Unequal Climate Policy in an Unequal World

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Introduction

- What is optimal climate policy in a world with inequality?
- We build a heterogeneous agent climate-macro model to
  - theoretically provide a characterization of the optimal carbon tax
  - quantitatively study the effects of climate policy on the economy, the climate, and the distribution of welfare over time.

Carbon Taxes and Inequality

- How are inequality and the optimal carbon tax related?
  - Carbon taxes affect inequality (can potentially hurt the poor) ⇒ We focus on policies that are neutral in terms of the initial income/wealth distribution.
  - Inequality affects the optimal carbon tax formula. We provide a formal characterization of the optimal carbon tax rate and a quantitative estimation of the tax rates.

A Win-Win Climate Policy

- The benefits from a better climate (reduction in global temperature) more than compensate the disutility from the distortions to the consumption bundle
  - There are no income effects, by construction
- The optimal carbon taxes are a win-win climate policy leading to welfare gains in the aggregate but also for every individual.
  - Everybody (present and future, rich and poor) is better-off.

Roadmap

1. Use simple model to characterize the optimal carbon tax formula under various constraints
    - no constraints ⇒ first-best Pigouvian tax
    - constrained efficiency: no transfers across households
    - constrained efficiency with uniform carbon tax across households
2. Generalize the analytical characterizations to a richer model
3. A quantitative application
    - Heterogeneous-agent macro-climate model
    - Calibration
    - Evaluate the aggregate and welfare consequences of enacting carbon taxes informed by theory

Related Literature

- **Carbon taxation with representative agent:** Nordhaus and Boyer (2003), Nordhaus (2007), Golosov et. al. (2014), Barrage (2018), Belfiori (2017).
- **Carbon taxation with heterogeneous agents:** Jacobs and Van Der Ploeg (2019), Douenne, Hummel and Pedroni (2023), Belfiori and Macera (2024), Fried et al. (2018, 2023), Krusell and Smith (2022), Känzig (2022).
- **Distributional role of carbon tax revenue:** Rausch et al. (2011), Pizer and Sexton (2019), Fullerton and Monti (2013), Goulder et. al. (2019).
- **Inequality and Carbon:** Sager (2019), Levinson and O'Brien (2019), Grainger and Kolstad (2010).

Simple Model

Model

- Economy populated by a continuum of households, indexed by i, with measure μ_i
- Two consumption goods, clean and dirty: (c^i_{ct}, c^i_{dt})
- Production of the clean and the dirty good uses labor to produce according to: $Y_{ct} = N_{ct}$; $Y_{dt} = N_{dt}$
- Consumption of the dirty good adds carbon to the atmosphere:

$$S_{t+1} = S_t(1-\delta) + \upsilon \sum_i \mu_i c^i_{dt}$$

Households

- Households' preferences over consumption and atmospheric carbon are given by

$$\sum_{t=0}^{\infty} \beta^t \left[u(c^i_{ct}, c^i_{dt}) - x(S_{t+1}) \right]$$

  where x is the climate damage function, $x' > 0$ and $x'' > 0$
- Households choose consumption (c^i_{ct}, c^i_{dt}) to maximize utility subject to budget constraints

$$p_{dt} c^i_{dt} + c^i_{ct} \leq \varepsilon^i_t + T^i_t, \;\; \forall t$$

  where $p_{ct} = w = 1$ and ε^i_t is the labor endowment, inelastically supplied.

Optimal Climate Policy

- The optimal allocation (with weights α_i) is the solution to

$$\max_{\left\{c^i_{ct}, c^i_{dt}, S_{t+1}\right\}_t} \sum_i \alpha_i \sum_{t=0}^{\infty} \beta^t \left[u\left(c^i_{dt}, c^i_{ct}\right) - x(S_{t+1})\right]$$

$$\text{s.t. } S_{t+1} \geq (1-\delta)S_t + \upsilon \sum_i \mu_i c^i_{dt} \quad \dots \quad (\beta^t \sigma_t)$$

$$\sum_i \mu_i \left(c^i_{ct} + c^i_{dt}\right) \leq \sum_i \mu_i \varepsilon_i \quad \dots \quad (\beta^t \lambda_t)$$

- The first order condition with respect to S_{t+1} implies:

$$\boxed{\sigma_t = \underbrace{\sum_{j=1}^{\infty} [\beta(1-\delta)]^{j-1} x'(S_{t+j})}_{\text{social cost of carbon}}}$$

Characterization of Optimal Allocation

- The first order conditions for clean and dirty consumption:

$$
\begin{aligned}
(c^i_{dt}) &: \frac{\alpha_i}{\mu_i} u^i_{dt} - \upsilon \sigma_t - \lambda_t = 0 \\
(c^i_{ct}) &: \frac{\alpha_i}{\mu_i} u^i_{ct} - \lambda_t = 0
\end{aligned}
$$

- These conditions hold for all i. Thus,

$$
\begin{aligned}
\lambda_t + \upsilon \sigma_t &= \boxed{\frac{\alpha_i}{\mu_i} u^i_{dt} \equiv u^\star_{dt} \ \ \forall i} \\
\lambda_t &= \boxed{\frac{\alpha_i}{\mu_i} u^i_{ct} \equiv u^\star_{ct} \ \ \forall i}
\end{aligned}
$$

$\Rightarrow$ Weight-adjusted marginal utilities are equated across agents.

Characterization of Optimal Allocation

- The planner wants to affect the relative price between clean and dirty consumption to reflect the social cost of carbon

$$\frac{u^i_{dt}}{u^i_{ct}} = 1 + \boxed{\frac{\upsilon \sigma_t}{u^\star_{ct}}}_{\text{Climate externality: Pigouvian tax}}$$

- The optimal allocation can be implemented in a market economy with:

$$\tau^\star_t = \frac{\upsilon \sigma_t}{u^\star_{ct}} \quad \forall t$$

Redistribution in the Optimal Policy

- If the planner is Utilitarian (i.e. $\alpha_i = \mu_i$), the optimal allocation involves significant redistribution across households.
- What if the planner uses Negishi weights (i.e. no incentive to redistribute)?
    - under certain conditions, we can show that the Negishi optimal carbon tax is (weakly) greater than the Utiliarian optimal tax.
- In what follows, we focus on a Utilitarian planner with constrained efficiency: no net transfers across households (à la Davila, Hong, Krussel, Rios-Rull 2012)

Constrained Efficient Climate Policy

- The optimal allocation $\left\{c^i_{ct}, c^i_{dt}, S_{t+1}\right\}_{t=0}^{\infty}$ maximizes

$$\sum_i \mu_i \sum_{t=0}^{\infty} \beta^t \left[u\left(c^i_{dt}, c^i_{ct}\right) - x(S_{t+1})\right] \text{ s.t.}$$

$$S_{t+1} \geq (1-\delta)S_t + \upsilon \sum_i \mu_i c^i_{dt}$$

$$c^i_{dt} + c^i_{ct} \leq \varepsilon^i_t \;\; \forall i, t$$

Proposition [Constrained Efficient Climate Policy]

Let $\left\{\tau_t^i, T_t^i\right\}_{t=0,\forall i}^{\infty}$ be a sequence of carbon taxes on dirty consumption and lump-sum transfers. The constrained efficient allocation can be implemented in a market economy with:

$$\tau_t^i = \frac{\upsilon \sigma_t}{u_{ct}^i}; \quad T_t^i = \tau_t^i c_{dt}^i \quad \forall i, t$$

1. The transfers guarantee that the consumer's budget constraint holds for all i.
2. The constrained efficient carbon tax is similar to the optimal one, but deviates in an important way: τ_t^i higher for wealthier households because they have a lower marginal utility

Takeaway

- The constrained efficient carbon tax in a heterogeneous economy is heterogeneous

Can we make it homogeneous?

- To get a homogeneous carbon tax as the outcome of an optimal policy design for a heterogeneous-agent economy, we must impose uniformity of the tax rate as an additional constraint in the planning problem.
- Using the optimality conditions, we must impose:

$$\frac{u^i_{dt}}{u^i_{ct}} = \frac{u^j_{dt}}{u^j_{ct}} \;\; \forall i, j, t$$

Uniform Constrained-Efficient Climate Policy

- The uniform constrained-efficient allocation $\left\{c_{ct}^{i}, c_{dt}^{i}, S_{t+1}\right\}_{t=0}^{\infty}$ maximizes

$$
\begin{aligned}
&\sum_{i} \mu_i \sum_{t=0}^{\infty} \beta^t \left[u\left(c_{dt}^{i}, c_{ct}^{i}\right) - x(S_{t+1})\right] \text{ s.t.} \\
&S_{t+1} \geq (1-\delta) S_t + \upsilon \sum_{i} \mu_i c_{dt}^{i} \\
&c_{dt}^{i} + c_{ct}^{i} \leq \varepsilon_t^{i} \ \ \forall i, t \\
&\frac{u_{dt}^{i}}{u_{ct}^{i}} = \frac{u_{dt}^{j}}{u_{ct}^{j}} \ \ \forall i, j, t
\end{aligned}
$$

Proposition [Uniform Constrained-Efficient Carbon Tax]

Let $\left\{\tau_t, T_t^i\right\}_{t=0,\forall i}^{\infty}$ be a sequence of carbon taxes on dirty consumption and lump-sum transfers. The uniform constrained efficient allocation can be implemented in a market economy with:

$$\tau_t = \frac{\upsilon \sigma_t}{\sum_i \frac{\mu_i c_t^i}{\sum_j \mu_j c_t^j} u_{ct}^i}; \quad T_t^i = \tau_t c_{dt}^i \quad \forall i, t$$

- The uniform constrained-efficient carbon tax uses a weighted average of marginal utilities to price the climate externality.
- When risk aversion is greater than 1, consumption-weighted average marginal utility is higher than marginal utility of average consumption

Generalizations of the Optimal Tax Formulas

- In the paper, we generalize the optimal tax derivations to include
    - non-homothetic preferences
    - stochastic shocks
    - endogenous labor and capital
    - ad hoc borrowing constraints
    - uniform tax/subsidy/transfer implementation
- We now turn to quantitative applications that incorporate these features to evaluate the aggregate and welfare consequences of implementing optimal climate policies.

Quantitative Model

Model

- Heterogeneous agents model with incomplete markets (Aiyagari, Bewley, Hugget, Imrohoroglu)
- Economy populated by a continuum of households, indexed by i, with measure μ_i
- Two consumption goods, clean and dirty: (c^i_{ct}, c^i_{dt})
- Production of the clean and the dirty good uses labor and capital with CRS technology: $Y_{ct} = F(K_{ct}, N_{ct})$; $Y_{dt} = F(K_{dt}, N_{dt})$
- Consumption of the dirty good adds carbon to the atmosphere:

$$S_{t+1} = S_t(1 - \delta) + \upsilon \sum_i \mu_i c^i_{dt} \tag{1}$$

Households

- Preferences over consumption, leisure, and carbon:

$$\mathbf{E}_0 \sum_{t=0}^{\infty} \beta^t \left[u(c^i_{ct}, c^i_{dt}, \ell^i_t) - x(S_{t+1})\right]$$

- Households choose consumption (c^i_{ct}, c^i_{dt}), capital k^i_t, and labor n^i_t to maximize utility subject to

$$p_{dt} c^i_{dt}(1+\tau_t) + c^i_{ct} + k^i_{t+1} - k^i_t \leq y^i_t, \quad \forall t$$
$$k^i_{t+1} \geq 0, \quad \forall t$$

where $p_{ct} = 1$, $\ell^i_t = 1 - n^i_t$, and

$$y^i_t \equiv w_t \varepsilon^i_t n^i_t - T(w_t \varepsilon^i_t n^i_t) + (r_t - \delta_k) k^i_t (1 - \tau_{kt}) + Tr^i_t$$

Calibration strategy

- Many model parameters affect both economic and climate outcomes (e.g., discount factor, disutility of work, preference for dirty good)
- Other parameters affect climate only (e.g., disutility from climate damage, carbon content of dirty consumption, carbon absorption). Why?
    1. climate damage enters separably in utility
    2. carbon does not directly affect production
- This allows us to first calibrate the model's economic parameters to an "economic" steady state, and then calibrate the model's climate parameters

Calibration: Preferences

- Utility function:

$$u\left(c_c, c_d, \ell\right) = \frac{\left(\left(c_c + \bar{c}\right)^{\gamma} c_d^{1-\gamma}\right)^{1-\kappa}}{1-\kappa} - \phi \frac{(1-\ell)^{1+\nu}}{1+\nu}$$

Parameters	Values	Targets / Source
Discount factor β	0.97	Wealth-to-GDP: 4.8 (2014)
Risk aversion κ	2	Standard value
Labor disutility, ϕ	29.6	Average hours: 30 percent
Frisch elasticity $1/\nu$	0.5	Standard value
Clean share γ	0.97	\$50/ton carbon tax leads to 0.8 degree reduction from BAU
Non-homotheticity $\bar{c}$	0.16	emissions intensity 31% higher for ▸ low-income than high-income households

Calibration: Technology and Shocks

- Production function: $F(K,N) = K^{\alpha}N^{1-\alpha}$
- Normal productivity: $\log(\varepsilon_t^i) = \rho\log(\varepsilon_{t-1}^i) + \xi_t^i,\ \xi_t^i \sim N(0,\sigma_\varepsilon^2)$
- Superstar state ε_{sup} to match wealth/earnings distribution

Parameters	Values	Targets / Source
Capital weight, α	0.36	capital income share: 36%
Capital depreciation, δ_k	0.05	standard value
Productivity persistence ρ	0.94	author estimates
Standard deviation, σ_ε	0.20	earnings Gini: 0.47
Superstar parameters		
productivity, $\varepsilon_{sup}/\varepsilon_{med}$	163	wealth share top 1.0%: 34%
persistence, $\pi(\varepsilon_{sup},\varepsilon'_{sup})$	0.94	wealth Gini: 0.83
entry probability, $\pi(1:9,\varepsilon'_{sup})$	6e-5	fraction of superstars: 0.1%

Calibration: Government

- Progressive earnings tax (Benabou, HSV, Daruich-Fernandez, ...)

$$T(y) = y - \tilde{y}^{\nu_y} \frac{1-\tau_y}{1-\nu_y} y^{1-\nu_y}$$

where $\tilde{y}^{\nu_y}$ is average earnings

Parameters	Values	Targets / Source
Average tax parameter, τ_y	0.23	average labor income tax: 13%
Progressivity parameter, ν_y	0.17	37.9% marginal tax rate on top 1% earners
Capital income tax, τ_k	0.27	Carey and Rabesona (2002)
Consumption tax, τ_c	0.06	Carey and Rabesona (2002)

Calibration: Climate

- Temperature function: $T_t = \frac{\lambda}{\log(2)} \log\left(\frac{S_t}{\overline{S}}\right)$ (Golosov et al. 2014)
- Climate damage function: $x(S) = \frac{\psi}{2} S^2$

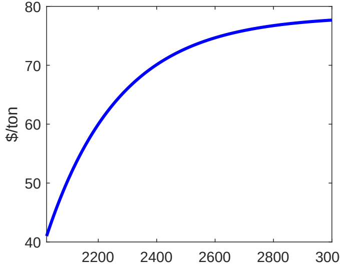
Parameters	Values	Targets / Source
Carbon absorption, δ	1/300	average life of carbon: 300 years
Carbon intensity, υ	326.4	1.4 degree increase by 2100 under BAU
Climate disutility, ψ	0.04	welfare loss from 2.5 degree increase $\approx$ 1.74 percent output reduction
Temperature parameters		
climate sensitivity, λ	3	doubling of carbon $\Rightarrow$ 3-degree increase
initial carbon, $\overline{S}$	581	pre-industrial carbon stock (gigatons)

Quantitative Exercises

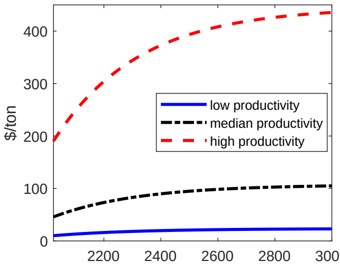
Carbon tax

- We use the Pigouvian tax formulas from our propositions
- Tax formulas depend on endogenous variables
    - carbon stocks, marginal utilities
    - start with BAU allocations to calculate carbon tax; solve transition;
    - update carbon tax with new allocations; repeat until convergence
- For today, heterogeneous carbon tax based on current productivity (+ history in progress)

(a) Uniform carbon tax

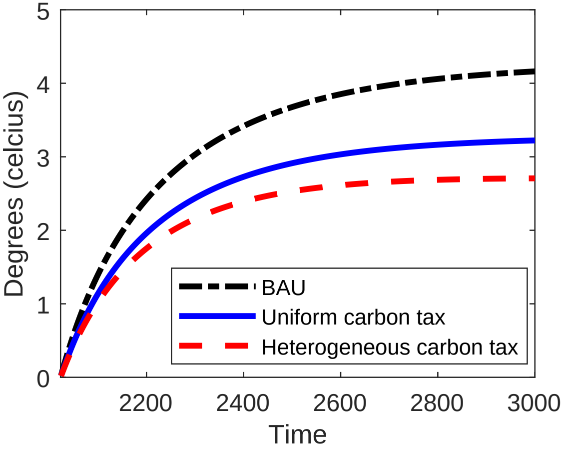


(b) Heterogeneous carbon tax



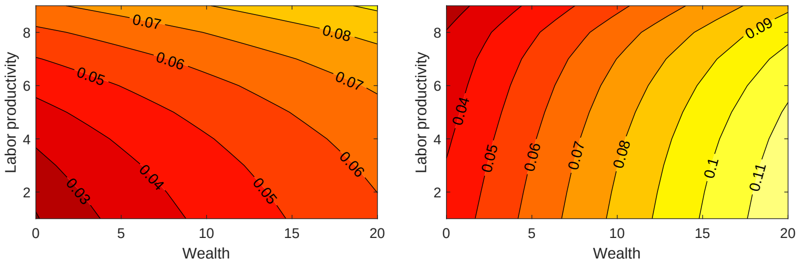
Global Temperature

- The carbon tax leads to a 1–2 degree reduction compared to BAU



Initial distribution of welfare (Pareto improving)

- Welfare gains (relative to BAU) positive for all! Especially for the wealthy



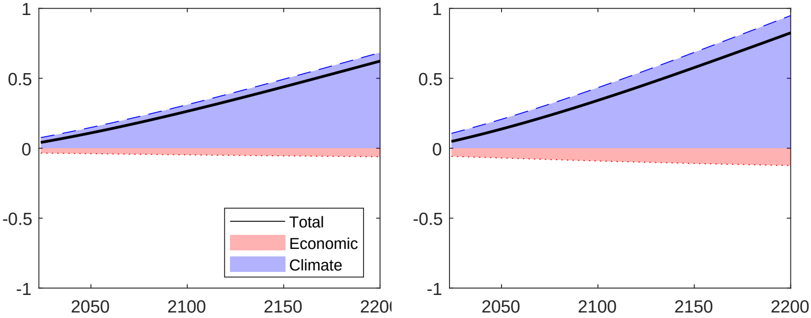
(a) Uniform carbon tax

(b) Heterogeneous carbon tax

Units: Permanent consumption equivalents (percent)

Average welfare decomposition over time

- Average welfare gains become large over time



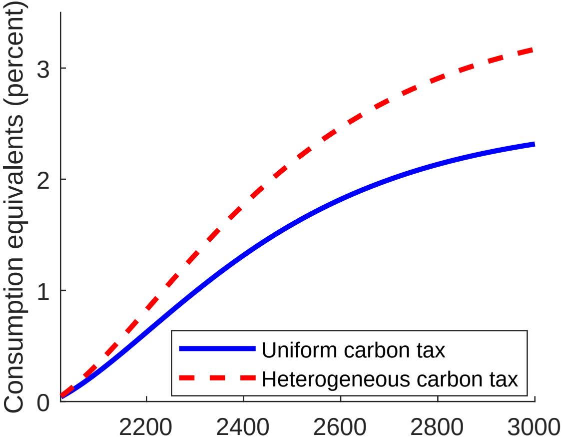
(a) Homogeneous carbon tax

(b) Heterogeneous carbon tax

Units: Permanent consumption equivalents (percent)

Average welfare gains over time

- Average welfare gains larger for the heterogeneous carbon tax, both initially and throughout the transition



Conclusions

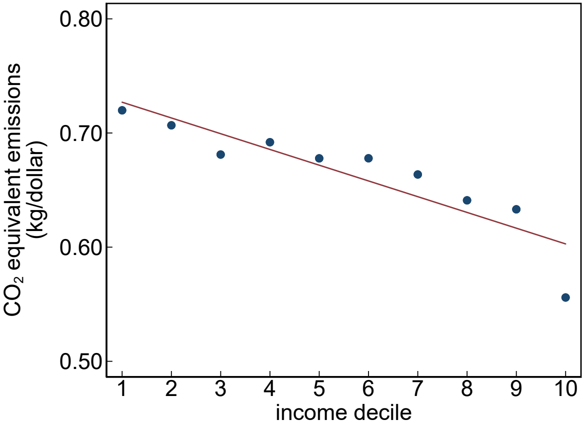
- Inequality is an important factor to consider in the design of optimal climate policy.
- Well-designed (informed by theory) climate policies can lead to Pareto improving welfare gains.
- Next steps:
  - Implement constrained optimal climate policy with carbon tax and clean subsidy

Appendix

Data back to calibration

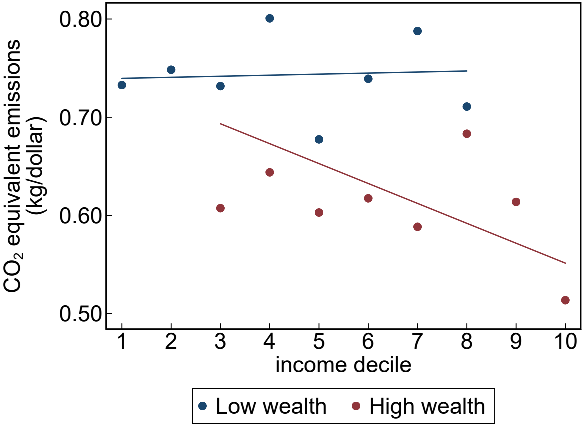
- We combine two datasets
- Environmental Protection Agency (EPA)
  - embodied emissions for 460 commodities (covering cradle → factory gate → shelf) details
- Consumer Expenditure Survey (CEX, 2019)
  - 671 expenditure categories
  - 5000+ working-age households
  - construct CEX-NAICS concordance examples
- Compute CO_2-equivalent embodied emissions per dollar spent, for each household

Embodied emission shares higher for low-income



back to calibration PSID

Embodied emission shares higher for low-income and low-wealth



back to calibration PSID

Embodied emissions and expenditure shares

- Emission intensities are higher for low-income households because they spend relatively more on high-intensity goods

Expenditure category	Embodied emissions (CO_2 kg/dollar)	Expenditure shares (percent)	
		Low income	High income
Utilities	1.71	11.0	6.8
Transportation	1.09	22.3	21.4
Food/Beverages at home	0.80	17.1	10.2
Household furnishings/equipment	0.28	2.5	4.4
Food/Beverages away from home	0.21	5.7	8.4
Clothing and footwear	0.20	2.3	3.5
Education and child care	0.18	1.0	9.3
Entertainment	0.15	4.0	7.2
Health care	0.14	7.2	9.5
Shelter	0.11	21.4	11.8
Other expenditures	0.10	5.6	7.6

High and low income correspond to the top and bottom deciles of income, respectively, conditional on working age.

back to calibration

Summary of empirical findings back to calibration

- Embodied emission intensities decline with income and wealth
- Robust to controlling for household characteristics: Regressions
  - household head age
  - household head education
  - household size
- Robust to:
  - alternative emissions dataset (FRS)
  - alternative expenditure dataset (PSID)

Selected examples of UCC-Naics concordance

back

UCC	Description	NAICS	Description	$C0_2e$ emissions (kg/2018 USD)
100210	Cheese	311513	Cheese Manufacturing	1.585
90110	Fresh Milk All Types	311511	Fluid Milk Manufacturing	1.323
80110	Eggs	112300	Chicken Egg Production	1.052
140110	Frozen Vegetables	311411	Frozen Fruit, Juice, Vegetable Mfg.	.846
610310	Pet Food	311111	Dog and Cat Food Mfg.	.75
530210	Intercity bus fares	485210	Interurban/Rural Bus Transportation	.515
170110	Cola Drinks	312111	Soft Drink Manufacturing	.444
190212	Dinner At Full Service	722511	Full-Service Restaurants	.255
450220	New Motorcycles	336991	Motorcycle, Bicycle, and Parts Mfg.	.254
370314	Boys pants and shorts	315220	Men's/Boys' Cut/Sew Apparel Mfg.	.187
630110	Cigarettes	312230	Tobacco Manufacturing	.153
560110	Physicians Services	621111	Offices of Physicians	.082

Details on embodied emissions data (EPA) back

- Included greenhouse gases: CO_2, Methane (CH_4), Nitrous Oxide (N_2), Other GHGs
- Convert to CO_2 using IPCC (The Intergovernmental Panel on Climate Change) AR4 (Assessment Report) GWP-100 (Global warming potential over 100 years, compared to CO_2)
- covers supply chain emissions (cradle to factory gate) and also margins (factory gate to shelf, including transportation, wholesale and retail)
- Environmentally-Extended Input-Output (EEIO) model
  - compute direct requirement matrix using Make/Use Tables
  - compute total requirement matrix using Leontief Inverse
  - combine with direct emissions factors from National Greenhouse Gas Industry Attribution Model (NGIAM)

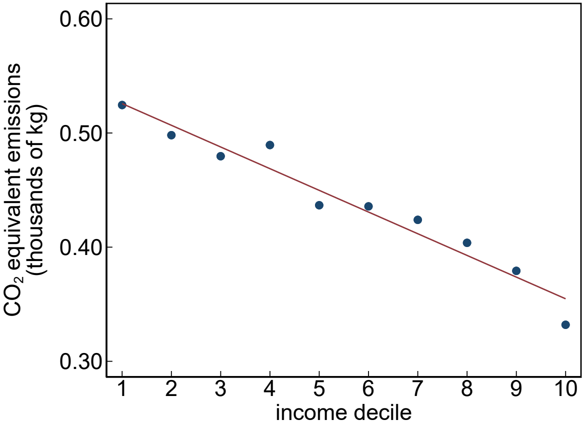
Embodied emission shares back

	(1)	(2)	(3)	(4)
Wealth	-1.68^{***}		-1.35^{***}	-1.10^{***}
	(0.053)		(0.068)	(0.070)
Income		-3.69^{***}	-1.79^{***}	-2.83^{***}
		(0.095)	(0.224)	(0.247)
College=1				-4.51^{***}
				(0.381)
Observations	16368	56122	16368	16368
Adjusted R^2	0.057	0.026	0.060	0.135

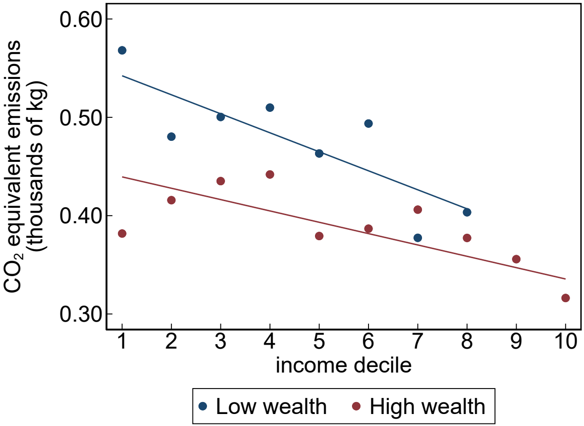
Standard errors in parentheses. $* \ p < 0.10$, $** \ p < 0.05$, $*** \ p < 0.01$
(4) additionally includes age and family size fixed effects.

- sd(log(wealth)) $= 3.3$
- sd(log(income)) $= 1.0$

Emission shares higher for low-income (PSID) back



Embodied emission shares higher for low-income and low-wealth (PSID) back



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