Policy implication:** instrument choice depends on institutional design; intermediary behavior shapes efficiency and equity.
- **Future work:** introduce risk aversion (in the random setup), extend to multi-period models to capture certificate allocation dynamics and the role of derivative markets.

Thank You

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