Carbon pricing with endogenous social preferences

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Outline

Motivations (i) - Robust market-based policy for climate change

- Carbon pricing to orient demand towards "low-carbon" goods (Baranzini et al., 2017; Crampton et al., 2017).
- Economic factors are not the only driver of demand: other social and intrinsic motivations need to be considered - status-seeking, imitation and social norms (Bénabou and Tirole, 2006).
- Robust policy for climate change must take into account changing preferences (Mattauch et al., 2016; 2018).

Motivations (ii) - Evidence for endogenous preferences

- Preferences are shaped by interactions with peers and more broadly by prevailing culture (Bowles, 1998).
- Empirical studies show the influence of visible behaviors of peers: solar panel adoption (Bollinger et al., 2012), modal choice (Weinberger and Goetzke, 2010), energy consumption (Alcott 2011; 2014)
- Experimental studies in neuroeconomics have confirmed the role of social context in formation of preferences (Fehr and Camerer, 2007; Mason et al., 2009; Engelmann and Hein, 2013)

Research questions

How to define a carbon tax that effectively reduces GHG emissions when agents interact and form preferences in a social network?

How does social network structure drive the policy's outcome?

Outline

Consumption choice under endogenous preferences

- Set of agents interacting in a fixed undirected social network N.
- Consumption choice between two goods: low-carbon L and high-carbon H.
- Consumption of agents depends on heterogeneous income and intrinsic preferences, and on the choice of their peers.

Endogenous social preferences (i)

- Agents maximize:

$$U_{i,t}(\alpha_{i,t}, H_{i,t}, L_{i,t}) = \left(\alpha_{i,t} H_{i,t}^{\frac{\sigma-1}{\sigma}} + (1-\alpha_{i,t}) L_{i,t}^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}}, \tag{1}$$

$$\text{s.t.} \quad L_{i,t} P_L + H_{i,t} P_H(\tau) \leq w_i$$

with $\alpha_i \in [0,1]$ the preference for H, σ the elasticity of substitution, w_i the income, P_H and P_L the prices of the goods.

- We normalize $P_L = 1$ and assume that carbon tax τ only affects H:

$$P_H(\tau) = p_H(1+\tau). \tag{2}$$

Endogenous social preferences (ii)

- Agents observe the share of each good consumed in their ego-network N_i.
- The preference for H, α_i, depends on fixed intrinsic preferences, $\pi_i \in [0, 1]$, and social influence $S_{i,t}$:

$$\alpha_{i,t}(\pi_i, S_{i,t}) \equiv (1-\gamma) \times \pi_i + \gamma \times S_{i,t} \tag{3}$$

$$S_{i,t} \equiv \frac{\sum_{j \in N_i} H_{j,t-1}}{\sum_{j \in N_i} H_{j,t-1} + L_{j,t-1}} \tag{4}$$

with $\gamma \in [0, 1]$ the strength of social influence in the formation of preferences. If $\gamma = 0$, agents exhibit standard fixed preferences.

Equilibrium demand

- Optimal demand of agent i, is conditional on agents' j consumption (and vice-versa). Influence of peers increases with her wealth.

- Properties of the utility function and social interactions ensure the existence and uniqueness of an equilibrium (Horst and Scheinkman, 2006). The equilibrium demand vector is a fixed point:

$$H_i^\star(\pi_i, P_H(\tau), w_i) = \underbrace{H_i\left(\pi_i, S_{i,t}(\{\mathbf{H_j^\star}\}_{j\in N_i}), P_H(\tau), w_i\right)}_{\text{Optimal demand given } H_j} \ \forall i \in N \tag{5}$$

- In equilibrium, demand and preference vectors are co-determined.

Carbon tax

The optimal tax $\tau^\star$ ensures that the total consumption H is equal to the GHG emission target Q:

$$\sum_{i \in N} H_i^\star(\pi_i, P_H(\tau^\star), w_i) = Q \tag{6}$$

With endogenous social preferences, we find that a tax has two effects on the consumption of H:

- A direct effect, through the negative price elasticity of demand.
- An indirect effect, through the changes in preferences due to social interactions.

$$\overbrace{\frac{\partial H_i(P_H(\tau), .)}{\partial \tau}}^{\text{Direct price effect}} + \underbrace{\frac{\partial H_i(\alpha_i, .)}{\partial \alpha_i} \frac{\partial \alpha_i}{\partial H_j(P_H(\tau), .)} \frac{\partial H_j(P_H(\tau), .)}{\partial \tau}}_{\text{Indirect price effect through changes in preferences}} \tag{7}$$

Social multiplier of carbon tax

- We derive the social multiplier Ω, which is the adjustment of the optimal tax due to social interactions and changes in preferences:

$$1 + \Omega \equiv \frac{\tau^F}{\tau^\star} \tag{8}$$

with τ^F the optimal tax under fixed preferences.

- $\Omega > 0 \Rightarrow$ Social interactions amplify direct effect of tax

- $\Omega < 0 \Rightarrow$ Social interactions counteract direct effect of tax

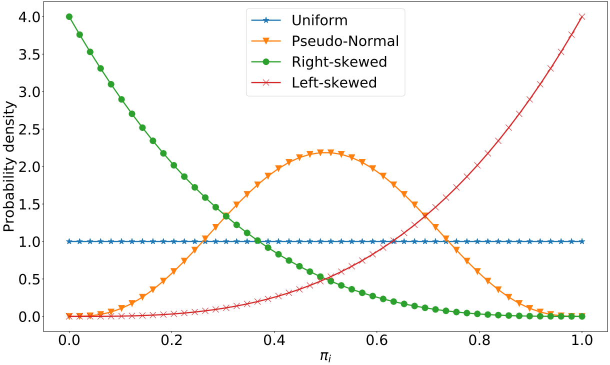
Outline

Drivers of the social multiplier

We investigate the influence of four factors on the social multiplier Ω:

1. Distribution of intrinsic preferences, π.
2. Topology of the social network, N.
3. Strength of the social influence in the formation of preferences, γ.
4. Distribution of income, w.

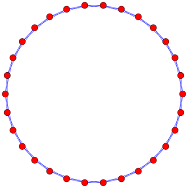
Drivers (i) - Distributions of intrinsic preference (π_i)



Drivers (ii) - Network topology

	Average Clustering	Average path length	Degree asymmetry (Skewness)
Regular	**50.00 %**	**1,250.00**	**0.00**
Small world	35.48 %	12.50	0.16
Random	0.04 %	6.76	0.50
Scale free	0.15 %	4.27	36.30

Table: Network Characteristics - 10,000 agents, 20,000 undirected links



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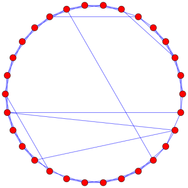

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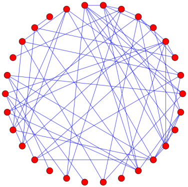

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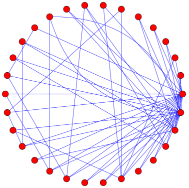


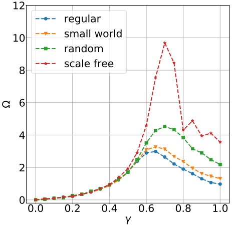
Drivers (iii) and (iv) - Income and strength of social influence

- With income inequality (Gini Index $= 0.43$) or without.
  - Income and degree distributions weakly correlated ($\rho = 0.24$).

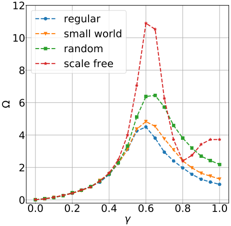
- Vary strength of social influence in the preference formation, γ, between 0 and 1. Eq. (3):

$$\alpha_{i,t}(\pi_i, S_{i,t}) \equiv (1-\gamma) \times \pi_i + \gamma \times S_{i,t}$$

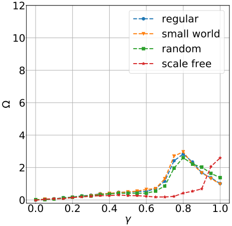
Results (i) - Social multiplier with income inequality



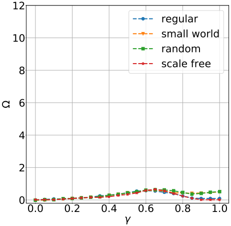
$\pi \sim$ Uniform



$\pi \sim$ Pseudo-Normal



$\pi \sim$ Right-skewed



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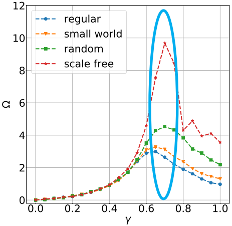

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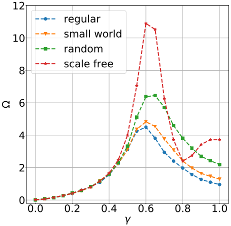

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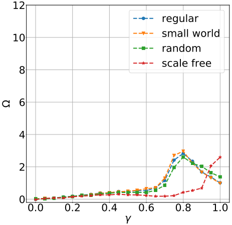

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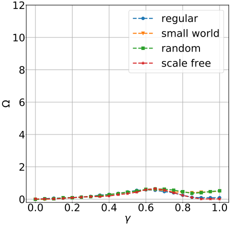

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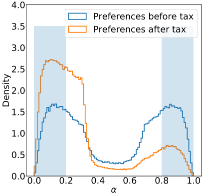
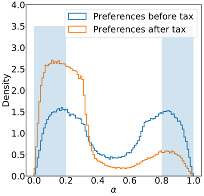
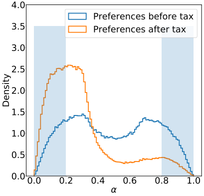
- Higher social multiplier when preferences are less polarized before the tax.
- Polarization increases with the strength of social influence γ. There is a $\gamma < 1$ that maximizes the social multiplier.



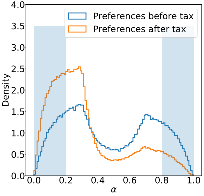
Regular



Small world



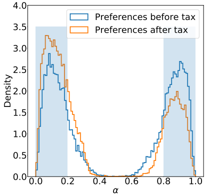
Random



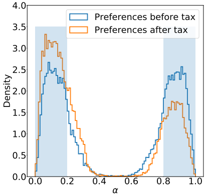
Scale free

Preference distribution in equilibrium, $\gamma = 0.7$, top-decile income

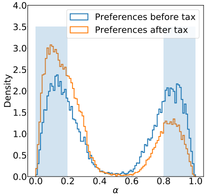
- Wealthy agents are generally more polarized.
- In scale free network wealthy agents are less polarized due to positive assortativity.



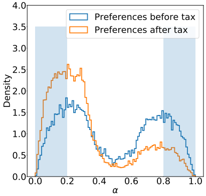
Regular



Small world



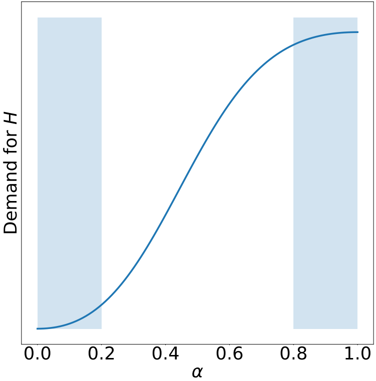
Random



Scale free

Polarized preferences and social multiplier

1. Social multiplier is driven by changes in preferences, α, due to social interactions.
2. Agents with "extreme" preferences react less to social interactions and contribute less to change preferences of neighbors.
3. Hence social multiplier is lower when preferences are polarized.

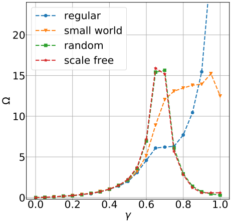


$$H = w\left(\frac{\alpha}{P_H(\tau)}\right)^{\sigma} \frac{1}{\alpha^{\sigma} P_H(\tau)^{1-\sigma} + (1-\alpha)^{\sigma}}$$

Results (ii)

	Income inequality
Clustering	Lower Ω: lock-in due to wealthy agents with high local influence and polarized preferences
Short average path length	Higher Ω: avoided lock-in because wealthy agents have lower social influence
Degree asymmetry	Higher Ω: wealthy agents less polarized because of positive assortativity

Results (iii) - Social multiplier with income equality



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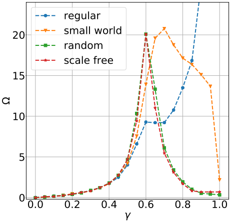

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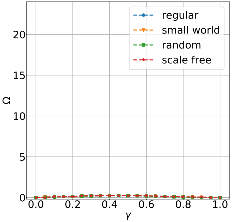

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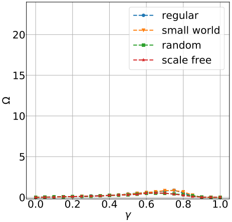

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Results (iv)

	Income inequality	Income equality
Clustering	Lower Ω: lock-in due to wealthy agents with high local influence	-
Short average path length	Higher Ω: avoided lock-in because wealthy agents have lower social influence	Higher Ω: better diffusion of changes in preferences
Degree asymmetry	Higher Ω: wealthy agents less polarized because of positive assortativity	Lower Ω: polarization due to influential well-connected agents

Outline

Conclusions

1. Tax affects consumption not only through the usual price elasticity but also through changes in preferences due to social interactions.
2. We derive the social multiplier, Ω, which is the amplification of the direct effect of the tax. A higher social multiplier helps to achieve the emission target.
3. The social multiplier is higher when preferences are not polarized. This happens when:
   - a majority of agents have "non-extreme" intrinsic preferences.
   - the social network has short average path length.
   - the income is equally distributed and the social network has a low degree asymmetry.
   - the income is unequally distributed and the social network has a high degree asymmetry.

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APPENDIX

1. Model
2. Results

MODEL

Endogenous preferences (i)

Assuming the budget constraint holds with equality, we write :

$$\alpha_{i,t}(\{H_j, w_j\}_{j \in N(i)}, P_H(\tau), \pi_i) = \gamma \frac{\sum_{j \in \mathrm{N}_i} H_{j,t-1}}{\sum_{j \in \mathrm{N}_i}(1 - P_H(\tau))H_{j,t-1} + w_j} + (1-\gamma)\pi_i. \quad (9)$$

With endogenous preferences, the utility at the optimum, of agent i is a function of her consumption, her intrinsic preference, the relative price of the high-carbon good, her income, and the consumption decisions and incomes of her neighbors.

Endogenous preferences (ii)

The variable $\rho_{i,j}$ encodes the effect of an increase in the consumption of the high-carbon good by agent j on the preference for the same good of agent i.

$$\rho_{i,j} \equiv \frac{\partial \alpha_{i,t}(H_j, .)}{\partial H_j} = \gamma \frac{T_i - (1 - P_H(\tau))\tilde{H}_i}{T_i^2} \geq 0 \tag{10}$$

with T_i being the total consumption in agent's i ego-network, and $\tilde{H}_i$ the consumption of high-carbon goods in agent i ego-network.
The effect of peers interactions depends implicitly on agents' income.The introduction of income inequality translates to asymmetric and weighted social interactions in the network.

$$\frac{\partial \rho_{i,j}}{\partial w_j} = \gamma \frac{T_i^2 + 2(T_i - (1 - P_H(\tau))\tilde{H}_i)((1 - P_H(\tau))H_{w_j} + 1)}{T_i^4} \geq 0 \tag{11}$$

Equilibrium

Equilibrium is defined as a vector of high-carbon consumption where no agents can be better off by deviating. The action space $\{H\}$ is compact and convex, and the utility function is continuous in the agent own choice and the choice of her peers. As our system only exhibits local interactions, the existence and uniqueness of the equilibrium follows from the concavity of the utility function, via a fixed-point argument (Horst and Scheinkmann, 2006).

$$H_i^\star(\pi_i, P_H(\tau), w_i) = \underbrace{H_i\left(\pi_i, S_{i,t}(\mathbf{H_j^\star}), P_H(\tau), w_i\right)}_{\text{Optimal demand given } H_j} \ \forall i \in N \tag{12}$$

Carbon Tax

Let Q denotes the GHG emission target and Q_0 the initial emission level. The objective is to find the lowest tax τ that could achieve the target. Hence, the optimal tax $\tau^\star$ solves:

$$\tau^\star = min\ \tau \qquad (13)$$
$$\text{s.t.} \sum_{i \in N} H_i^\star(\pi_i, P_H(\tau), w_i) \leq Q.$$

As $H_i^\star(P_H(\tau), .)$ is decreasing in τ, solving Eq.(13) is equivalent to finding τ satisfying the following equality:

$$\sum_{i \in N} H_i^\star(\pi_i, P_H(\tau), w_i) = Q. \qquad (14)$$

Carbon tax and social interactions (out of equilibrium)

The carbon tax indirectly alters preferences through the social interactions between agents defined in Eq.(10). The effect of a tax on high carbon consumption of agent i taking preferences of agents j as constant is (out of equilibrium):

$$\frac{dH_i(P_H(\tau), \alpha_i, .)}{d\tau} = \frac{\partial H_i(P_H(\tau), .)}{\partial \tau} + \frac{\partial H_i(\alpha_i, .)}{\partial \alpha_i} \frac{\partial \alpha_i}{\tau}$$
$$= \overbrace{\frac{\partial H_i(P_H(\tau), .)}{\partial \tau}}^{\text{Direct price effect}} + \underbrace{\frac{\partial H_i(\alpha_i, .)}{\partial \alpha_i} \frac{\partial \alpha_i}{\partial H_j(P_H(\tau), .)} \frac{\partial H_j(P_H(\tau), .)}{\partial \tau}}_{\text{Indirect price effect through changes in preferences}} \tag{15}$$

Let F be:

$$F(H^\star(\pi, P_H(\tau), w), P_H(\tau), w) = H^\star(\pi, P_H(\tau), w) - H(\alpha^\star, P_H(\tau), w) = 0 \tag{16}$$

By the implicit function theorem:

$$\frac{\partial H^\star(\pi, P_H(\tau), w)}{\partial \tau} = (I + \omega(\tau)) \frac{\partial H(\alpha, P_H(\tau), w)}{\partial \tau}\bigg|_{\alpha=\alpha^{\star,0}} \tag{17}$$

with $(I + \omega(\tau)) = F_H^{-1}$

and $\alpha^{\star,0}$ the equilibrium preferences before the tax.

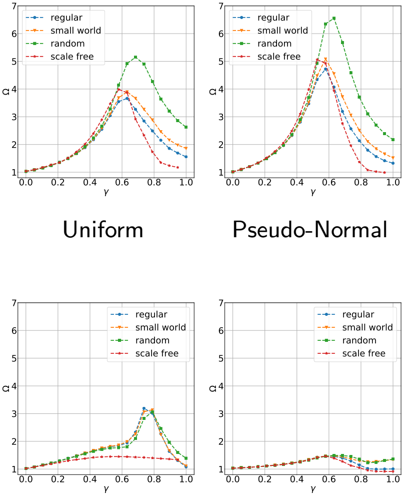
$(I + \omega(\tau))$ will contribute to define the social multiplier of the carbon tax. See Horst and Scheinkmann (2006) for a formal analysis of social multiplier in system of local interactions.

RESULTS

Sign of social multiplier

- In a vast majority of cases $\Omega > 0$ implying that the social interactions strengthen the first-order price effect.
- $\Omega < 0$ in a population with a majority of agents with strong intrinsic preferences for high-carbon interacting in a scale free network with very high degree asymmetry (almost star network).

Results - Social multiplier with income inequality - SF almost star-network, skewness = 0.77



Uniform

Pseudo-Normal

Right-skewed

Left-skewed