Climate Change Mitigation Policies: Aggregate and Distributional Effects

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Motivation

Main problem:

- **Climate change:** One of the humanity's most pressing problems
- **Main driver:** Carbon emissions (e.g. burning coal, oil and gas to produce energy)
- **Spatial-temporal externality:** carbon tax
- **Complication:** economic effects

This paper

- **Aggregate and distributional** effects of climate change policies (e.g. Nordhaus, 1994)
- Carbon tax to reach the **Paris-agreement:**
  - limit global warming to below 2 degrees Celsius, preferably to 1.5 degrees Celsius
- **Model-based simulations for 6 different economies:**
  Brazil, Canada, China, India, Mexico, USA

Different mix of energy production

Different mix of production sectors

Model economy

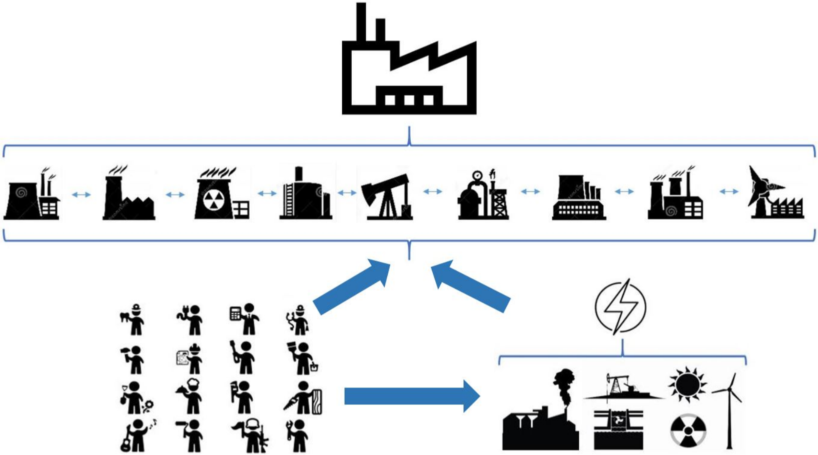
Heterogeneous households:

- Education decision
- Abilities over different sectors

Production:

- Multi-sector with Input-Output linkages:
  - 14 production sectors
- Energy-producing sectors
  - oil, coal, natural gas and green (4 energy sectors)

The economy in one picture



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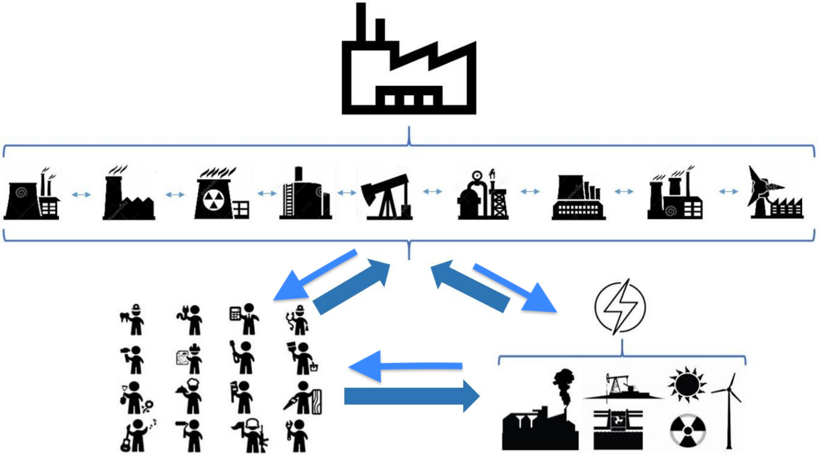
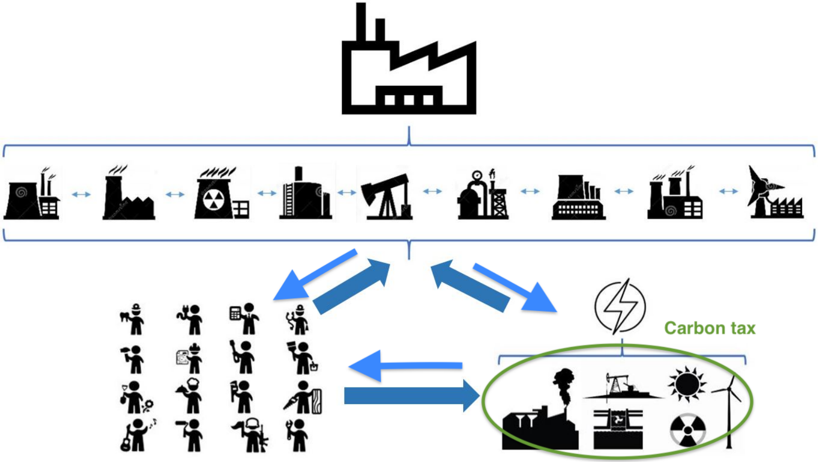


Carbon tax



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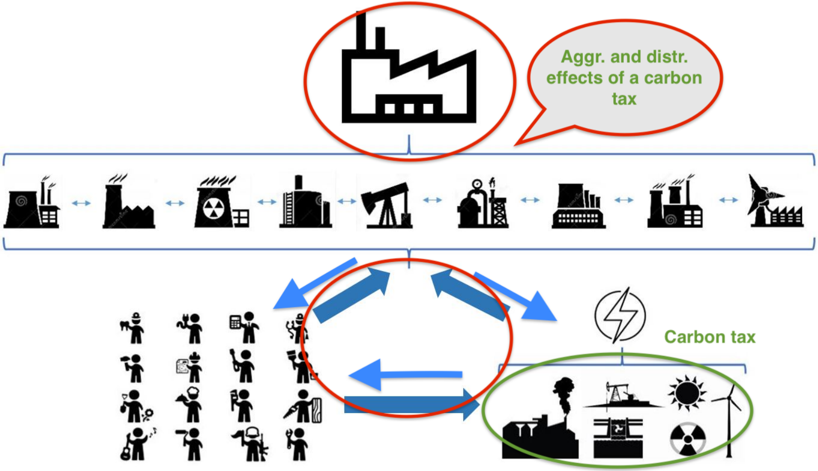


Quantitative Results

- Estimate tax for US to reach the Paris Agreement:
  - Decrease CO_2 emissions by 26%
  - In the model: 32.3% carbon tax

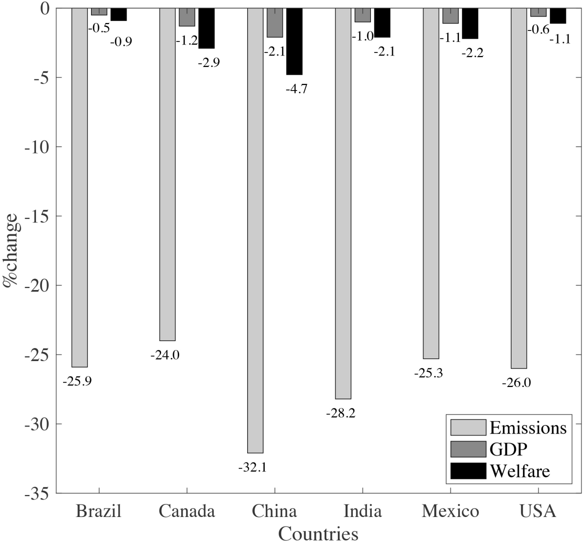
Data & Calibration

- Add a 32.3% carbon tax on oil, coal and natural gas energy sectors

- Apply the same tax (or the same level of reduction in emission) to the remaining five countries

- Investigate the effects of carbon tax in four scenarios:
  1. Wasteful Spending
  2. Green Subsidy
  3. Useful Spending (subsidising non-dirty sectors)
  4. Education Subsidy (subsidising education in non-dirty sectors)

Aggregate Effects: 32.3% carbon tax



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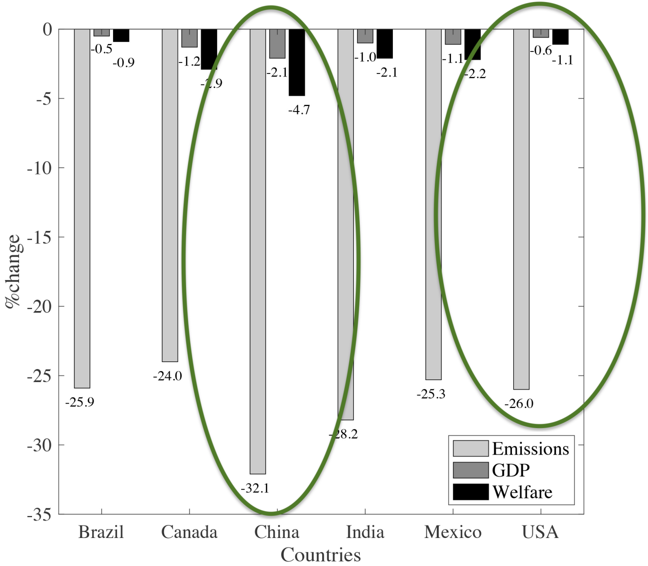

US vs. China

	Same Policy, Diff. Emissions		Diff. Policies, Same Emissions	
	United States	**China**	**United States**	**China**
Tax Rate	32.3%	32.3%	32.3%	25.40%
%Δ Total Emissions	-26.0%	-32.1%	-26.0%	-26.0%
%Δ GDP	-0.6%	-2.1%	-0.6%	-1.5%
%Δ Consumption	-1.7%	-6.0%	-1.7%	-4.7%
Welfare	-1.1%	-4.7%	-1.1%	-3.6%

Revenue Recycling Schemes

United States: 32.3% Carbon Tax				
	Emissions	GDP	Consumption	Welfare
Wasteful Spending	-26.0	-0.6	-1.7	-1.1
Green Subsidy	-24.3	-0.3	-0.3	-0.3
Useful Spending	-25.3	-0.5	-0.5	0.1
Education Subsidy	-26.0	0.4	-0.7	0.1

Other countries

Revenue Recycling Schemes

United States: 32.3% Carbon Tax				
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Wasteful Spending	-26.0	-0.6	-1.7	-1.1
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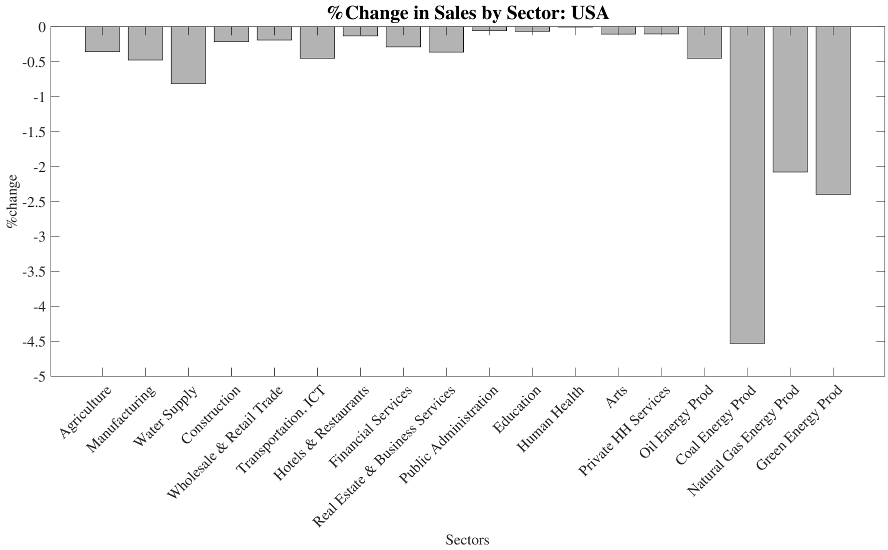
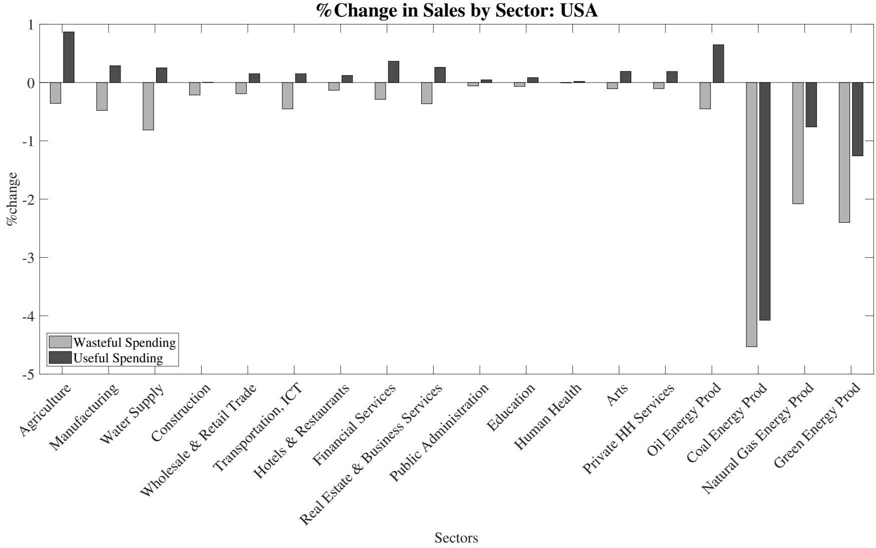
Other countries

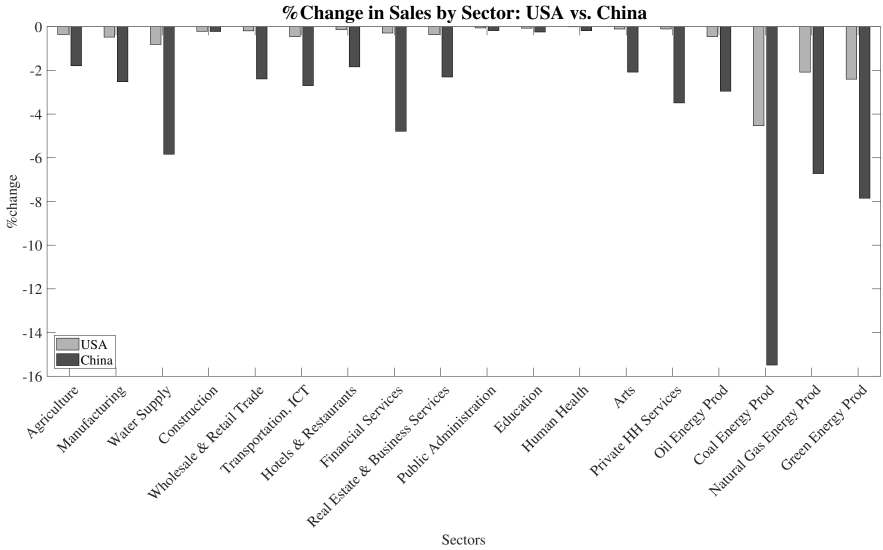
Sectoral-level Analysis



Sectoral-level Analysis: Wasteful vs Useful Spending



Sectoral-level Analysis: US vs China



Distributional Effects: Individual-level Analysis

United States	Wasteful Spending		Green Subsidy		Useful Spending		Education Subsidy	
	CE (%)	LFP (%)	CE (%)	LFP (%)	CE (%)	LFP (%)	CE (%)	LFP (%)
Non-dirty sectors, stayers	-1.1	99.4	1.1	99.3	0.2	99.4	0.1	99.4
Non-dirty sectors, switchers	-1.0	0.1	9.5	0.1	0.2	0.1	0.1	0.1
Dirty sectors, stayers	-12.9	0.4	-11.5	0.4	-11.9	0.4	-11.9	0.4
Dirty sectors, switchers	-6.8	0.1	-5.7	0.1	-5.7	0.1	-5.7	0.1
Aggregate	-1.1	100.0	-0.3	100.0	0.1	100.0	0.1	100.0

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Aggregate	-1.1	100.0	-0.3	100.0	0.1	100.0	0.1	100.0

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Concluding remarks

This paper:

- Framework to study aggregate and distributional effects of climate change mitigation policies
- Model calibrated to disaggregated data for six countries

Key takeaways:

- In general, relative small aggregate effects to reach Paris Agt.
- Effects depend on a country's sectoral composition
- Important sectoral effects
- Workers in dirty sectors lose the most; small fraction of the LF

Appendix

Households

Utility (consumption c and schooling s):

$$U = c^{\gamma}(1-s)$$

Human capital (goods e and sector j):

$$h(s,e) = s^{\phi_j} e^{\eta}$$

Budget (ability z_j):

$$c = w_j h(s,e) z_j - e$$

Indirect utility:

$$U_j^* = \left[z_j \underbrace{w_j s_j^{\phi_j} (1-s_j)^{\frac{1-\eta}{\gamma}}}_{\tilde{w}_j} \eta^{\eta} (1-\eta)^{(1-\eta)} \right]^{\frac{\gamma}{1-\eta}}$$

Occupational choice

- Distribution over abilities (Fréchet):

$$F(z_1, ..., z_J) = \exp\left(-\sum_{j=1}^{J}(z_j)^{-\lambda}\right)$$

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$$\hat{w}_j = \tilde{w}_j \cdot z_j \text{ where } \tilde{w}_j = w_j s_j^{\phi_j}(1 - s_j)^{\frac{(1-\eta)}{\gamma}}$$

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- Returns of a worker in sector j with sector-specific ability z_j:

$$\hat{w}_j = \tilde{w}_j \cdot z_j \text{ where } \tilde{w}_j = w_j s_j^{\phi_j}(1 - s_j)^{\frac{(1-\eta)}{\gamma}}$$

- Individuals will sort into the occupation that provides them with the highest relative returns, such that:

$$l_j = \begin{cases} 1 & \text{iff } \tilde{w}_j z_j = \max_s\{\tilde{w}_s z_s\} \\ 0 & \text{otherwise} \end{cases}$$

Occupational Choice

Proposition 1:

The share of workers q_j in sector j is given by:

$$q_j = \frac{\tilde{w}_j^{\lambda}}{\sum_k \tilde{w}_k^{\lambda}}, \text{ where } \tilde{w}_j = w_j {s_j}^{\phi_j}(1 - s_j)^{\frac{1-\eta}{\beta}} \quad \forall j.$$

- Occupational shares depend on the distribution of innate abilities

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- Occupational shares depend on the distribution of innate abilities

Proposition 2:

The effective labor supply for sector j is given by:

$$L_j^s = ({s_j}^{\phi_j})^{\frac{1}{1-\eta}} (\eta w_j)^{\frac{\eta}{1-\eta}} q_j^{1 - \frac{1}{\lambda}\frac{1}{1-\eta}} \Gamma\left(1 - \frac{1}{\lambda}\frac{1}{1-\eta}\right) \quad \forall j.$$

- Efficiency units of labor in every sector depend on workers' innate abilities and human capital accumulation

Production

Intermediate Goods:

$$Y_j = L_j^{\beta_j} \prod_{k=1}^{J} x_{jk}^{\nu_{jk}}, \;\; \beta_j, \nu_{jk} \in [0,1]; \text{ and } \beta_j + \sum_{k=1}^{J} \nu_{jk} = 1,$$

- of which 4 energy sectors: oil, coal, gas and green

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- of which 4 energy sectors: oil, coal, gas and green

Final Good:

$$Y_f = \prod_{j=1} \left(Y_j^F\right)^{\sigma_j}, \ \sigma_j \in [0{,}1) \text{ and } \sum_{j=1}^{J} \sigma_j = 1.$$

Equilibrium
Carbon Tax
Data & Calibration

Equilibrium

An equilibrium of the economy consists of prices (prices for each intermediate good j), wages per efficiency unit of labor in each sector, individual choices $\{c^i, s^i, e^i\}$, an occupational choice for each person, efficiency units of labor supplied and demanded, and intermediate and final goods such that:

- Workers choose the occupation that offers the highest utility
- Given occupational choice, workers choose $\{c^i, s^i, e^i\}$
- All firms maximize profits
- All markets clear (labor and output markets)

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Carbon Taxation

As in Golosov et al. (2014), carbon tax depends on the carbon intensity of each good:

$$\tau_{oil} = \tau \cdot g_{oil}, \text{ where } g_{oil} = 84.6\%$$
$$\tau_{coal} = \tau \cdot g_{coal}, \text{ where } g_{coal} = 71.6\%$$
$$\tau_{gas} = \tau \cdot g_{gas}, \text{ where } g_{gas} = 73.4\%$$

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$$\tau_{gas} = \tau \cdot g_{gas}, \text{ where } g_{gas} = 73.4\%$$

Note that, $\tau_{green} = 0$, but it can be < 0 if subsidized!

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Data

Countries:

- Brazil, Canada, China, India, Mexico, US

Datasets:

1. World Input Output Database (WIOD) for:
   - National input-output tables
   - Sectoral energy use by fuel type (Environmental accounts)
   - Sectoral emissions from each fuel (Environmental accounts)
   - Labor force participation shares (Socio-economic accounts)
   - Average sectoral wages (Socio-economic accounts)

2. Integrated Public Use Microdata Series (IPUMS) for:
   - Average schooling attainment by sector
   - Income distribution

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Calibration

	Externally Calibrated Parameters	Value	Data Source
J	number of sectors	18	WIOD
ν_{js}	input output shares		WIOD
β_j	labor shares		WIOD
g_{oil}	carbon intensity of oil	84.6%	Golosov et al. (2014)
g_{coal}	carbon intensity of coal	71.6%	Golosov et al. (2014)
$g_{naturalgas}$	carbon intensity of natural gas	73.4%	Golosov et al. (2014)
g_{green}	carbon intensity of green	0%	Golosov et al. (2014)
η	public expenditure on education		World Develpment Indicators
	Internally Calibrated Parameters		**Moment(s) Targeted**
σ_j	expenditure shares in final good		Sectoral value added (WIOD)
ϕ_j	returns of schooling in sector j		Sectoral average wages (WIOD)
γ	consumption weight in u		Mincerian return to schooling (IPUMS)
λ	Fréchet dispersion parameter		Coef. of variation in earnings (IPUMS)

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Data

1. We use data from the World Input Output Database that provides national input-ouptut tables for 50 countries
2. WIOD presents 34 sectors in each I-O table
3. We create an Energy Sector by aggregating “Mining and Quarrying” and “Electricity, gas, steam and air conditioning supply”
4. We then split the Energy sector into ‘oil’, ‘coal’, ‘natural gas’, and ‘green’ based on energy breakdown in the Environmental Accounts of the World Input Output Database
5. We aggregate the remaining 32 sectors into 14 sectors based on the top-level aggregation of ISIC Rev 4
6. In summary, we have a total of 18 sectors, four of them are energy sectors (i.e. oil, coal, natural gas and green)

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Table: Intermediate Goods Sectors

Sectors (J=16)	Sectors (J=15)	Sectors (J=18)
1. Agriculture, hunting, forestry and fishing	1. Agriculture, hunting, forestry and fishing	1. Agriculture, hunting, forestry and fishing
2. **Mining and Quarrying**	2. Manufacturing	2. Manufacturing
3. Manufacturing	3. Water supply	3. Water supply
4. **Electricity** and Water supply	4. Construction	4. Construction
5. Construction	5. Wholesale and retail trade	5. Wholesale and retail trade
6. Wholesale and retail trade	5. Hotels and restaurants	6. Hotels and restaurants
7. Hotels and restaurants	7. Transport, storage and communications	7. Transport, storage and communications
8. Transport, storage and communications	8. Financial services and insurance	8. Financial services and insurance
9. Financial services and insurance	9. Real estate, renting and business activities	9. Real estate, renting and business activities
10. Real estate, renting and business activities	10. Public administration and defense	10. Public administration and defense
11. Public administration and defense	11. Education	11. Education
12. Education	12. Health and social work	12. Health and social work
13. Health and social work	13. Other services activities	13. Other services activities
14. Other services activities	14. Private households services	14. Private households services
15. Private households services	15. **Energy Production**	15. **Oil energy production**
16. Private households services		16. **Coal energy production**
		17. **Natural gas energy production**
		18. **Green energy production**

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Matching the data

1. In order to estimate λ, we follow the methodology from Hsieh et al. (2019). We use micro-data from IPUMS to fit the distribution of residuals from a cross-sectional regression of log income earned on 7x18 age-industry dummies in a given year
2. For each country with available data, we run the regression for each year in which data is available.
3. We exploit the tractability of the Fréchet distribution and calculate the coefficient of variation of wages across all industries in every year:

$$\frac{Variance}{Mean^2} = \frac{\Gamma(1 - \frac{2}{\lambda})}{\left[\Gamma(1 - \frac{1}{\lambda})\right]^2}$$

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Aggregate Effects (Other countries)

Brazil	**GDP**	**Consumption**	**Welfare**
Wasteful Spending	-0.5	-1.4	-0.9
Green Subsidy	-0.2	-0.2	-0.2
Useful Spending	-0.4	-0.4	0.1
Education Subsidy	0.4	-0.5	0.1
Mexico	**GDP**	**Consumption**	**Welfare**
Wasteful Spending	-1.1	-3.4	-2.2
Green Subsidy	-0.7	-0.7	-0.8
Useful Spending	-1.0	-1.0	0.4
Education Subsidy	1.0	-1.4	0.0
India	**GDP**	**Consumption**	**Welfare**
Wasteful Spending	-1.0	-2.9	-2.1
Green Subsidy	-0.5	-0.5	-0.7
Useful Spending	-0.8	-0.8	0.0
Education Subsidy	0.7	-1.2	-0.2
China	**GDP**	**Consumption**	**Welfare**
Wasteful Spending	-2.1	-6.0	-4.7
Green Subsidy	-1.2	-1.2	-1.9
Useful Spending	-1.9	-1.9	-0.4
Education Subsidy	0.9	-3.1	-1.7
Canada	**GDP**	**Consumption**	**Welfare**
Wasteful Spending	-1.2	-3.9	-2.9
Green Subsidy	-0.8	-0.8	-0.9
Useful Spending	-1.1	-1.1	0.2
Education Subsidy	1.2	-1.6	-0.3

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Mexico - with and without wedges

Mexico - with wedges	**GDP**	**Consumption**	**Welfare**
Wasteful Spending	-1.1	-3.3	-2.4
Green Subsidy	-0.7	-0.7	-0.8
Useful Spending	-0.9	-0.9	0.5
Education Subsidy	1.0	-1.3	-0.3
Mexico - without wedges	**GDP**	**Consumption**	**Welfare**
Wasteful Spending	-1.1	-3.4	-2.2
Green Subsidy	-0.7	-0.7	-0.8
Useful Spending	-1.0	-1.0	0.4
Education Subsidy	1.0	-1.4	0.0

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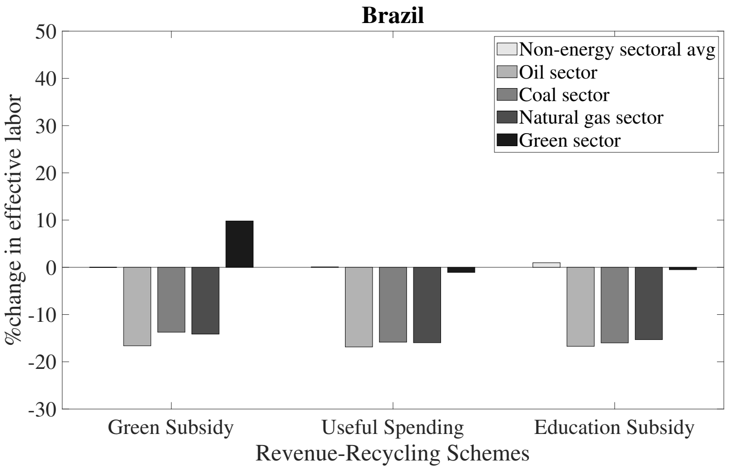
Distributional Effects: Sectoral-level Analysis



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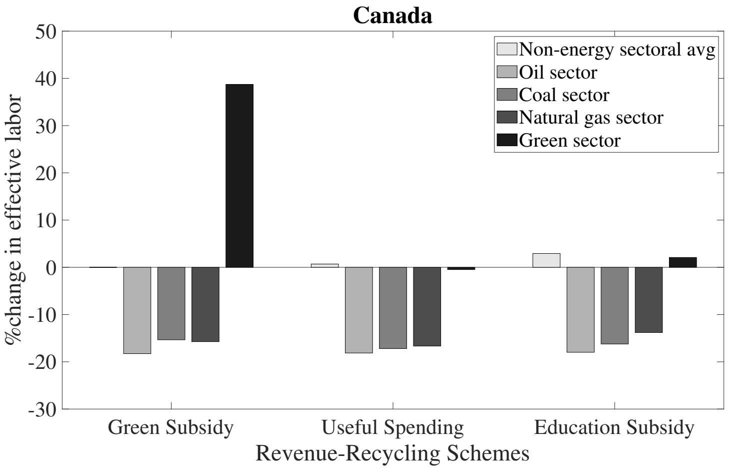

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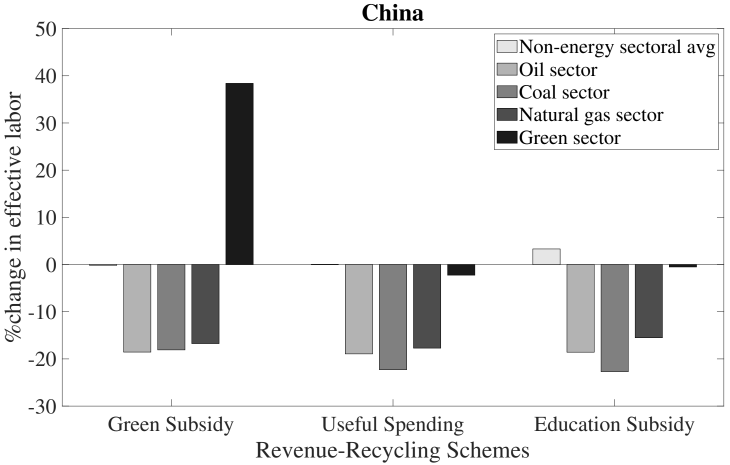

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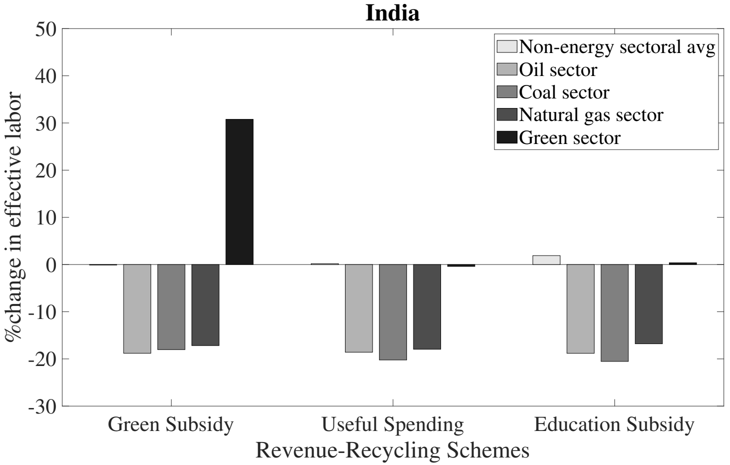

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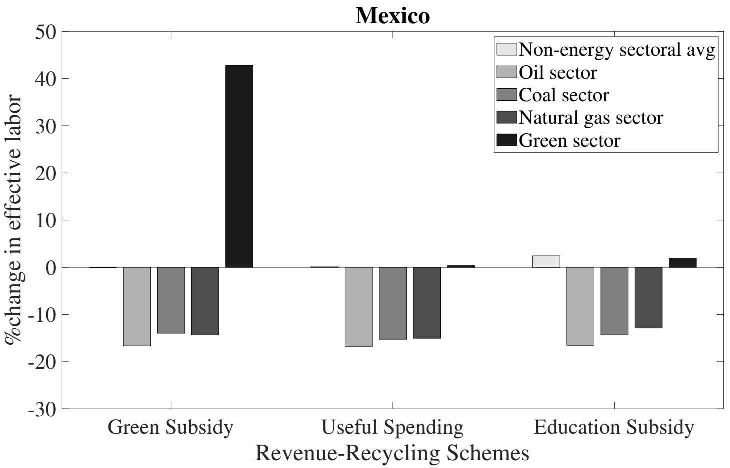

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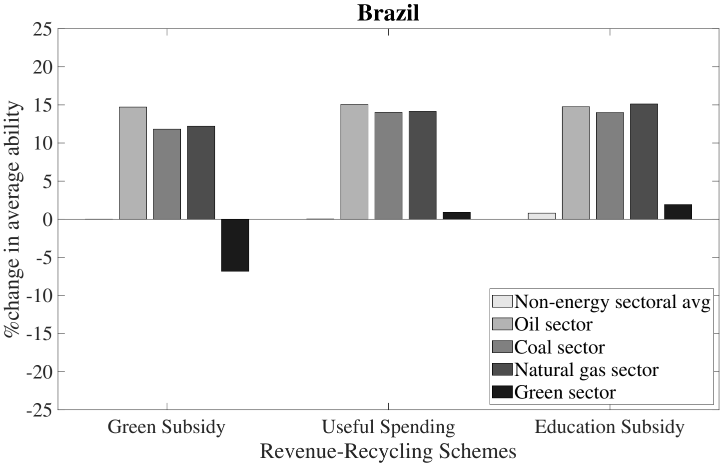

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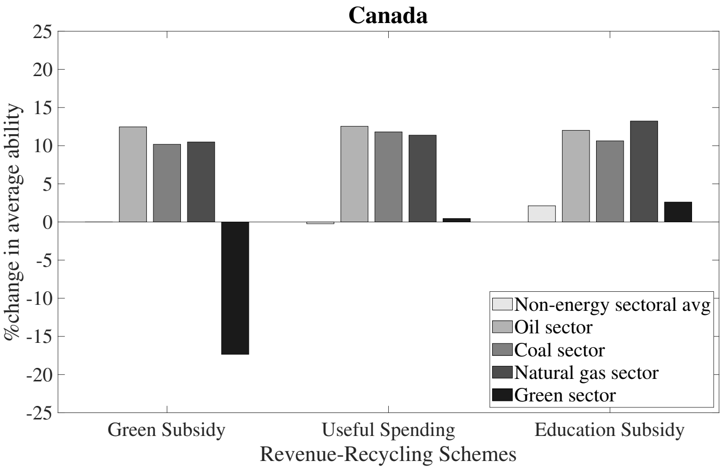

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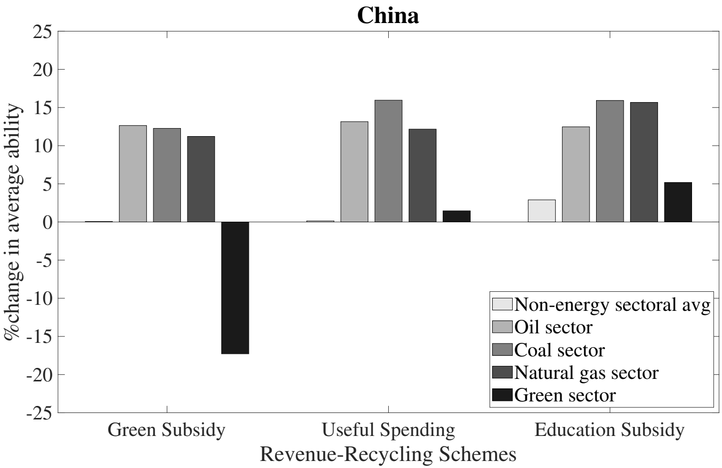

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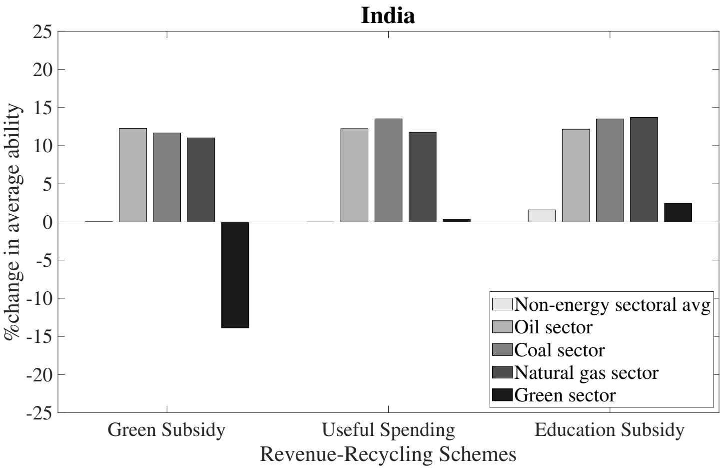

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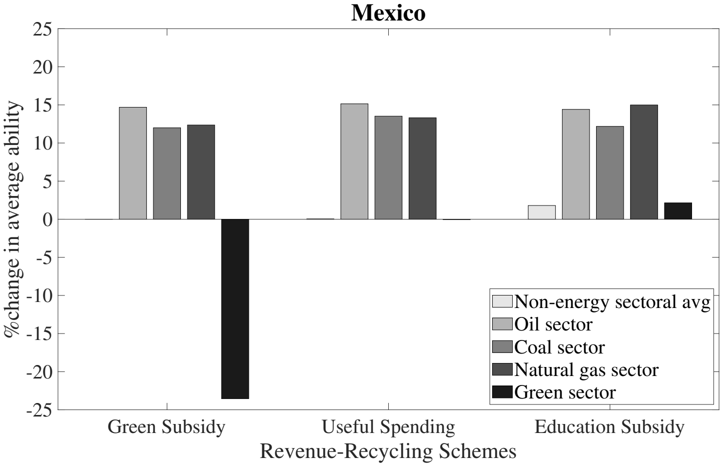
Distributional Effects: Sectoral-level Analysis



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Distributional Effects: Individual-level Analysis

Brazil	Wasteful Spending		Green Subsidy		Useful Spending		Education Subsidy	
	CE (%)	LFP (%)	CE (%)	LFP (%)	CE (%)	LFP (%)	CE (%)	LFP (%)
Non-dirty sectors, stayers	-0.9	99.6	0.4	99.7	0.1	99.7	0.1	99.6
Non-dirty sectors, switchers	-0.9	0.1	2.8	0.1	0.2	0.1	0.1	0.1
Dirty sectors, stayers	-14.6	0.2	-12.7	0.2	-13.7	0.2	-13.7	0.2
Dirty sectors, switchers	-7.7	0.1	-6.5	0.1	-6.8	0.1	-6.8	0.1
Aggregate	-0.9	100.0	-0.2	100.0	0.1	100.0	0.1	100.0

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Distributional Effects: Individual-level Analysis

Canada	Wasteful Spending		Green Subsidy		Useful Spending		Education Subsidy	
	CE (%)	LFP (%)	CE (%)	LFP (%)	CE (%)	LFP (%)	CE (%)	LFP (%)
Non-dirty sectors, stayers	-2.6	96.9	0.6	96.4	0.5	96.9	0.0	96.9
Non-dirty sectors, switchers	-2.5	0.2	9.1	0.7	0.5	0.2	0.1	0.2
Dirty sectors, stayers	-13.4	2.1	-11.6	2.1	-11.3	2.1	-11.2	2.1
Dirty sectors, switchers	-7.8	0.7	-5.6	0.8	-5.2	0.8	-5.4	0.7
Aggregate	-2.9	100.0	-0.9	100.0	0.2	100.0	-0.3	100.0

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Distributional Effects: Individual-level Analysis

China	Wasteful Spending		Green Subsidy		Useful Spending		Education Subsidy	
	CE (%)	LFP (%)	CE (%)	LFP (%)	CE (%)	LFP (%)	CE (%)	LFP (%)
Non-dirty sectors, stayers	-4.7	98.2	-0.5	98.0	-0.6	98.4	-1.7	98.2
Non-dirty sectors, switchers	-4.5	0.4	6.0	0.7	-0.4	0.3	-1.4	0.4
Dirty sectors, stayers	-16.7	0.9	-13.0	1.0	-13.0	0.9	-14.1	0.9
Dirty sectors, switchers	-10.4	0.4	-6.9	0.4	-6.4	0.4	-7.5	0.4
Aggregate	-4.7	100.0	-1.9	100.0	-0.4	100.0	-1.7	100.0

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Distributional Effects: Individual-level Analysis

India	Wasteful Spending		Green Subsidy		Useful Spending		Education Subsidy	
	CE (%)	LFP (%)	CE (%)	LFP (%)	CE (%)	LFP (%)	CE (%)	LFP (%)
Non-dirty sectors, stayers	-2.0	98.6	0.5	98.2	0.0	98.6	-0.2	98.6
Non-dirty sectors, switchers	-1.9	0.2	5.9	0.5	0.1	0.1	-0.1	0.2
Dirty sectors, stayers	-13.8	0.9	-11.9	0.9	-11.9	0.9	-12.2	0.9
Dirty sectors, switchers	-7.6	0.4	-5.9	0.3	-5.6	0.4	-5.9	0.4
Aggregate	-2.5	100.0	-0.7	100.0	0.0	100.0	-0.2	100.0

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Distributional Effects: Individual-level Analysis

Mexico	Wasteful Spending		Green Subsidy		Useful Spending		Education Subsidy	
	CE (%)	LFP (%)	CE (%)	LFP (%)	CE (%)	LFP (%)	CE (%)	LFP (%)
Non-dirty sectors, stayers	-1.9	98.6	1.5	98.4	0.5	98.6	0.3	98.6
Non-dirty sectors, switchers	-1.9	0.2	13.7	0.4	0.7	0.2	0.3	0.2
Dirty sectors, stayers	-14.5	0.9	-13.1	0.9	-12.8	0.9	-12.6	0.9
Dirty sectors, switchers	-8.1	0.3	-6.6	0.3	-5.9	0.3	-6.1	0.3
Aggregate	-2.7	100.0	-0.8	100.0	0.4	100.0	0.0	100.0

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