Modelling environmental policy impacts on firms' carbon emissions

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Tópicos

Contexto–Motivação

Methods–Validation

Results

Contexto–Motivação

Introduction

- PolicySpace3–simulação computacional–**plataforma de análise de políticas públicas** *ex ante*

1. Simulação e cenários PlanHab–política melhorias + cenários investimento habitação, 3 macro-cenários
2. Matrizes tempo deslocamento com/sem investimentos transportes BNDES
3. Emissões no nível da firma
4. Demonstração ABM como ferramenta de causalidade

Motivação

- Emissions reduction requires effective fiscal instruments (taxes, subsidies) + SBCE [**?** **?** **?**]
- Standard models assume equilibrium, representative agents, limited **heterogeneity** ...
- ... firms differ, interact regionally, invest unevenly, and respond non-linearly [**?**]

Contribuições e Pergunta

- **Ao modelo**:
  - sectoral emissions mapping/eco-efficiency
  - intermediate firm-to-firm market,
  - **input–output matrices** + municipal–level decomposition, connection rest of the country with metropolis
  - linking investment to emissions

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- **Pergunta**: *"How do carbon taxes and innovation subsidies influence firms' technology adoption decisions, industrial carbon emissions, and socioeconomic output in Brazil?"*

Related work–sample...

- **Policy mechanisms and firms' response**: carbon taxes [**?**], energy efficiency [**?**], economic impact [**? ?**], pricing mechanisms [**?**] ...
- **ABMs**: better for "emergent behaviors and feedback loops" + heterogeneous agents and adaptive behavior $->$ suited for "dynamic environmental and economic interactions" [**? ? ? ?**]. Applied to environment [**? ? ? ? ?**]

Methods–Validation

Methodology

- Empirical, spatial, Agent-based Model–comprehensive platform
- **Agents**: workers, households, firms, municipalities, bank
- **Markets**: goods and services, intermediate firm-to-firm, housing credit, housing, rental, labor

Basics

- **Initialization from data**: census data, workers surveys [RAIS, 2010], geolocation (firms, households), mortality, fertility, FPM, input-output matrix, shapes: áreas ponderação, wages, qualification, number of members, gender, interest, government jobs, FGTS, SBPE
- 2010–2040 com **projections**: demographics, number of firms, interest
- Any municipality sets–185 Urban concentration areas [IBGE, 2022]
- **Monthly steps**: production and firm-to-firm market $>$ demographics, migration (housing market–endogenous household formation), $>$ consumption $>$ collection taxes, investment infrastructure $>$ labor market–adaptive behavior

Details–firms' production

$$Q_t = \left(\sum_{i=1}^{n} q_i^{\alpha} \right) R_{ts}(A_i) \tag{1}$$

where $(q_i)_1^n$ productivity of employees (labor),
R_{ts} sector-specific technology from IO output table [**?**]
and A firm-specific technology, endogenous innovation to reduce input constraints

Household consumption decision

Family consumes permanent income [**?**], based on members' [past] wages, real estate assets, and savings.

A. Separate expenses for renting, banking loans, goods' consumption, and investments in that order.

B. Calculate permanent income: Loans impact on a lower long-run permanent income consumption–house may appreciate in the market.

C. Total spending equals permanent income.

Emissions, environmental processes, ecoefficiency

Emissions as a by-product of economic activity (caveat: wage mass as a proxy) [**?**]. Exogenous input (from RAPP e RAIS) [**?** **?**][1]

$$\epsilon_s = \frac{W_{s,t_0}}{E_{s,t_0}} \tag{2}$$

where E_{s,t_0} and W_{s,t_0} total observed emissions and total wages, for sector s

Firm-level emissions

$$E_{it} = A_{it}\frac{W_{it}}{\epsilon_{sr,t}} \tag{3}$$

W_{it} total wages paid (endogenous)

[1] SEEG 5 setores genéricos. Alvarenga Júnior, 2024 (in process)

Firm's investment decision

$$A_{t,f} = \begin{cases} \rho A_{t-1,f}, & \text{with probability } P\left(\frac{I}{W}\right) \\ A_{t-1,f}, & \text{otherwise.} \end{cases} \tag{4}$$

$$\frac{I}{W} = \frac{1}{\lambda} \ln \frac{\lambda(1-\rho)C_T}{W(1-\mu)(1-s_{env})} \tag{5}$$

where μ discount rate, λ calibrated parameter, and s_{env} subsidies level

1. Assess past emissions and production costs
2. Determine optimal investment in efficiency
3. Observe investment outcome—if successful, update A, apply improved technology.

Policy tests

1. **Emission Tax:** tax equivalent to $R\$40$ unit of carbon dioxide equivalent CO_2e [**?**]; revenue of around 1% of the simulated GDP, consistent observed values
2. **Subsidies:** 25% of the investment, analogous to lower interest rate loans or direct tax exemption
3. **Combined Policy:** Both an emission tax and innovation subsidies are applied simultaneously.

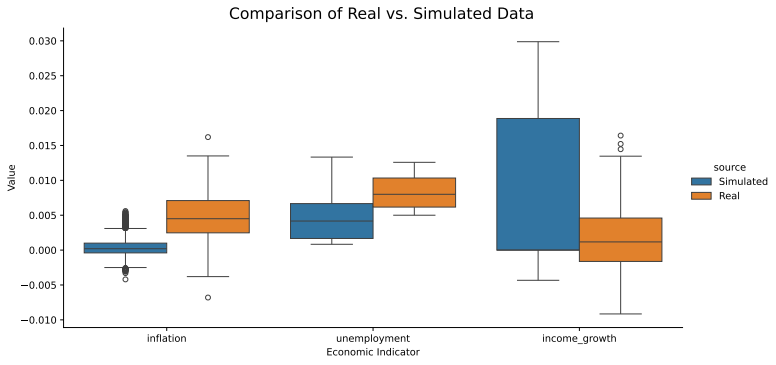
Validation strategy

1. theoretically coherent in its core mechanisms;
2. empirically grounded in its initial state;
3. and capable of generating stylized macroeconomic patterns.

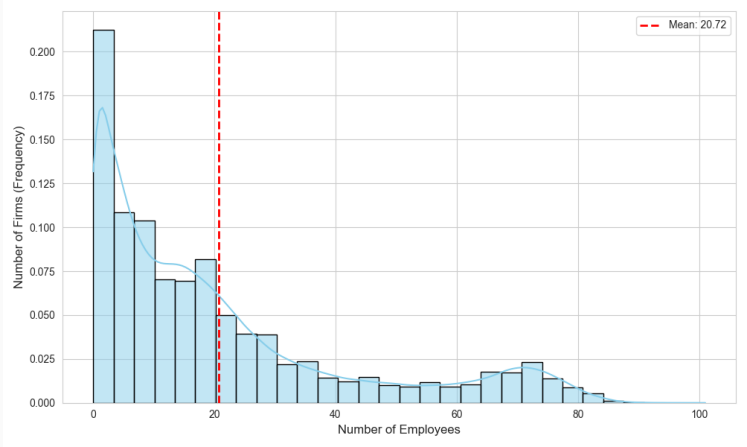
Model data inputs and theoretical foundations

Component	Empirical Data Source	Theoretical Foundation
Household Agents	**Initialization**: Demographics and location (Census/IBGE). **Parametrization**: Consumption shares (Input-Output Tables).	**Consumption**: *Permanent Income Model*—spending smoothed based on expected future income.
Firm Agents	**Initialization**: Number, sector, location (RAIS). **Parametrization**: Emissions intensity (RAPP).	**Pricing**: *Sticky-Price Mechanism*—responds to inventory and market. **Investment**: *Adaptive Cost Optimization*—present and expected cost-benefit analysis.
Bank Agent	**Parametrization**: Interest rates (Central Bank of Brazil).	-
Goods Market	**Structure**: Inter-sectoral demand (Regionalized Input-Output Tables).	**Production**: *Input-Output (Leontief) Model*—fixed input proportions. **Consumption**: Price and distance preference over random firm subset.
Spatial Environment	**Initialization**: Geographic distribution (RAIS and Census).	-

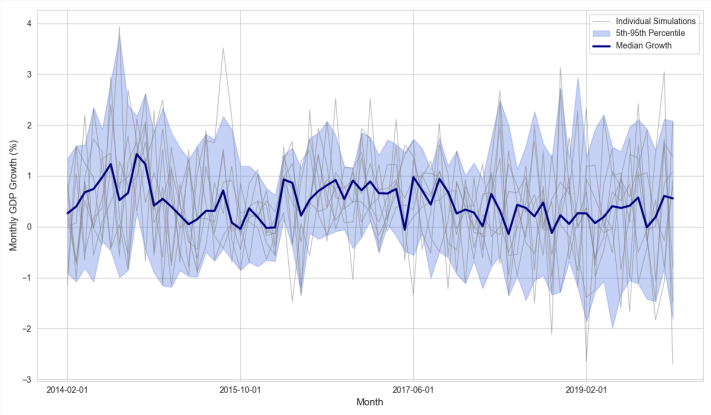
Macroeconomic patterns



(a) Real vs Simulated indicators



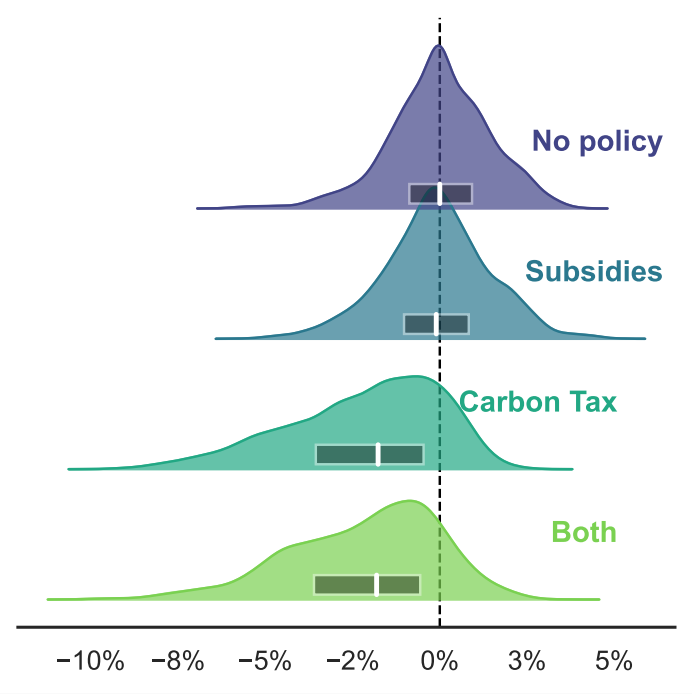
(b) Firm distribution



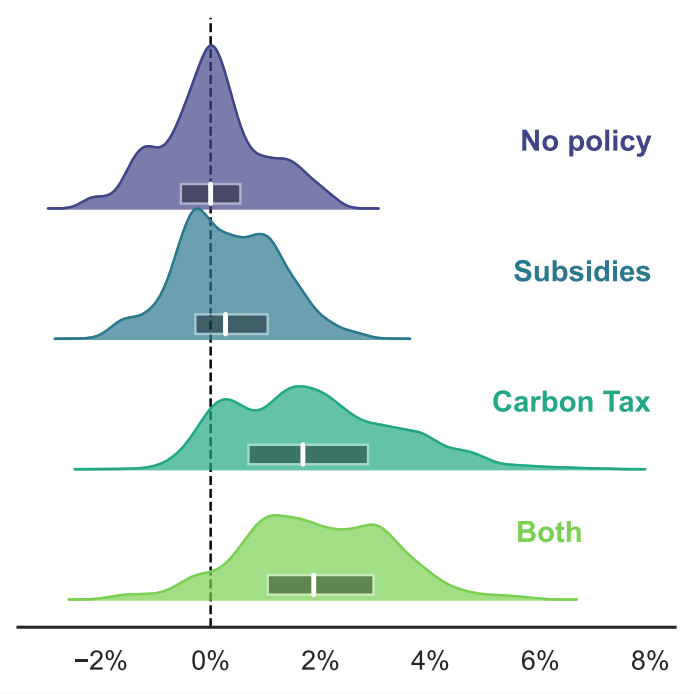
(c) Income growth dynamics

Results

Policy scenario results I

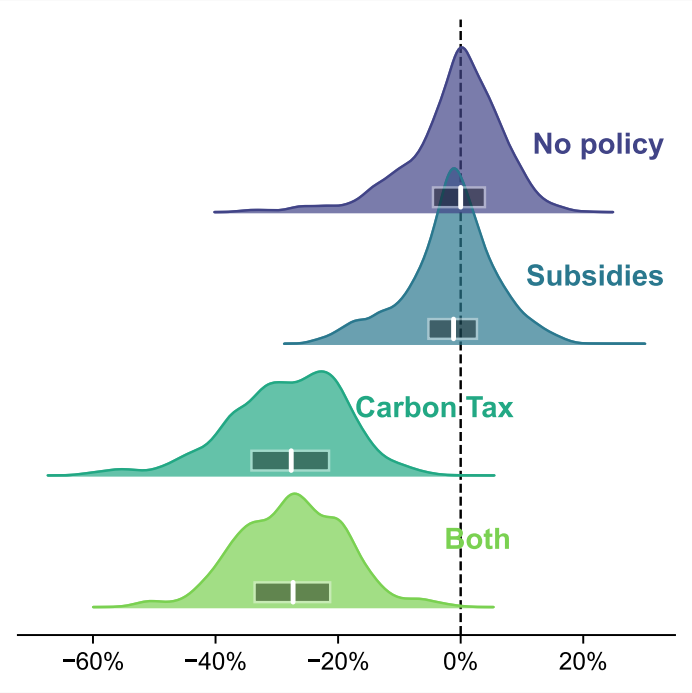


(a) GDP Index

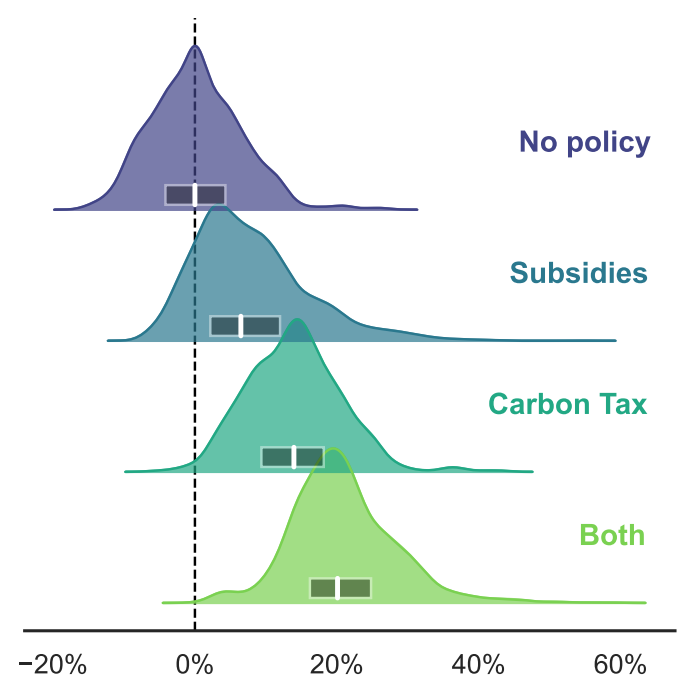


(b) Gini Index

Policy scenario results II



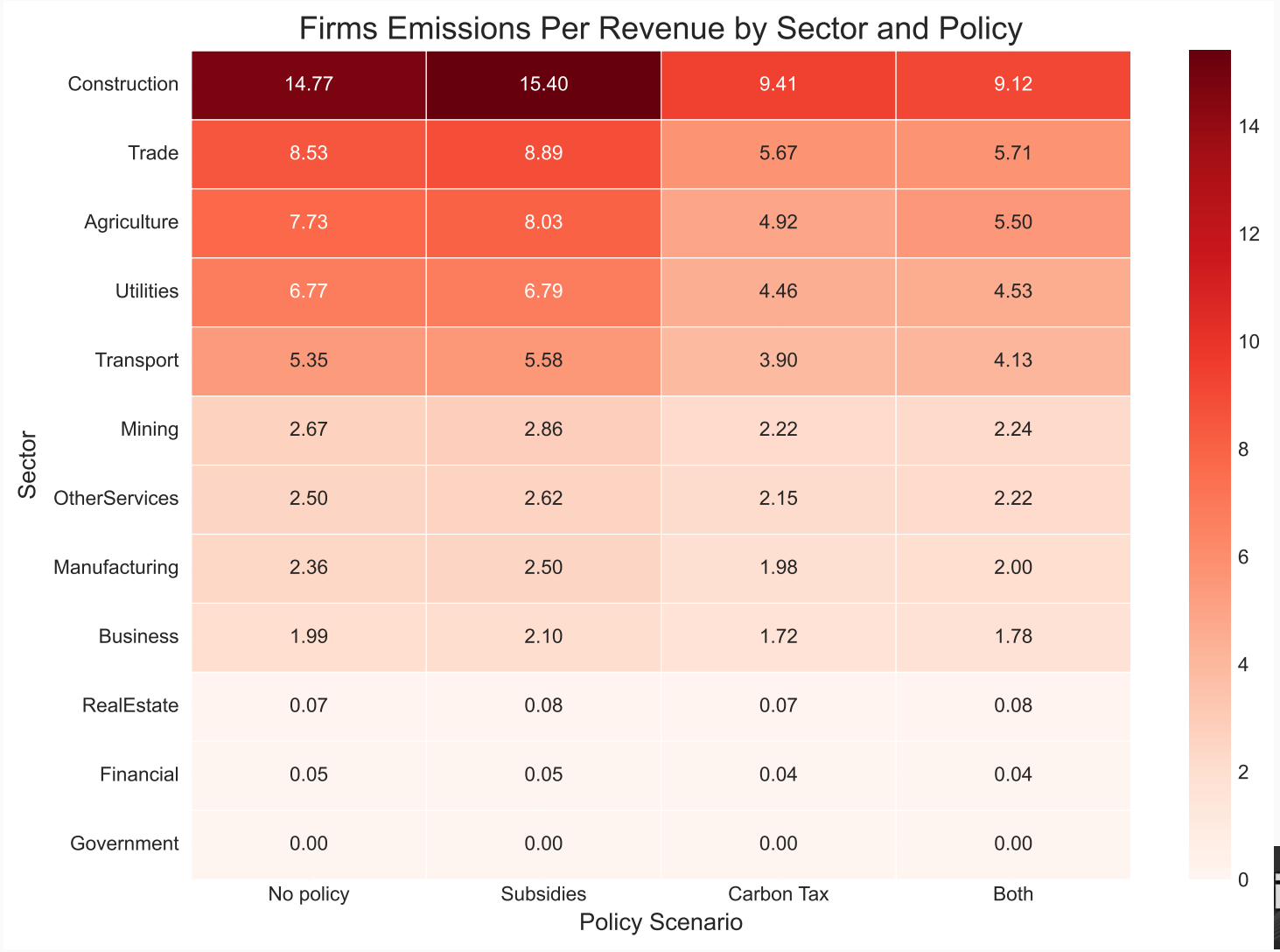
(c) Emissions



(d) Median Innovation Investment

Distributions of key outcome indicators across four policy scenarios

Sectorial results. Emissions/GDP. Avg. intensity



Take-away message and policy

- Modeled carbon tax & green subsidy interactions in a spatial-sectoral ABM.
- No single policy excels; designing effective policy mixes is a key challenge.
- Subsidies alone: negligible effect. Carbon tax: effective but with economic cost.
- Combined policy failed to achieve synergy.
- Subsidies must compensate for tax-induced economic losses.
- Decarbonization was driven more by tax-induced economic contraction than by technology alone.

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Obrigado!

Perguntas?