Income Inequality and Carbon Consumption

Evidence from Environmental Engel Curves

(GRI WP 285 & CCCEP WP 319)

Lutz Sager

London School of Economics

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Motivation: The "equity-pollution" dilemma

Existing literature: Income and carbon

- Income is strong predictor for CO_2 footprint (e.g. Chancel & Piketty, 2015)
- **BUT** Income elasticity < 1 (e.g. Chakravarty et al., 2009)
  - Necessities are carbon-intensive (e.g. Pearce, 1991)
  - Regulation / taxation can be regressive (e.g. Poterba, 1991)

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The "equity-pollution" dilemma:

Given the higher pollution intensity of consumption per unit of expenditure by poorer households, progressive redistribution may result in higher aggregate pollution from consumption.

Overview & Contribution

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- Estimate GHG content of household consumption in United States (1996-2009)
- Estimate Environmental Engel curves (EEC) following Levinson & O'Brien (*forthcoming*)
  - Upward-sloping, Concave, Shifting down
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- Use parametric EECs to decompose CO_2e between / within time
- Quantify the "equity-pollution" dilemma:
  - Marginal redistribution: +5.1 per cent in CO_2
  - Full redistribution: +2.3 per cent
  - Hypothetical Sweden: +1.5 per cent

Previous literature: Inequality & emissions

Theory: How inequality may affect environmental outcomes

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Evidence: Association between inequality and emissions

- Baek & Gweisah (2013): positive association (time-series, US, 1967-2008)
- Heerink et al. (2001): negative association (panel, 180 countries, 1961-2001)
- Others; BUT problems of identification for causal inference

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- Others; BUT problems of identification for causal inference

Contribution: I estimate the "equity-pollution" dilemma based on household consumption data within one country (United States).

Data

Data Sources:

- U.S. Consumer Expenditure Survey (CEX)
  - 51,265 CU (1996 - 2009, yearly)
- World Input-Output Database (WIOD)
  - Trade flows between 40 countries, 35 sectors
  - Emissions per sector (CO_2, CH_4, N_2O)

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GHG Accounting:

- Input-output based accounting of indirect emissions $kgCO_2/\$$
  - Accounting for global supply chain
  - Accounting for imported final goods
- Direct emission factors for transport fuels, heating fuels and electricity

Methodology: From consumption to emissions

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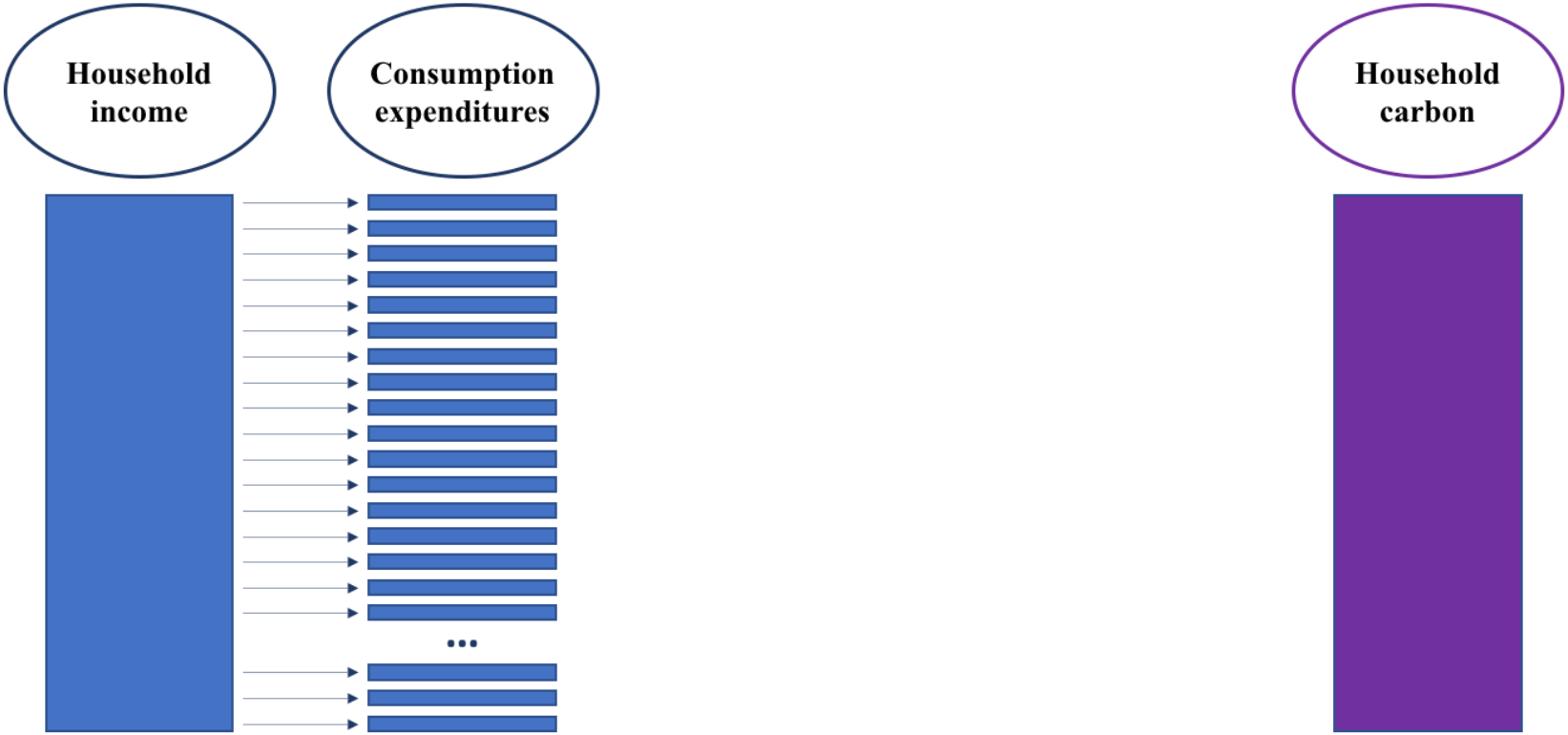

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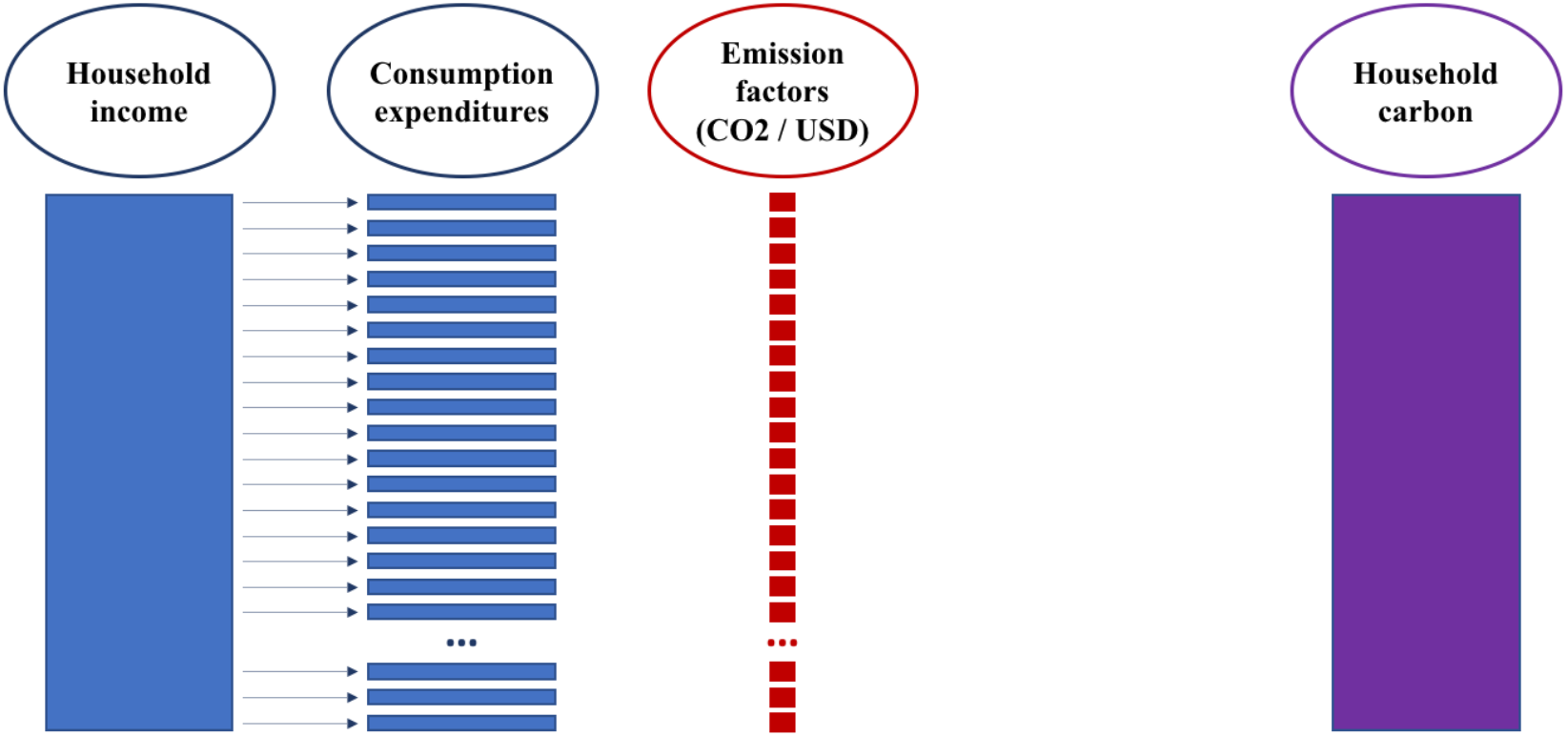

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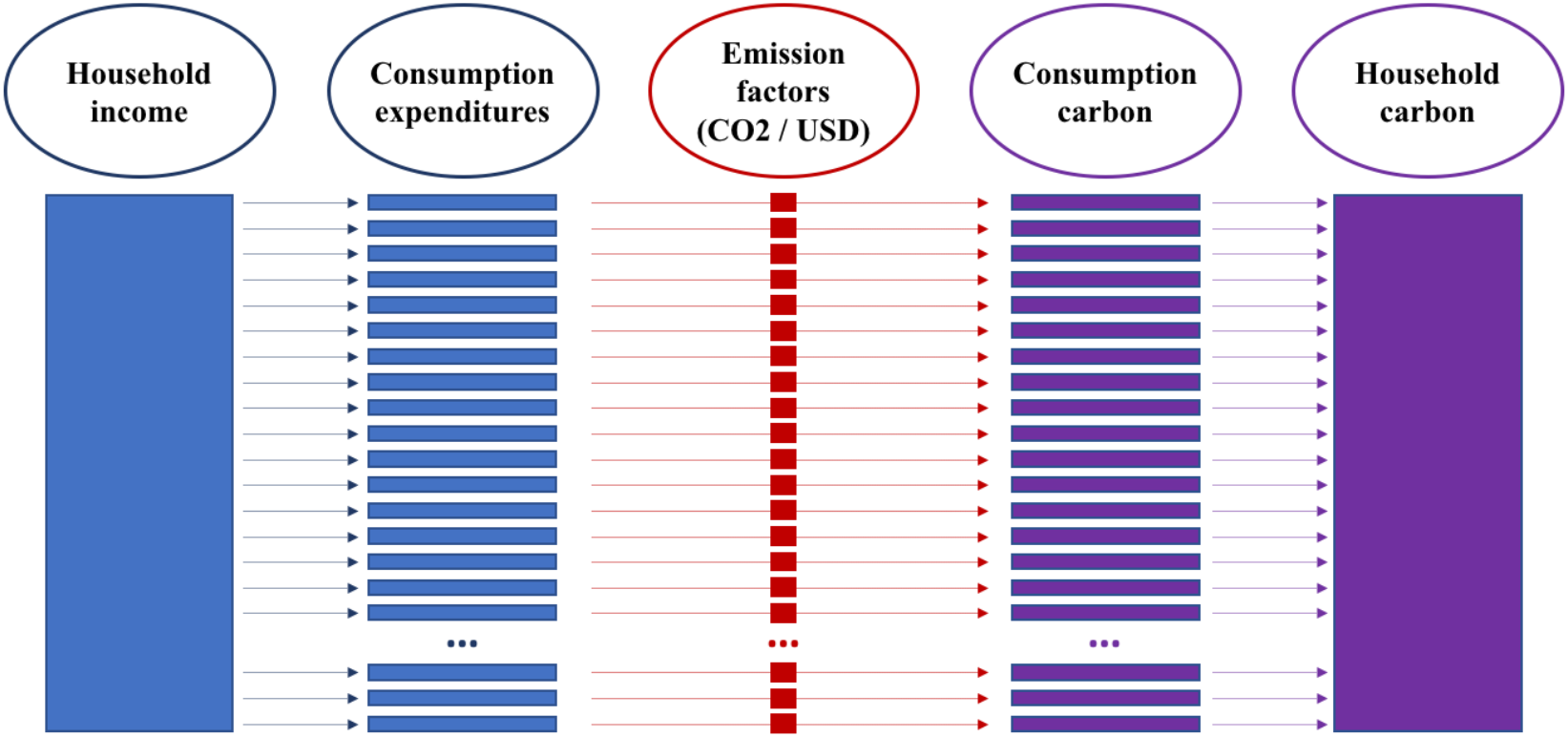

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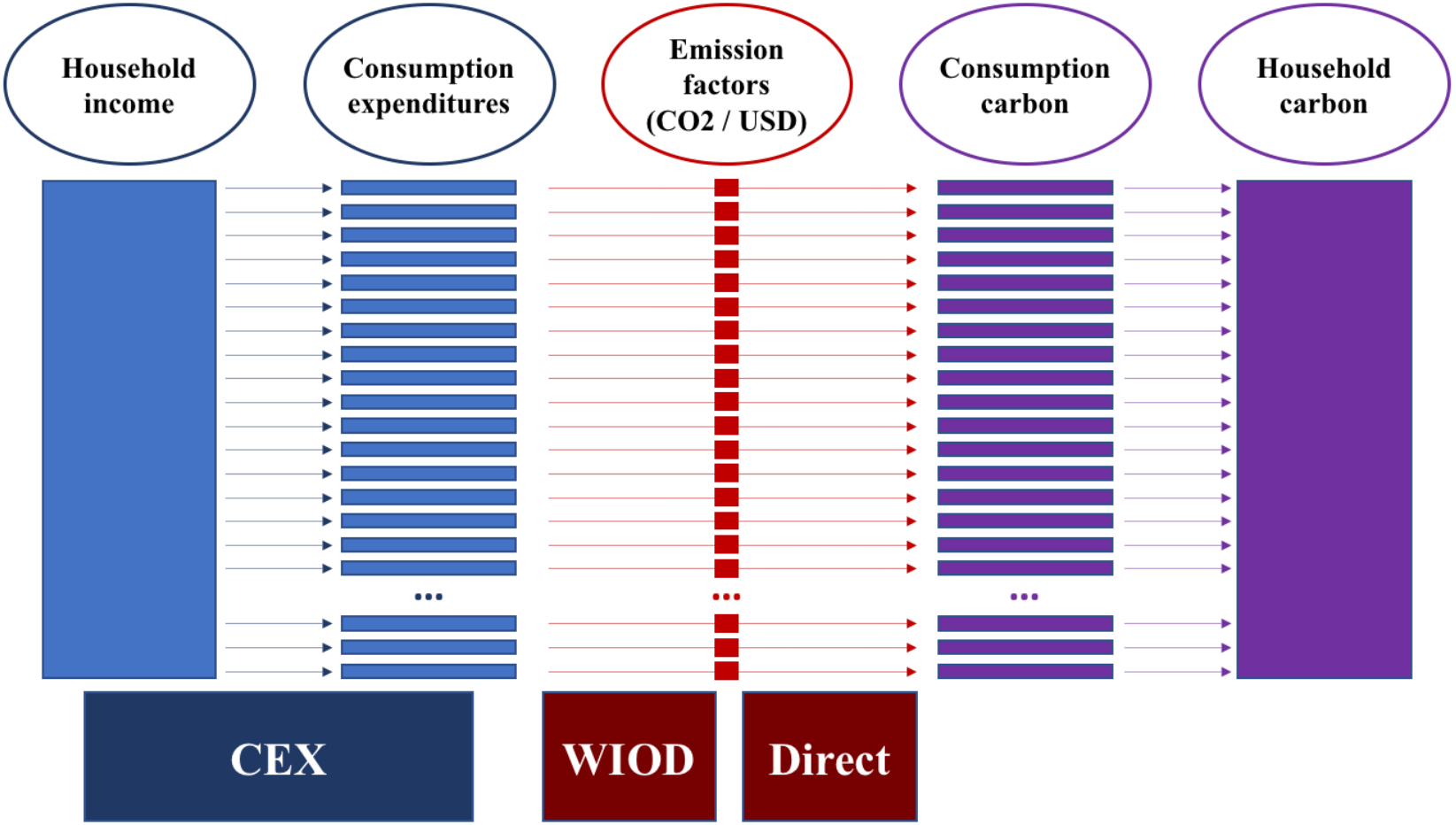


Final sample

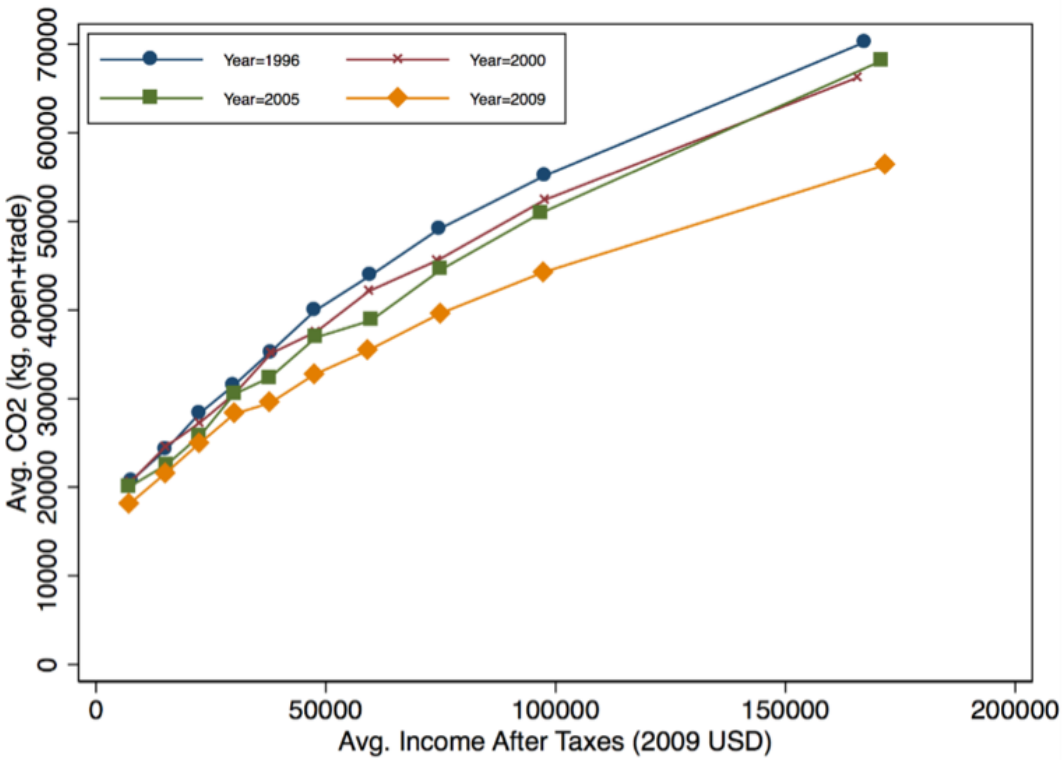
Table 1: Summary Statistics

	(1) N	(2) mean	(3) sd	(4) min	(5) max	(6) Gini (2009)
Income before tax (k$)	51,265	54.88	50.73	0.00100	510.1	0.45
Income after tax (k$)	51,265	51.86	47.09	0.00100	389.0	0.44
Expenditure (k$)	51,265	42.14	35.98	2.439	1,411	0.33
HH CO_2 (kg, closed)	51,265	34,371	18,992	515.8	435,572	0.28
HH CO_2 (kg, open)	51,265	36,915	20,919	627.7	479,490	0.28
HH CO_2 (kg, open+trade)	51,265	37,574	21,545	656.3	517,434	0.29
HH CH_4 (kg, open+trade)	51,265	320.5	182.8	5.284	6,206	0.29
HH N_2O (kg, open+trade)	51,265	11.59	6.252	0.0890	105.9	0.28
HH GHG (kg CO_2e, open+trade)	51,265	51,927	29,039	915.5	759,985	0.28
Age (HH head)	51,265	51.63	16.85	15	94	
Family size	51,265	2.586	1.496	1	14	
Population weight	51,265	15,882	5,940	460.4	81,398	
Year	51,265	2,003	4.109	1,996	2,009	

Notes: Estimates for household emissions contained in consumption expenditure according to methodology described. All other variables from the US Consumer Expenditure Survey.

Results: Descriptive Engel curves

Figure 1: Descriptive Environmental Engel curve – Household CO_2



Notes: Decile averages of household income after tax (2009 USD) and estimated CO_2-content of consumption (current technology). Household weights as provided by CEX sample. Households with negative reported after-tax income are excluded.

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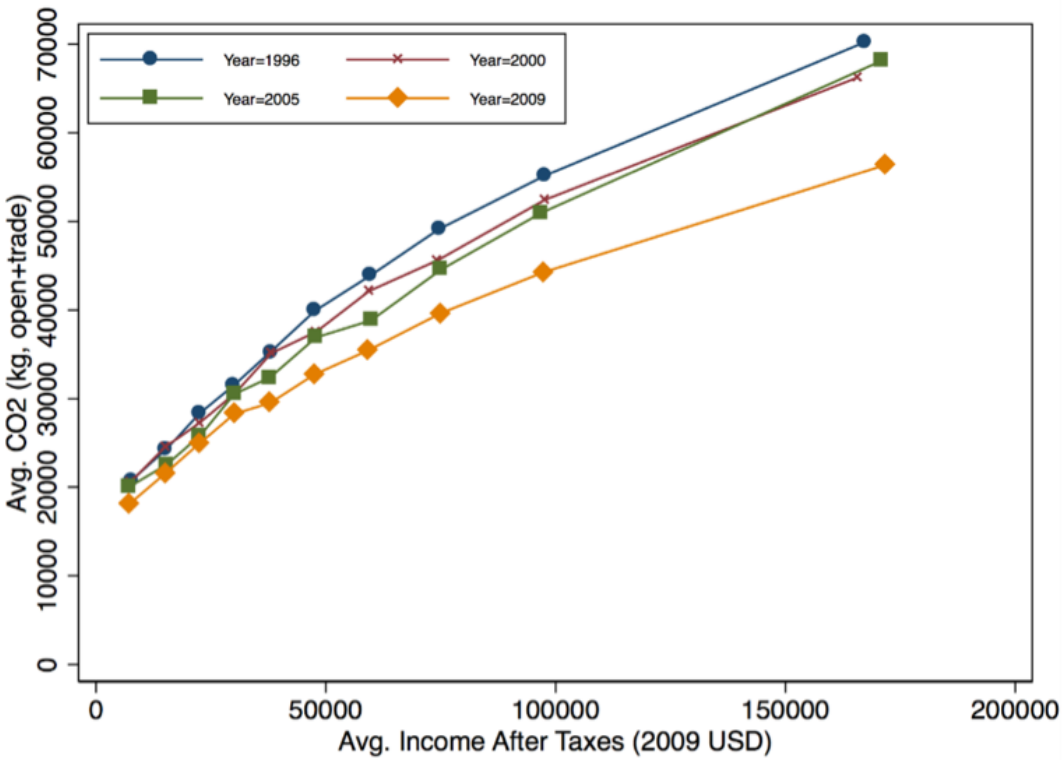

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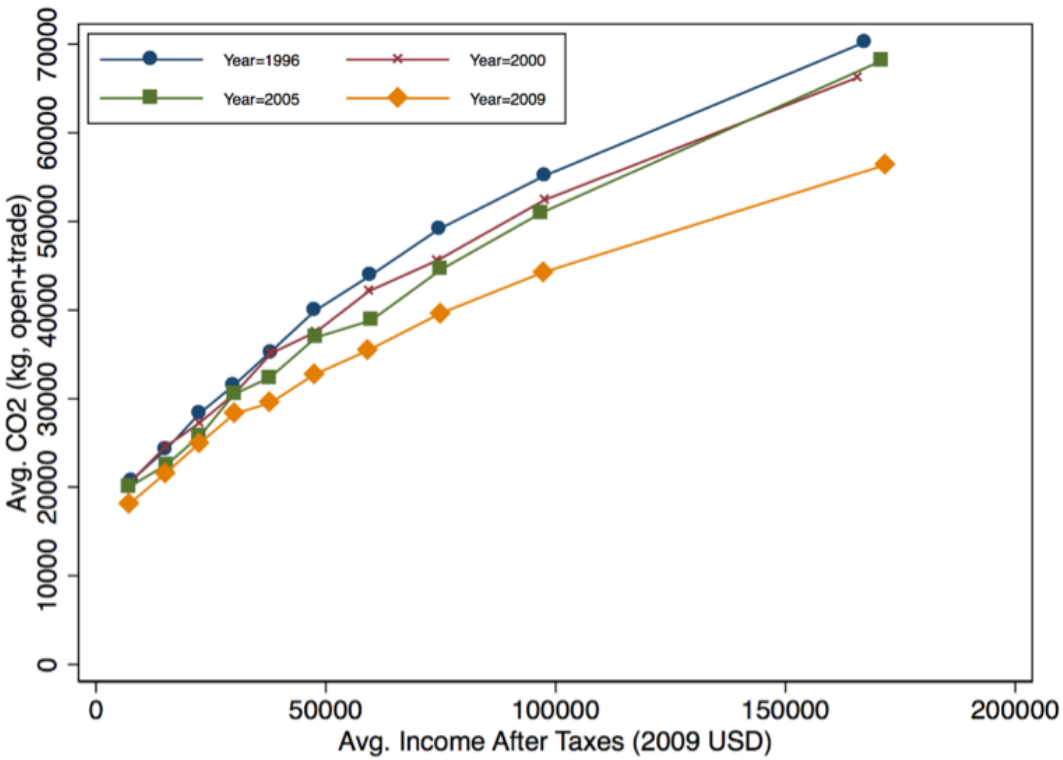

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1. **EECs are increasing**
2. **EECs are concave**

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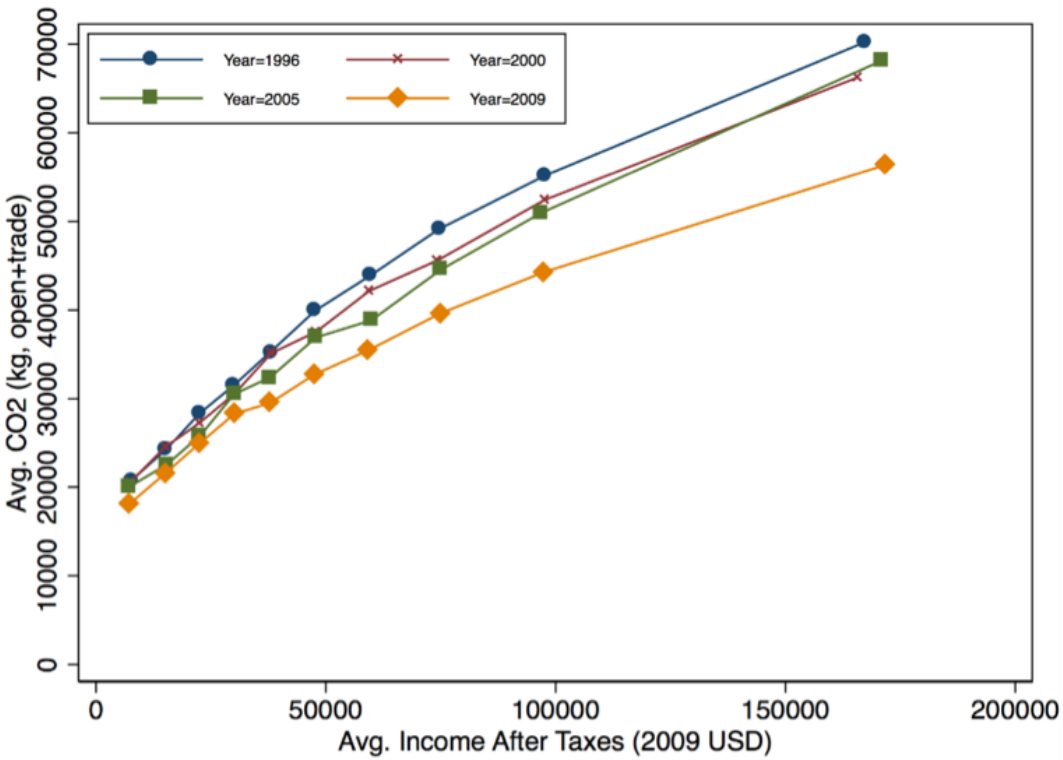

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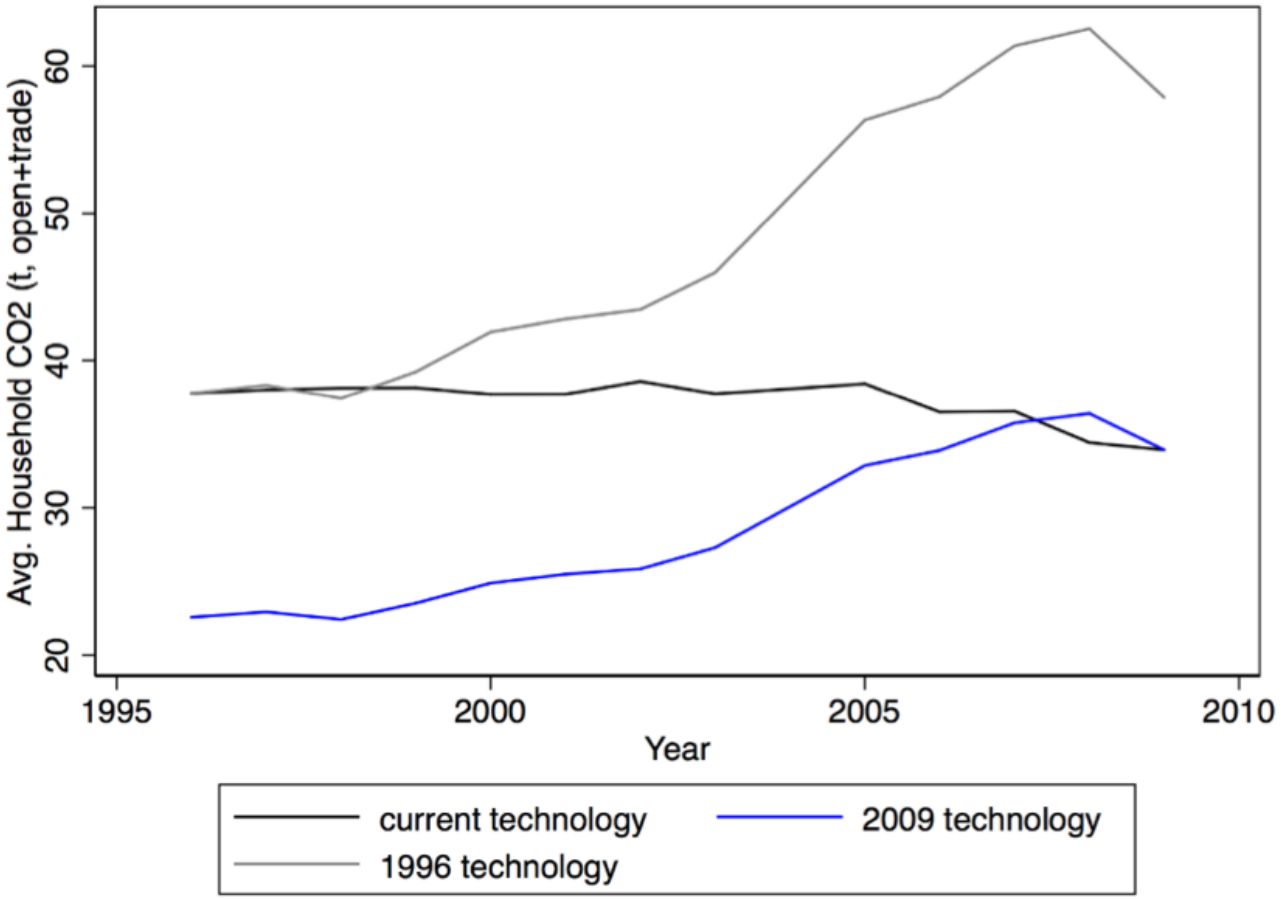
1. **EECs are increasing**
2. **EECs are concave**
3. **EECs shift down over time**

Results: Technology Improvements

Figure 2: Technology improvement



Detail

Notes: Averages of estimated CO_2-content of consumption (current technology, constant 1996, and constant 2009 technology). Household weights as provided in CEX sample. Households with negative reported after-tax income and income above USD 400k excluded.

Results: Parametric Engel curves

Further analyses require additional assumptions:

1. Inclusion of control variables
2. Specific functional form for EEC
3. Assume (conditional) homogeneity of preferences

Empirical specification:

$$y_{it} = \beta_{1t} m_{it} + \beta_{2t} m_{it}^2 + \mathbf{x}_{\mathbf{it}}' \delta_{\mathbf{t}} + \epsilon_{it} \tag{1}$$

Household carbon (y_{it}); After tax income (m_{it}); Controls ($\mathbf{x}_{\mathbf{it}}'$)

Results: Parametric Engel curves - Estimates

Table 3: Parametric estimates of quadratic EECs (1996 / 2009)

	1996		2009	
	(1) OLS (income)	(2) OLS (full)	(3) OLS (income)	(4) OLS (full)
Income (k USD, after tax)	**597.537*** **	**397.392*** **	**333.674*** **	**223.187*** **
	(30.6475)	**(33.8508)**	**(12.5338)**	**(13.3885)**
Income squared (k USD)	**-1.264*** **	**-0.566** **	**-0.538*** **	**-0.258*** **
	(0.2389)	**(0.2478)**	**(0.0571)**	**(0.0571)**
Family size		7,224.712***		6,045.746***
		(721.2440)		(640.5012)
Family size squared		-531.372***		-390.455***
		(96.7207)		(89.3228)
Age of household head		882.973***		602.852***
		(83.5928)		(68.3003)
Age squared		-7.216***		-4.566***
		(0.7774)		(0.6224)
Married (binary)		3,017.720***		3,498.022***
		(727.3970)		(516.9155)
Race (Black)		-4,538.612***		-2,222.663***
		(833.7596)		(625.6325)
Race (Native American)		-4,061.459***		-3,850.197
		(1,517.4194)		(2,381.0824)
Race (Asian / Pacific)		-6,459.371***		-3,523.863***
		(1,242.5257)		(1,202.1452)

Results: Parametric Engel curves - Estimates

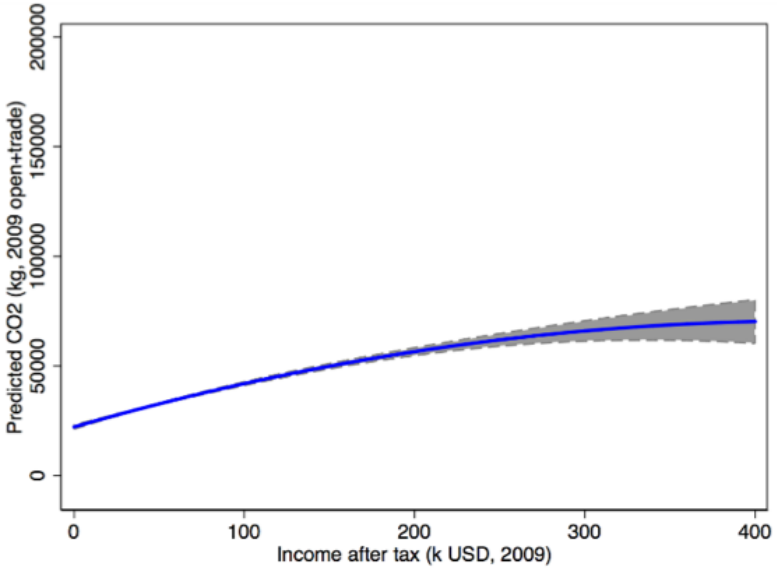
Race (Multi-race)				3,073.647
				(2,920.3731)
Education (below high school)		1,543.111**		1,527.981**
		(758.2393)		(595.5659)
Education (high school)		3,874.106***		3,552.079***
		(804.1852)		(612.2637)
Education (some college/vocational)		4,583.578***		3,130.905***
		(979.1615)		(743.7333)
Education (college degree or higher)		3,360.628**		3,048.080***
		(1,425.7927)		(1,113.4889)
Region (Midwest)		-147.868		-2,074.284***
		(792.3300)		(631.2095)
Region (South)		1,582.209**		-499.459
		(800.7617)		(604.0257)
Region (West)		-1,986.629**		-2,938.677***
		(846.8349)		(682.1159)
Constant	18,110.522***	-17,674.053***	17,360.021***	-10,358.121***
	(686.5682)	(2,350.5535)	(446.1919)	(2,047.4550)
Observations	3,069	3,069	4,407	4,378
R-squared	0.450	0.552	0.402	0.506

Notes: Estimates from linear regression. Household weights as provided in CEX sample. Households with reported after-tax income below USD 10k excluded. Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

Results: Parametric Engel curves - Quadratic fit

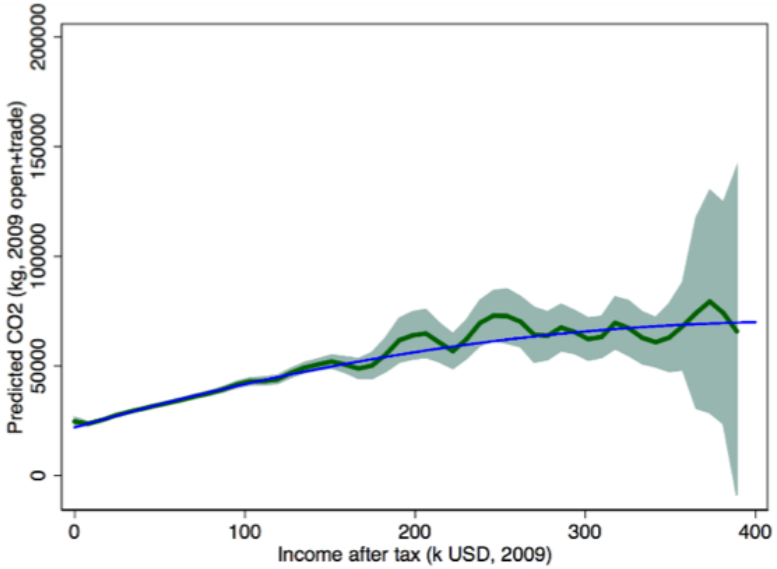
Figure 4: Environmental Engel curves – CO_2 – 2009

Figure 4a: Quadratic fit



Note: Blue = fitted values of quadratic model (holding other covariates constant at mean);Grey = 95% confidence intervals

Figure 4b: Nonparametric fit



Note: Green = fitted values of semiparametric model & 95% confidence intervals; Blue = fitted values of quadratic model

Table 2: Goodness of fit – Nonparametric vs. polynomial

Polynomial degree tested	(0) None	(1) Linear	(2) Quadratic	(3) Cubic	(4) Quartic
T test (standardised)	26.395^{***}	1.911^{*}	**0.792**	0.770	0.596
[p value]	[0.00]	[0.09]	**[0.73]**	[0.84]	[0.97]

Notes: Hardle and Mammen (1993) test for goodness of fit of polynomial adjustment; different polynomial degrees by column; 2009 data

Results: Household carbon - Decomposition over time

Table 4: Movement along parametric EECs - CO_2 (1996 vs. 2009)

	Change due to movement along EECs	
	(1)	(2)
Income after tax	4.9*	
Income squared	-1.0*	
Expenditure		7.7*
Expenditure squared		-0.8*
Family size	-0.1	0.0
Family size squared	0.1	0.0
Age	1.0*	0.8*
Age squared	-0.7*	-0.6*
Married	0.0	0.0
Race dummies	0.0	0.0
Education dummies	0.1*	0.0
Regional dummies	-0.1*	-0.1*
Total change due to income (movement along EECs)	**3.9**	
Total change due to expenditure (movement along EECs)		**6.9**
Total change due to other demographics	**0.4**	**0.2**
Unexplained difference (shift in EECs)	**7.0**	**4.4**

Decomposition: Oaxaca-Blinder

- Increase of 11.3t in household carbon between 1996 (22.6t) and 2009 (33.9t) [2009 technology]

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Decomposition: Oaxaca-Blinder

- Increase of 11.3t in household carbon between 1996 (22.6t) and 2009 (33.9t) [2009 technology]
- **Income (after tax) explains 3.9t (35 per cent)**
- **Expenditure explains 6.9t (61 per cent)**
- Other variables explain little

Results: Household carbon inequality - Decomposition

Table 5: Inequality decomposition – Household CO_2 (1996 / 2009)

	(1) 1996 (income)	(2) 1996 (full)	(3) 2009 (income)	(4) 2009 (full)
Income after tax	0.642	0.427	0.606	0.407
Income (squared)	-0.192	-0.0861	-0.204	-0.0984
Famiy size		0.215		0.207
Family size (squared)		-0.0889		-0.0773
Age		-0.0902		-0.0597
Age (squared)		0.112		0.0686
Married		0.0327		0.0407
Race (sum)		0.012		0.004
Education (sum)		0.018		0.012
Region (sum)		0.001		0.002
Residual	0.550	0.448	0.598	0.494
Observations	3,069	3,069	4,407	4,378
Total contribution of income	**45%**	**34%**	**40%**	**31%**
Total contribution of other demographics	**NA**	**21%**	**NA**	**20%**
Unexplained (residual)	**55%**	**45%**	**60%**	**49%**

Notes: Inequality decomposition based on coefficient estimates from linear regression models (Table 2). Calculations made using Stata module INEQRBD by Fiorio and Jenkins (2007). Household weights as provided

Factor decomposition:

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Factor decomposition:

Shorrocks (1982)

- **Income explains 31-45 per cent** of variation in CO_2
- Family size explains ca. 13 per cent
- Other variables explain little
- Large unexplained variation

Results: The "equity-pollution" dilemma

So, by how much would income redistribution increase CO_2?

Results: The "equity-pollution" dilemma

Expected effect of marginal transfer between two random households:

$$E_{ij}\left(\frac{\partial y_i}{\partial m_i} - \frac{\partial y_j}{\partial m_j} | m_j > m_i\right) = -2\hat{\beta}_2 E_{ij}\left(m_j - m_i | m_j > m_i\right)$$
$$= -2\hat{\beta}_2 \Psi(F(m))$$

Gini's Mean Difference: $\Psi(F(m)) = \int\int |y - z| dF(y) dF(z)$ or $\frac{1}{N(N-1)} \sum_{i=1}^{N} \sum_{j=1}^{N} |m_i - m_j|, \; i \neq j$

Difference in emissions when moving to "full equality":

$$\hat{\beta}_2 \left[\overline{m}^2 - \frac{1}{N} \sum_{i=1}^{N} m_i^2 \right]$$

Results: The "equity-pollution" dilemma

Table 6: The "equity-pollution dilemma" – Comparison of pollutants (2009)

	(1) CO_2	(2) CO_2e	(3) CH_4	(4) N_2O
Income (k USD, after tax)	223.187***	304.581***	1.996***	0.045***
	(13.3885)	(18.3258)	(0.1285)	(0.0040)
Income squared (k USD, after tax)	-0.258***	-0.336***	-0.002***	-0.000***
	(0.0571)	(0.0785)	(0.0006)	(0.0000)
Observations	4,378	4,378	4,378	4,378
R-squared	0.506	0.525	0.506	0.476
HH characteristics	YES	YES	YES	YES
Implied "equity-pollution dilemma"				
Avg. emissions per income (kg per k USD)	563.3	789.9	5.186	0.169
$-2\hat{\beta}_2\Psi$	28.55	37.23	0.214	0.0047
Marginal effect of redistribution	**+5.1%**	**+4.8%**	**+4.2%**	**+2.8%**
Effect of full redistribution	+2.3%	+2.1%	+1.8%	+1.3%

Notes: Estimates from linear regression. Household weights as provided in CEX sample. Households with negative reported after-tax income and income above USD 400k excluded. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Conclusion

- Estimate Environmental Engel Curves (EECs) for CO_2e embedded in consumption (United States, 1996-2009)
  - Upward-sloping, Concave, Shifting down
  - Approximated well by 2nd degree polynomial
- De-compose embedded CO_2e between / within time
- Quantify the "equity-pollution" dilemma:
  - Marginal redistribution: +5.1 per cent
  - Full redistribution: +2.3 per cent
  - Hypothetical Sweden: +1.5 per cent

Thank you!

Comments & Question welcome

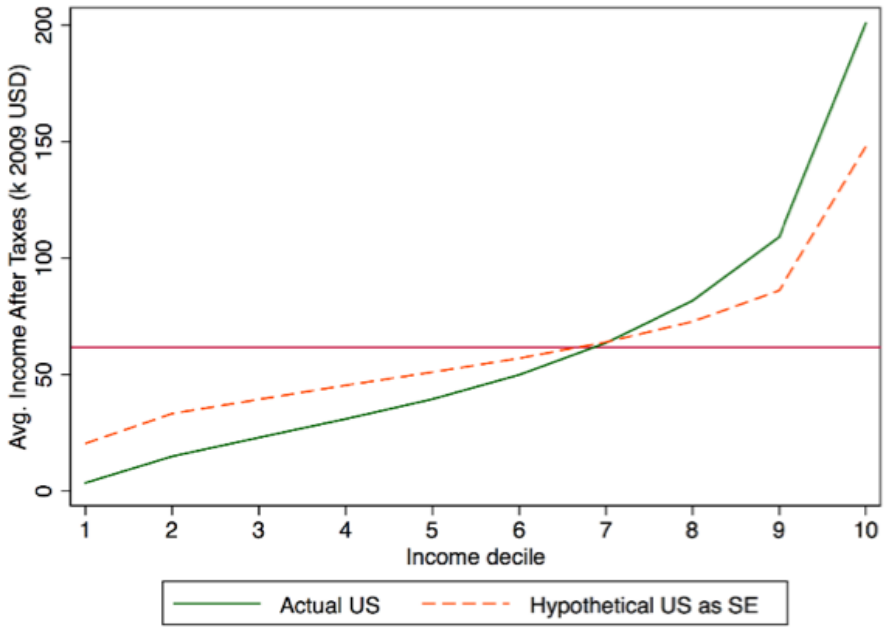
l.sager@lse.ac.uk

Appendix: The "equity-pollution" dilemma

Hypothetical Sweden (2009): +1.5 % in CO_2 (0.5t per CU)

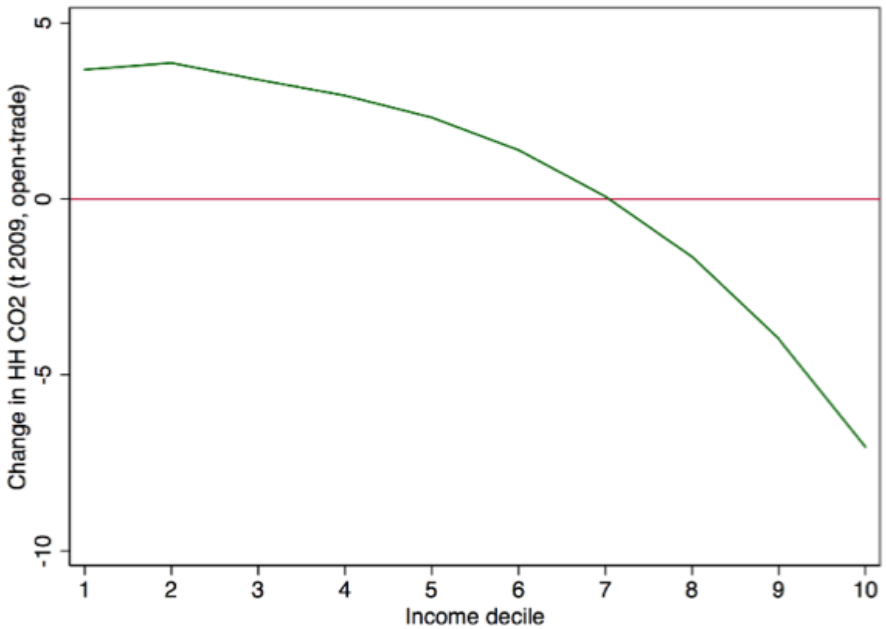
Figure 7: Hypothetical income distribution – Sweden – 2009

Figure 7a: Comparison – Household incomes



Note: Green = Average household income after as observed in analysis sample; Green = Average household income after scaling of US distribution to mirror decile shares of Swedish distribution of disposable household income. Both by income deciles, 2009 data.

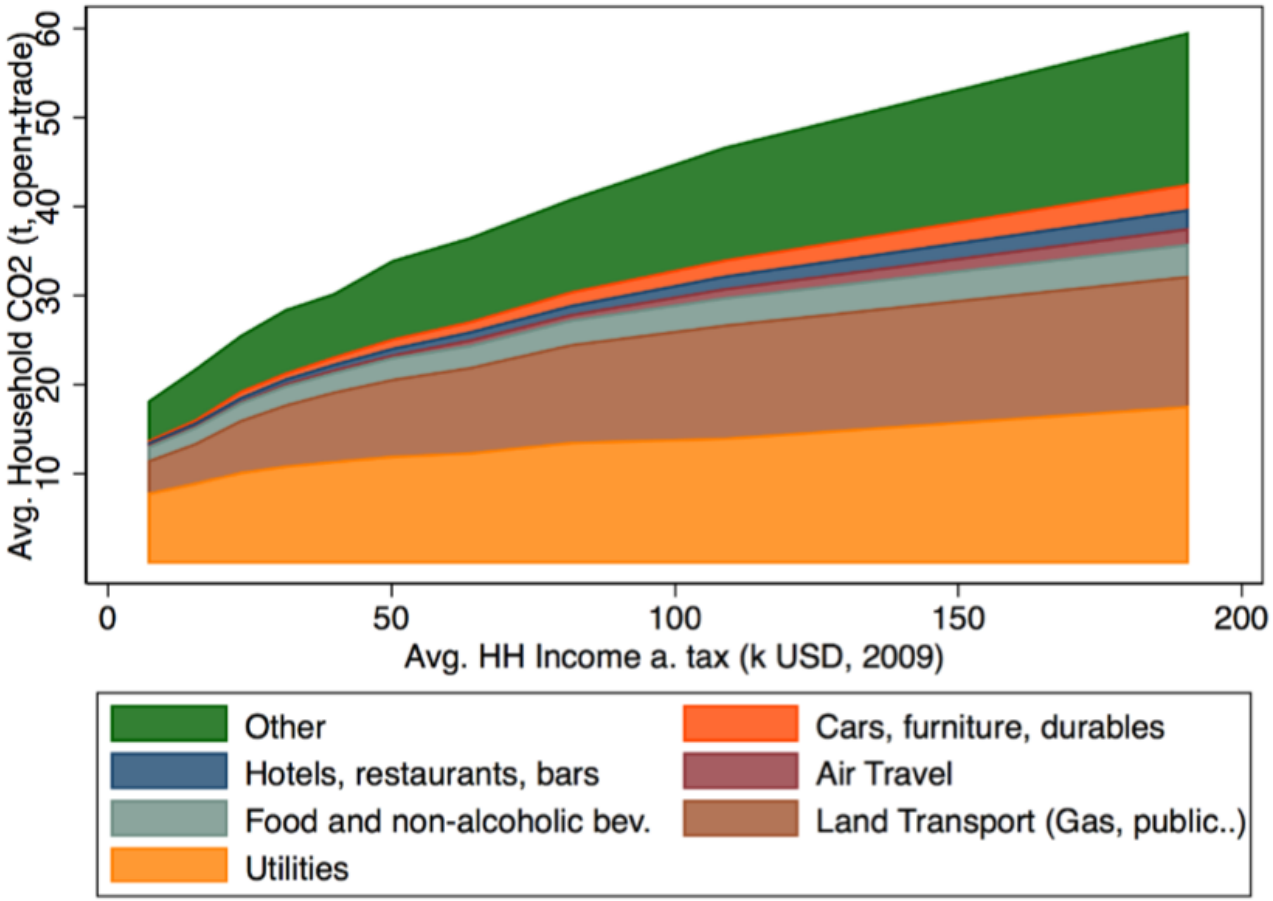
Figure 7b: Predicted change in HH carbon



Note: Predicted difference between average household CO_2 by income decile between hypothetical distribution emulating Sweden and actual distribution in the United States. Calculations based on estimates reported in Table 3, Column 4. 2009 data.

Appendix: Descriptive Engel curves

Figure A.2: Carbon Consumption Breakdown – 2009



Notes: Decile averages of household income after tax (2009 USD) and estimated CO_2-content of consumption (current technology). Household weights as provided by CEX sample. Households with reported after-tax income below 0 USD and above USD 400 k excluded.