Climate Policies, Labor Markets, and Macroeconomic Outcomes in Emerging Economies[1]

Alan Finkelstein Shapiro   Victoria Nuguer

Tufts University and Inter-American Development Bank

World Bank/LACEA/Maryland Workshop on Informality in LAC

[1] The views in this paper are solely the responsibility of the authors and should not be interpreted as reflecting the views of the Inter-American Development Bank.

Motivation

- Global impetus to address climate change
- **Key issues in discussions of carbon taxation/climate policies:**
  - Adverse impact on job creation, firms, employment, and GDP
  - Costs of transition to lower-carbon economy
- **Reductions in CO2 emissions by advanced economies (AEs) alone are insufficient** to limit temperature rise (IMF WEO 2020)
- **Emerging economies** need to be **part of reduction efforts**

Motivation

- **Group of emerging economies (EMEs)**
  - Largest contributor to global CO_2 emissions after U.S., China, EU-28 countries (10 percent of global emissions)
  - Greater reliance on polluting energy sources
  - Stable share of global economic activity but **growing share of global emissions** (+ larger projected climate damages)
- **EMEs** have a **distinct employment and firm structure**
  - High barriers to firm formality and low formal job creation
  - Prevalence of small, informal, less productive firms
  - **Large self-employment shares** and weak safety nets
  - **Climate policies may affect this structure!**

But bulk of macro research on climate policies has focused on AEs

What We Do

- Build a **macro search and matching model** with 5 features:
  1. Salaried employment and **self-employment (SE)**
  2. Labor force participation (LFP)
  3. Salaried firm entry and selection into formality
  4. Energy sector with pollution externalities and (costly) abatement
  5. **Choice between regular (polluting) and green (non-polluting) energy technologies**
- **Endogenous technological composition of goods and energy production**
  $\Rightarrow$ Policies **reshape** production and energy structure of economy
- Match average EME employment, firm, energy structure
- Analyze labor market + aggregate effects of $\Downarrow$ emissions by 25 percent with carbon tax/policies in energy sector (IMF WEO 2022)

Four Main Findings

- **A carbon tax on harmful emissions from energy sector:**
  - $\Uparrow$ share of energy producers using green tech. and share of green energy
  - $\Uparrow$ energy prices
  - $\Downarrow$ salaried firm creation, number of formal firms, formal employment share, and $\Uparrow$ SE, unemployment, LFP
  - $\Uparrow$ informality and $\Downarrow$ consumption, output, welfare
- **Producers' ability to adopt green tech.: key to limiting adverse effects of policy**
  - No green-tech. adoption margin $\Rightarrow$ output, welfare losses x 2
  - No green energy whatsoever $\Rightarrow$ output, welfare losses x 3
  - Green energy and tech. adoption limit $\Uparrow$ in energy prices!

Four Main Findings (Continued)

- **SE plays a key role in labor market, aggregate effects of tax**
  - Policy moves resources away from salaried (more productive) firms and towards (less productive) SE
  - $\Uparrow$ Search for SE opportunities $\Uparrow$ overall LFP (reduces welfare)
  - $\Uparrow$ SE share: responsible for 30 percent of output cost, 45 percent of welfare cost
- **Joint policy: $\Downarrow$ emissions with tax + $\Downarrow$ regulatory cost of becoming formal firm**
  - Virtually eliminates output, welfare costs from carbon tax
  - But only if energy producers can adopt green tech.!

If time permits, alternative climate policies + transitional dynamics

Main Contributions

- **New macro framework + analysis of climate policies in EMEs**
  - Model employment, firm, endogenous energy structure in EMEs
  - Quantitative relevance of **endogenous** transition to lower-carbon economy via green tech. adoption **in the presence of firm and labor informality**
  - Most macro analyses of carbon taxes focus primarily on AEs and abstract from green-tech. adoption choices Related Literature
- **Relevance of SE (and firm structure) for climate-policy outcomes in EMEs**
  - AE-based models would give distorted picture of policy effects

KEY FACTS

EMPLOYMENT, FIRM, AND ENERGY STRUCTURE

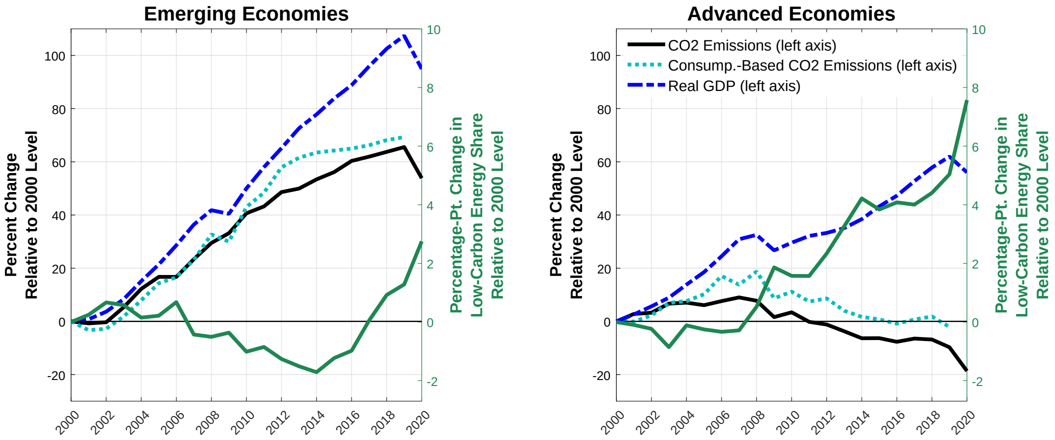
IN EMERGING ECONOMIES

Employment, Firm, and Energy Structure in EMEs

Well known EME group: Argentina, Brazil, Chile, Colombia, Indonesia, Malaysia, Mexico, Peru, Philippines, South Africa, Thailand, Turkey

1. **Self-employment** represents **40 percent of total employment** (vs. 14 percent in AEs)
2. 95+ percent of firms are micro, small, medium enterprises (MSMEs), and **70 percent of MSMEs are informal** (vs. 30 percent in AEs)
3. Small, medium, and large **formal firms** account for **50+ percent of formal employment and GDP**
4. **Fossil fuels** (coal, gas, oil) represent **84 percent of current energy sources, 65 percent of electricity sources** (vs. 73 and 40 percent in AEs)

Emissions, Economic Activity, and Low-Carbon Energy



Sources: World Bank and Global Carbon Project via Our World in Data.

(2-PAGE) MODEL SUMMARY

Model Structure: General Environment

- Economy comprised of households, salaried and SE goods-producing firms, and energy producers; households own all producers
- **Salaried search frictions and household LFP + SE decisions**
  (Unemployment with explicit search for salaried-job/SE opportunities)
- Salaried firm entry is endogenous and subject to sunk entry costs
  (Bilbiie, Ghironi, and Melitz, 2012)
- Salaried firms **choose** whether to be formal or informal
  (Production-technology/productivity tradeoff)
- Energy is used by salaried firms and by households
  (Same conclusions if SE also use energy to produce)

Model Structure: Key Features

▸ Full Model Details

- **Endogenous polluting-green energy production:** based on productivity draw, energy producers choose polluting or green tech.
  - **Polluting tech.** uses regular capital, **generates harmful (TFP-reducing) emissions subject to carbon tax** $\tau \geq 0$, but can choose abatement spending
  - **Green tech.** uses "green" capital, is **emissions-free, subject to fixed cost** $\varphi_e > 0$
  - Baseline: carbon tax revenue rebated back to household lump sum
- Salaried firms use labor, regular capital, and energy to produce; SE use own labor
- **Endog. formal-informal (*f* or *i*) salaried firm structure:** based on productivity draw, firms choose to incur fixed cost $\varphi_f > 0$ and become formal $\Rightarrow$ access to more productive, capital-intensive technology (exogenous + endogenous productivity components)
- **Endogenous SE entry** based on household LFP decisions

QUANTITATIVE ANALYSIS

Quantitative Analysis

- Baseline economy: **zero carbon tax τ**
- Standard parameters from EME, macro-environmental literatures
- Key **calibration targets using EME averages:**
  - Share of SE in total employment (36 percent)
  - Share of f employment in total employment (54 percent)
  - Share of f-firms' output in total output (70 percent)
  - Cost of becoming formal firm (8 percent of income per capita)
  - Share of polluting energy in total energy (84 percent)
  - Damages-GDP ratio from 1-degree-Celsius temp. increase (1.25 percent)

Increase τ to generate 25-percent reduction in long run emissions (IMF WEO 2022)

Functional Forms Damages Functional Form Parameter Values

Long Run Impact of Carbon Tax

Variable	Baseline $\tau = 0$	After Tax	Percent (%) or Perc.-Pt. (PP) Change Relative to Baseline
Total Output (Y)	1.716	1.701	**-0.857** %
Consumption (c)	1.284	1.277	**-0.491** %
Salaried Firms (N_s)	16.813	16.327	**-2.888** %
Price of Energy	0.011	0.012	**11.628** %
Welfare Gain (% of c)	–	–	**-1.848** %
Share of f Firms (N_f / N_s)	3.39%	3.39%	0.005 PP
Share of f Output in Y	70.00%	69.27%	**-0.732** PP
Formal Empl. Share	54.20%	53.15%	**-1.047** PP
SE Share	36.00%	37.30%	**1.297** PP
Unempl. Rate	8.15%	8.30%	0.153 PP
LFP Rate	63.00%	63.37%	0.368 PP
Share of e Firms Using g Tech.	1.03%	4.69%	3.666 PP
Green Energy Share	16.00%	33.51%	17.515 PP
Tax Rev.-Output Ratio	0.00%	0.14%	0.144 PP

Computing Welfare Gain

Emissions Growth and Change in SE Share: Model vs. Data

The Role of Green Tech. Adoption and Green Energy

Variable	**Benchmark**	**No Green Tech. Adopt.**	**No Green Energy**
	Percent Δ	**Percent Δ**	**Percent Δ**
Total Output (Y)	**-0.857**	**-1.452**	**-2.634**
Consumption (c)	-0.491	-0.613	-1.055
Salaried Firms (N_s)	-2.888	-4.729	-8.503
Energy Price	**11.628**	**17.760**	**19.260**
Welfare Gain (% of c)	**-1.848**	**-2.744**	**-4.847**
	Perc.-Pt. Δ	**Perc.-Pt. Δ**	**Perc.-Pt. Δ**
Share of f Firms (N_f / N_s)	0.005	0.008	0.015
Share of f Output in Y	**-0.732**	**-1.175**	**-2.153**
Formal Employment Share	**-1.047**	**-1.675**	**-3.034**
SE Share	**1.297**	**2.080**	**3.764**
Unempl. Rate	**0.153**	**0.245**	**0.442**
LFP Rate	**0.368**	**0.538**	**0.964**
Share of e Firms Using g Tech.	3.666	—	—
Share of Green Energy	17.515	9.040	—
Tax Rev.-Output Ratio	0.144	0.270	0.387

The Role of Changes in Self-Employment

Variable	**Benchmark**	**SE Share Held at Baseline***
	Percent Δ	**Percent Δ**
Total Output (Y)	**-0.857**	**-0.534**
Consumption (c)	-0.491	-0.455
Salaried Firms (N_s)	-2.888	-1.022
Energy Price	**11.628**	**11.258**
Welfare Gain (% of c)	**-1.848**	**-1.033**
	Perc.-Pt. Δ	**Perc.-Pt. Δ**
Share of f Firms (N_f / N_s)	0.005	0.000
Share of f Output in Y	-0.732	-0.117
Formal Employment Share	**-1.047**	**0.001**
SE Share	**1.297**	0.000*
Unempl. Rate	0.153	0.239
LFP Rate	0.368	0.126
Share of e Firms Using g Tech.	3.666	3.913
Share of Green Energy	17.515	18.283
Tax Rev.-Output Ratio	0.144	0.147

Joint Carbon Tax-Firm Formality Policy

▸ Strength of φ_f Changes

Variable	Benchmark	Joint Policy
	$\Uparrow \tau$	$\Uparrow \tau + \Downarrow \varphi_f$ (by 8.5%)
	Percent Δ	**Percent Δ**
Total Output (Y)	**-0.857**	**0.086**
Consumption (c)	-0.491	0.190
Salaried Firms (N_s)	-2.888	-0.116
Energy Price	**11.258**	**11.130**
Welfare Gain (% of c)	**-1.848**	**0.022**
	Perc.-Pt. Δ	**Perc.-Pt. Δ**
Share of f Firms (N_f / N_s)	0.005	0.332
Share of f Output in Y	-0.732	0.345
Formal Employment Share	**-1.047**	**0.307**
SE Share	**1.297**	**0.055**
Unempl. Rate	0.153	0.004
LFP Rate	0.368	**-0.057**
Share of e Firms Using g Tech.	3.666	4.081
Share of Green Energy	17.515	18.790
Tax Rev.-Output Ratio	0.144	0.148

Joint Policy, Green Tech. Adoption, and Green Energy

Variable	Benchmark Model $\Uparrow \tau + \Downarrow \varphi_f$	No Green Tech. Adopt. $\Uparrow \tau + \Downarrow \varphi_f$	No Green Energy $\Uparrow \tau + \Downarrow \varphi_f$
	Percent Δ	Percent Δ	Percent Δ
Total Output (Y)	0.086	-0.565	-1.850
Consumption (c)	0.190	0.046	-0.448
Salaried Firms (N_s)	-0.116	-2.113	-6.176
Welfare Gain (% of c)	0.022	-0.962	-3.251
	Perc.-Pt. Δ	Perc.-Pt. Δ	Perc.-Pt. Δ
Share of f Firms (N_f/N_s)	0.332	0.336	0.347
Share of f Output in Y	0.345	-0.118	-1.136
Formal Employment Share	0.307	-0.362	-1.802
SE Share	0.055	0.882	2.656
Unempl. Rate	0.004	0.102	0.311
LFP Rate	-0.057	0.124	0.572
Share of e Firms Using g Tech.	4.081	—	—
Share of Green Energy	18.790	9.742	—
Tax Rev.-Output Ratio	0.148	0.284	0.412

ALTERNATIVE CLIMATE POLICIES

Increase in Carbon Tax (τ)

vs. Reduction in Green-Tech. Adoption Cost (φ_e)

vs. Reduction in Green-Capital Price (r_k^g)

Alternative Climate Policies: Same 25% Emissions Reduction

Variable	$\Uparrow \tau$	$\Downarrow \varphi_e$	$\Downarrow r_k^g$
	Percent Δ	**Percent Δ**	**Percent Δ**
Total Output (Y)	-0.857	-0.415	0.526
Consumption (c)	-0.491	-0.441	0.115
Salaried Firms (N_s)	-2.888	-1.545	1.491
Energy Price	**11.628**	**7.491**	**-2.750**
Welfare Gain (% of c)	-1.848	-1.252	0.705
	Perc.-Pt. Δ	**Perc.-Pt. Δ**	**Perc.-Pt. Δ**
Share of f Firms (N_f/N_s)	0.005	0.002	-0.003
Share of f Output in Y	-0.732	-0.422	0.308
Formal Employment Share	-1.047	-0.604	0.450
SE Share	1.297	0.743	-0.563
Unempl. Rate	0.153	0.087	-0.069
LFP Rate	0.368	0.260	-0.117
Share of e Firms Using g Tech.	3.666	15.884	7.268
Share of Green Energy	17.515	27.724	29.177
Tax Rev.-Output Ratio	0.144	0.000	0.000

TRANSITIONAL DYNAMICS

▸ Transitional Dynamics

Conclusion

- Study labor market, macro consequences of climate policies in energy sector in EMEs
- Build a macro-search model with EME employment, firm, energy structure
  - Equilibrium unemployment and LFP, formal and informal salaried employment, **and SE**
  - Endogenous salaried firm entry and selection into formality
  - Energy sector with pollution externalities
  - Energy producers' **choice** between polluting or green technologies
- Carbon tax $\Downarrow$ formal employment, output, consumption, welfare; $\Uparrow$ SE and unemployment
  - SE response shapes extent of output and welfare losses
  - Green tech. adoption $\Rightarrow$ limits adverse policy effects
  - **Joint carbon tax-firm formality policy can eliminate output, welfare costs**

APPENDIX

Why Use a Model

- **Challenging** to analyze labor market, macro effects of carbon taxation and climate policies empirically
  - Existing studies have focused on non-EME cases: British Columbia (Bernard et al., 2018) and Europe (Metcalf and Stock, 2020)
  - Most EMEs either do not have carbon taxes or their introduction has been very recent
  - Difficult to identify key forces or underlying mechanisms empirically
  - **All the more so in EMEs due to data limitations**

- A microfounded macro model disciplined with EME data can provide useful insights into the quantitative relevance of key margins of adjustment to policy

Back

Related Literature

- **Macro-climate, labor markets in advanced economies (AEs)**
  - Acemoglu, Akcigit, Hanley, and Kerr (2016), Annicchiarico, Correani, and Di Dio (2018), Fried (2018a), Barrett, Bergant, Chateau, and Mano (2021), Fried, Novan, and Peterman (2021b), Adao, Narajabad, and Temzelides (2022), Jondeau, Levieuge, Sahuc, and Vermandel (2022)
  - Hafstead and Williams III (2018, 2021), Aubert and Chiroleu-Assouline (2019), Fernandez Intriago (2020), Castellanos and Heutel (2021), Finkelstein Shapiro and Metcalf (2023)
- **Macro-climate and macro-climate-labor beyond AEs**
  - Bento, Jacobsen, and Liu (2018), Cavalcanti, Hasna, and Santos (2022)
  - Reidt (2021), Fernandez Intriago and MacDonald (2022)

Back

MODEL DETAILS

Salaried Goods-Producing Firms

Back to Model Summary

- Endog. measure $N_{s,t}$ of salaried firms, incur sunk entry cost $\varphi_s > 0$
- Upon entry, draw idiosyncratic prod. a_s from distribution $G(a_s)$
- **2 available technologies** (capital k, salaried labor n, energy e)
  - **Informal** $i \Rightarrow$ produce $D(x_t) z_{i,t} F(n_{i,t}, k_{i,t}, e_{i,t})$
  - **Formal** $f \Rightarrow$ produce $D(x_t) z_{f,t} H(n_{f,t}, k_{f,t}, e_{f,t})$
  - H more capital intensive than F and $z_f > z_i$
  - **Pollution damages** $D(x_t)$ depend on pollution stock $x_t = f(x_{t-1}, em_t)$ and emissions em_t and **reduce aggregate productivity**

Salaried Firms and Formality Choice

Back to Model Summary

- Firms with $a_s < \bar{a}_{s,t}$ adopt i technology and become informal
- Firms with $a_s \geq \bar{a}_{s,t}$ adopt f technology and become formal
  - To do so, must incur fixed cost of firm formality $\varphi_f > 0$
  - **Choice to become formal $\Leftrightarrow$ choice over production technology**
- Formality decision generates two endogenous measures of salaried firms:

$$N_{i,t} = G(\bar{a}_{s,t})N_{s,t}$$

$$N_{f,t} = (1 - G(\bar{a}_{s,t}))N_{s,t}$$

- **Endogenous salaried formal-informal production structure!**

Production Details Optimality Conditions Tech. Adoption Details

Energy Producers

Back to Model Summary

- Measure one of monopolistically-competitive energy producers: energy used by salaried firms and households
- Draw idiosyncratic prod. a_e from distribution $G(a_e)$
- **2 available technologies** (capital k_e)
  - regular (polluting) $\Rightarrow$ produce $e_{r,t}=D(x_t)z_{e,t}k^r_{e,t}$ and generate emissions $em_t = (1-\mu_t)f(e_{r,t})$ as by-product, where μ_t is endogenous abatement rate and $f' > 0$
  - green (non-polluting) $\Rightarrow$ produce $e_{g,t}=D(x_t)z_{e,t}k^g_{e,t}$ without emissions
  - Assume tech.-specific green capital $k^g_{e,t}$ is "imported" (exogenous price)

Energy Producers and Technology Choice

Back to Model Summary

- Energy producers with $a_e < \bar{a}_{e,t}$ adopt r technology
  - Face carbon tax τ_t on em_t
  - Can abate em_t at total cost $\Gamma_t = (\mu_t)^\eta D(x_t) z_{e,t} k^r_{e,t}$, $\eta > 1$
- Producers with $a_e \geq \bar{a}_{e,t}$ adopt g technology
  - No carbon tax τ_t or abatement costs
  - But must incur fixed cost $\varphi_g > 0$
- Tech. adoption decision generates subsegments of energy producers:

$$N_{r,t} = G(\bar{a}_{e,t})$$

$$N_{g,t} = (1 - G(\bar{a}_{e,t}))$$

- **Endogenous polluting-green energy production structure!**

Production Details Optimality Conditions Tech. Adoption Details

Households, SE, and Market Clearing

Back to Model Summary

- Utility from consumption of goods c and energy e_h (complements), disutility from labor force participation (LFP)
- Make decisions over salaried firm creation (incur sunk entry costs)
- **LFP decisions: choose measures of salaried formal (f), salaried informal (i), and SE (o) searchers** s_f, s_i, s_o and desired employment in each category
- Receive salaried labor income, SE labor income $D(x_t)p_{o,t}z_{o,t}n_{o,t}$, and income from owning production firms, energy producers
- Baseline: receive carbon-tax revenue as lump sum transfer
- Total output: CES aggregator of total salaried-firm output $Y_{s,t}$ and total SE output $Y_{o,t}$

Household Details | Optimality Conditions | Nash Wages and Market Clearing

Salaried Intermediate Goods Production

Back to Model Details

- WLOG, separate salaried production into intermediate goods (tech.) and final goods (firms)
- Representative salaried firm produces two categories of intermediate goods, i and f
- Production of each intermediate good requires capital k, salaried labor n, energy e
- Labor is subject to search frictions: post vacancies $v_{j,t}$ at cost $\psi_j > 0$ for $j \in \{i, f\}$
- Each salaried intermediate goods category $j \in \{i, f\}$ is sold to a salaried final-goods firm at price $mc_{j,t}$
- Unbounded number of imperfectly-compet. final-goods firms salaried $N_{s,t}$ select into i or f technology based on idiosyncratic productivity a_s and fixed cost φ_f

Salaried Intermediate Goods Production

Back to Model Details

Choose $v_{i,t}$, $v_{f,t}$, $n_{i,t}$, $n_{f,t}$, $k_{i,t}$, $k_{f,t}$, $e_{i,t}$, $e_{f,t}$ to max $\mathbb{E}_0 \sum_{t=0}^{\infty} \Xi_{t|0} \Pi_{s,t}$ subject to

$$\Pi_{s,t} = [D(x_t) z_{i,t} mc_{f,t} F(n_{i,t}, k_{i,t}, e_{i,t}) - w_{i,t} n_{i,t} - r_{k,t} k_{i,t}$$

$$-\rho_{e,t} e_{i,t} - \psi_i v_{i,t}] + [D(x_t) z_{f,t} mc_{f,t} H(n_{f,t}, k_{f,t}, e_{f,t})$$

$$-w_{f,t} n_{f,t} - r_{k,t} k_{f,t} - \rho_{e,t} e_{f,t} - \psi_f v_{f,t}],$$

$$n_{i,t} = (1 - \rho_s) n_{i,t-1} + v_{i,t} q(\theta_{i,t}),$$

$$n_{f,t} = (1 - \rho_s) n_{f,t-1} + v_{f,t} q(\theta_{f,t}),$$

Optimality Conditions

Back to Model Summary

Standard capital and energy demand functions:

$$D(x_t)mc_{i,t}z_{i,t}F_{k_i,t} = r_{k,t}$$

$$D(x_t)mc_{f,t}z_{f,t}H_{k_f,t} = r_{k,t}$$

and

$$D(x_t)mc_{i,t}z_{i,t}F_{e_i,t} = \rho_{e,t}$$

$$D(x_t)mc_{f,t}z_{f,t}H_{e_f,t} = \rho_{e,t}$$

Back to Model Details

Optimality Conditions

Back to Model Summary

Standard salaried job creation conditions:

$$\frac{\psi_i}{q(\theta_{i,t})} = D(x_t) mc_{i,t} z_{i,t} F_{n_i,t} - w_{i,t} + (1-\rho_s)\mathbb{E}_t \Xi_{t+1|t} \frac{\psi_i}{q(\theta_{i,t+1})}$$

and

$$\frac{\psi_f}{q(\theta_{f,t})} = D(x_t) mc_{f,t} z_{f,t} H_{n_f,t} - w_{f,t} + (1-\rho_s)\mathbb{E}_t \Xi_{t+1|t} \frac{\psi_f}{q(\theta_{f,t+1})}$$

Back to Model Details

Salaried Final-Goods Firms

Back to Model Details

Individual-salaried-firm profits from producing using i and f technologies:

$$\pi_{i,t}(a_s) = \left[\rho_{i,t}(a_s) - \frac{mc_{i,t}}{a_s}\right] y_{i,t}(a_s)$$

$$\pi_{f,t}(a_s) = \left[\rho_{f,t}(a_s) - \frac{mc_{f,t}}{a_s}\right] y_{f,t}(a_s) - \varphi_f$$

where $\rho_{j,t}(a_s)$ is firm a_s's real price, $mc_{j,t}$ is the price of goods produced with tech. j, and $y_{j,t}(a_s)$ is firm a_s's output for $j \in \{i, f\}$

Total profits for salaried firm a_s: $\pi_{s,t}(a_s) = \pi_{i,t}(a_s) + \pi_{f,t}(a_s)$

Demand function for firm a_s's output $y_{j,t}(a_s)$ for $j \in \{i, f\}$:

$$y_{j,t}(a_s) = (\rho_{j,t}(a_s)/\, p_{j,t})^{-\varepsilon} Y_{s,t}$$

where $Y_{s,t}$ is total salaried output, $p_{s,t}$ is the relative price of Y_s, t

Salaried Final-Goods Firms: Pricing, Tech. Choice

Back to Model Details

Optimal real price for salaried firm a_s using tech. $j \in \{i, f\}$ is standard

$$\rho_{j,t}(a_s) = \frac{\varepsilon}{\varepsilon - 1} \frac{mc_{j,t}}{a_s}$$

Idiosyncratic productivity threshold $\bar{a}_{s,t}$ implies indifference between technologies:

$$\pi_{f,t}(\bar{a}_{s,t}) = \pi_{i,t}(\bar{a}_{s,t})$$

Average idiosyncratic productivity levels:

$$\widetilde{a}_{f,t} = \left[\frac{1}{1 - G(\bar{a}_{s,t})} \int_{\bar{a}_{s,t}}^{\infty} a_s^{\varepsilon - 1} dG(a_s) \right]^{\frac{1}{\varepsilon - 1}}$$

$$\widetilde{a}_{i,t} = \left[\frac{1}{G(\bar{a}_{s,t})} \int_{a_{min}^s}^{\bar{a}_{s,t}} a_s^{\varepsilon - 1} dG(a_s) \right]^{\frac{1}{\varepsilon - 1}}$$

Salaried Final-Goods Production: Averages

Back to Model Details

Average salaried firm profits:

$$\widetilde{\pi}_{s,t} = \left(\frac{N_{i,t}}{N_t}\right)\widetilde{\pi}_{i,t} + \left(\frac{N_{f,t}}{N_t}\right)\widetilde{\pi}_{f,t}$$

where $\widetilde{\pi}_{i,t} \equiv \pi_{i,t}(\widetilde{a}_{i,t})$, and $\widetilde{\pi}_{f,t} \equiv \pi_{f,t}(\widetilde{a}_{f,t})$

Also, define $\widetilde{\rho}_{i,t} \equiv \rho_{i,t}(\widetilde{a}_{i,t})$, $\widetilde{\rho}_{f,t} \equiv \rho_{f,t}(\widetilde{a}_{f,t})$, $\widetilde{y}_{i,t} \equiv y_{i,t}(\widetilde{a}_{i,t})$ and $\widetilde{y}_{f,t} \equiv y_{f,t}(\widetilde{a}_{f,t})$

Total salaried-firm output: $Y_{s,t} = \left(\int_{\zeta \in Z} y_{s,t}(\zeta)^{\frac{\varepsilon-1}{\varepsilon}} d\zeta\right)^{\frac{\varepsilon}{\varepsilon-1}}$, $\varepsilon > 1$ where each firm produces differentiated output variety ζ and individual firm output is $y_{s,t}(\zeta)$; for simplicity, index firm ζ by a_s

Intermediate Energy-Goods Production

Back to Model Details

- WLOG, separate production into intermediate energy goods (tech.) and final-energy producer (firms)
- Representative energy producer produces two categories of intermediate energy goods, r and g
- Production of each intermediate energy good requires capital k
- Each intermediate energy good category $j \in \{r, g\}$ is sold to a final-energy producer at price $mc_{j,t}$
- Fixed measure of imperfectly-compet. final-energy producers select into r or g technology based on idiosyncratic productivity a_e and fixed cost φ_g

Intermediate Energy-Goods Production

Back to Model Details

Choose $k^r_{e,t}$, $k^g_{e,t}$, $mu_{e,t}$ to max $\mathbb{E}_0 \sum_{t=0}^{\infty} \Xi_{t|0} \Pi_{e,t}$ subject to

$$\Pi_{e,t} = \left[D(x_t) z_{e,t} mc^r_{e,t} k^r_{e,t} - r_{k,t} k^r_{e,t} - \tau_t em_t - \Gamma_t\right]$$

$$+ \left[D(x_t) z_{e,t} mc_{g,t} k^g_{e,t} - r^g_{k,t} k^g_{e,t}\right],$$

$$em_t = (1 - \mu_{e,t}) \left[D(x_t) z_{e,t} k^r_{e,t}\right]^{1-\nu},$$

and

$$\Gamma_t = \gamma \mu^{\eta}_{e,t} D(x_t) z_{e,t} k^r_{e,t}$$

where $r^g_{k,t}$ is exogenous ("imported" $k^g_{e,t}$ assumption)

Optimality Conditions

Back to Model Details

Standard capital demand conditions:

$$D(x_t)z_{e,t}mc^r_{e,t} = r_{k,t} + \tau_t em_{k^r_e,t} + \Gamma_{k^r_e,t}$$

and

$$D(x_t)z_{e,t}mc^g_{e,t} = r^g_{k,t}$$

Optimal emissions abatement rate $\mu_{e,t}$:

$$\tau_t \left(D(x_t)z_{e,t}k^r_{e,t}\right)^{-\nu} = \gamma\eta\mu^{\eta-1}_{e,t}$$

Final Energy Producers

Back to Model Details

Individual-energy-producer profits from using r and g tech.:

$$\pi^{r}_{e,t}(a_e) = \left[\rho^{r}_{e,t}(a_e) - \frac{mc^{r}_{e,t}}{a_e}\right] e_{r,t}(a_e)$$

$$\pi^{g}_{e,t}(a_e) = \left[\rho^{g}_{e,t}(a_e) - \frac{mc^{g}_{e,t}}{a_e}\right] e_{g,t}(a_e) - \varphi_g$$

where $\rho^{j}_{e,t}(a_e)$ is energy producer's a_e's real price, $mc^{j}_{e,t}$ is the price of energy produced with tech. j, and $e_{j,t}(a_e)$ is energy producer's a_e's output for $j \in \{r, g\}$

Total profits for energy producer a_e: $\pi_{e,t}(a_e) = \pi^{r}_{e,t}(a_e) + \pi^{g}_{e,t}(a_e)$

Demand function for energy producer a_e's output $e_{j,t}(a_e)$ for $j \in \{r, g\}$:

$$e_{j,t}(a_e) = \left(\rho^{j}_{e,t}(a_e) \Big/ \rho_{e,t}\right)^{-\varepsilon_e} E_t$$

where E_t is total energy and its relative price is $\rho_{e,t}$

Final Energy Producers: Pricing, Tech. Choice

Back to Model Details

Optimal real price for energy producer a_e using tech. $j \in \{r, g\}$ is standard

$$\rho^j_{e,t}(a_e) = \frac{\varepsilon_e}{\varepsilon_e - 1} \frac{mc^j_{e,t}}{a_e}$$

Idiosyncratic productivity threshold $\bar{a}_{e,t}$ implies indifference between technologies:

$$\pi^g_{e,t}(\bar{a}_{e,t}) = \pi^r_{e,t}(\bar{a}_{e,t})$$

Average idiosyncratic productivity levels:

$$\tilde{a}^g_{e,t} = \left[\frac{1}{1 - G(\bar{a}_{e,t})} \int_{\bar{a}_{e,t}}^{\infty} a_e^{\varepsilon_e - 1} dG(a_e)\right]^{\frac{1}{\varepsilon_e - 1}}$$

$$\tilde{a}^r_{e,t} = \left[\frac{1}{G(\bar{a}_{e,t})} \int_{a^e_{min}}^{\bar{a}_{e,t}} a_e^{\varepsilon_e - 1} dG(a_e)\right]^{\frac{1}{\varepsilon_e - 1}}$$

Energy Production: Averages

Back to Model Details

Average energy producer profits:

$$\widetilde{\pi}_{e,t} = N_{r,t}\widetilde{\pi}^r_{e,t} + N_{g,t}\widetilde{\pi}^g_{e,t}$$

where $\widetilde{\pi}^r_{e,t} \equiv \pi_{r,t}(\widetilde{a}^r_{e,t})$, and $\widetilde{\pi}^g_{e,t} \equiv \pi^g_{e,t}(\widetilde{a}^g_{e,t})$

Also, define $\widetilde{\rho}^r_{e,t} \equiv \rho^r_{e,t}(\widetilde{a}^r_{e,t})$, $\widetilde{\rho}^g_{e,t} \equiv \rho^g_{e,t}(\widetilde{a}^g_{e,t})$, $\widetilde{e}_{r,t} \equiv e_{r,t}(\widetilde{a}^r_{e,t})$ and $\widetilde{e}_{g,t} \equiv e_{g,t}(\widetilde{a}^g_{e,t})$

Total energy: $E_t = \left(\int_0^1 e_t(a_e)^{\frac{\varepsilon_e - 1}{\varepsilon_e}} da_e\right)^{\frac{\varepsilon_e}{\varepsilon_e - 1}}$, $\varepsilon_e > 1$ where each energy producer produces differentiated energy a_e and individual energy-producer output is $e_t(a_e)$

Households

Back to Model Details

Choose c_t, $e_{h,t}$, searchers $s_{f,t}$, $s_{i,t}$, $s_{o,t}$, desired empl. $n_{i,t}$, $n_{f,t}$, $n_{o,t}$, new salaried firms, $A_{s,t}$, and $N_{s,t+1}$ to maximize

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\mathbf{u}(c_t, e_{h,t}) - \mathbf{h}(lfp_{i,t}, lfp_{f,t}, lfp_{o,t})\right]$$

subject to the budget constraint

$$c_t + \varphi_s A_{s,t} = w_{i,t} n_{i,t} + w_{f,t} n_{f,t} + k_{t+1} - (1-\delta) k_t$$

$$+ \widetilde{\pi}^y_{s,t} N_{s,t} + \Pi_{e,t} + p_{o,t} D(x_t) z_{o,t} n_{o,t} + r_{k,t} k_t + \Pi_{a,t} + T_t,$$

the evolution of salaried employment in $j \in \{i, f\}$ and SE

$$n_{j,t} = (1-\rho_s) n_{j,t-1} + s_{j,t} f(\theta_{j,t}),$$

$$n_{o,t} = (1-\rho_o) n_{o,t-1} + s_{o,t} \phi_o,$$

and the evolution of salaried firms

$$N_{s,t+1} = (1-\delta_s)\left[N_{s,t} + A_{s,t}\right]$$

Household Optimality Conditions

Back to Model Details

Optimal firm creation condition:

$$\varphi_s = (1-\delta_s)\mathbb{E}_t \Xi_{t+1|t}\left[\widetilde{\pi}_{s,t+1} + \varphi_s\right]$$

Capital Euler equation:

$$1 = (1-\delta)\mathbb{E}_t \Xi_{t+1|t}\left[r_{k,t+1} + (1+\delta)\right]$$

Household Optimality Conditions

Back to Model Details

Participation decision in salaried employment category $j \in \{i, f\}$:

$$\left(\frac{\mathbf{h}_{lfp_{j,t}}}{\varrho(\theta_{j,t})\mathbf{u}'(c_t)}\right) = w_{j,t}$$

$$+(1-\rho_s)\mathbb{E}_t\Xi_{t+1|t}\left(1-\varrho(\theta_{j,t+1})\right)\left(\frac{\mathbf{h}_{lfp_{j,t+1}}}{\varrho(\theta_{j,t+1})\mathbf{u}'(c_{t+1})}\right)$$

Participation decision in self-employment:

$$\left(\frac{\mathbf{h}_{lfp_{o,t}}}{\phi_o\mathbf{u}'(c_t)}\right) = p_{o,t}D(x_t)z_{o,t}$$

$$+(1-\rho_o)\mathbb{E}_t\Xi_{t+1|t}\left(1-\phi_o\right)\left(\frac{\mathbf{h}_{lfp_{o,t+1}}}{\phi_o\mathbf{u}'(c_{t+1})}\right)$$

Nash Wages and Unemployment

Back to Model Details

Bilateral Nash bargaining between firm and workers:

$$w_{i,t} = \nu_n \left[D(x_t) mc_{i,t} z_{i,t} F_{n_{i,t}} + (1-\rho_s) \mathbb{E}_t \Xi_{t+1|t} \psi_i \theta_{i,t+1} \right]$$

and

$$w_{f,t} = \nu_n \left[D(x_t) mc_{f,t} z_{f,t} H_{n_{f,t}} + (1-\rho_s) \mathbb{E}_t \Xi_{t+1|t} \psi_f \theta_{f,t+1} \right]$$

where $0 < \nu_n < 1$ is the bargaining power of workers

Total LFP is $lfp_t = lfp_{i,t} + lfp_{f,t} + lfp_{o,t}$ so that the **unemployment rate** is

$$ur_t \equiv \frac{((1-\varrho(\theta_{i,t}))s_{i,t} + (1-\varrho(\theta_{f,t}))s_{f,t} + (1-\phi_o)s_{o,t})}{lfp_t}$$

Market Clearing

Back to Model Details

Market clearing for each category of salaried firm:

$$D(x_t) z_{i,t} F(n_{i,t}, k_{i,t}, e_{i,t}) = N_{i,t} \left(\frac{\widetilde{y}_{i,t}}{\widetilde{a}_{i,t}} \right)$$

and

$$D(x_t) z_{f,t} H(n_{f,t}, k_{f,t}, e_{f,t}) = N_{f,t} \left(\frac{\widetilde{y}_{f,t}}{\widetilde{a}_{f,t}} \right)$$

Market clearing for each category of energy producers:

$$D(x_t) z_{e,t} k^r_{e,t} = G(\bar{a}_{e,t}) \left(\frac{\widetilde{e}_{r,t}}{\widetilde{a}^r_{e,t}} \right)$$

and

$$D(x_t) z_{e,t} k^g_{e,t} = [1 - G(\bar{a}_{e,t})] \left(\frac{\widetilde{e}_{g,t}}{\widetilde{a}^g_{e,t}} \right)$$

Market Clearing (Continued)

Back to Model Summary

Total energy:

$$E_t = e_{h,t} + e_{i,t} + e_{f,t}$$

Total capital:

$$k_t = k_{i,t} + k_{f,t} + k^r_{e,t}$$

The resource constraint of the economy is

$$\begin{gathered} Y_t = c_t + \psi_i v_{i,t} + \psi_f v_{f,t} + \varphi_s A_{s,t} + \varphi_f N_{f,t} \\ + \varphi_e [1 - G(\bar{a}_{e,t})] + k_{t+1} - (1-\delta) k_t + \Gamma_t + r^g_{k,t} k^g_{e,t} \end{gathered}$$

Back to Model Details

Matching Process Details

Matching function for salaried employment category $j \in \{i, f\}$:

$$m(s_{j,t}, v_{j,t}) = s_{j,t} v_{j,t} / (s_{j,t}^{\xi} + v_{j,t}^{\xi})^{1/\xi},$$

where $\xi > 0$, $s_{j,t}$ are searchers in salaried employment category j, and $v_{j,t}$ are vacancies in that same category

Then, the job-finding and job-filling probabilities are defined as

$$\varrho(\theta_{j,t}) = v_{j,t} / (s_{j,t}^{\xi} + v_{j,t}^{\xi})^{1/\xi}$$

$$q(\theta_{j,t}) = s_{j,t} / (s_{j,t}^{\xi} + v_{j,t}^{\xi})^{1/\xi}$$

where market tightness is $\theta_{j,t} \equiv v_{j,t} / s_{j,t}$

Functional Forms

- Utility over goods and energy consumption: $\mathbf{u}(c_t) = \frac{((c_t)^(1-\sigma_e) * (e_{h,t})^(\sigma_e))^{1-\sigma_c}}{1-\sigma_c}$
- LFP disutility: $\mathbf{h}(lfp_{i,t}, lfp_{f,t}, lfp_{o,t}) = \left[\frac{(\kappa_i(lfp_{i,t}) + \kappa_f(lfp_{f,t} + \kappa_o(lfp_{o,t})))^{1+1/\phi_n}}{1+1/\phi_n}\right]$
- Distributions of a_j for $j \in \{s, e\}$: $G(a) = \left[1 - \left(a^j_{min}/a_j\right)^{k_p}\right]$
- CD production, i salaried output: $F(n_{i,t}, k_{i,t}, e_{i,t}) = (n_{i,t})^{1-\alpha_i-\alpha_e}(k_{i,t})^{\alpha_i}(e_{i,t})^{\alpha_e}$
- CD production, f salaried output: $H(n_{f,t}, k_{f,t}, e_{f,t}) = (n_{f,t})^{1-\alpha_f-\alpha_e}(k_{f,t})^{\alpha_f}(e_{f,t})^{\alpha_e}$

Back

Functional Forms (Continued)

- Pollution damages: $D(x_t) = exp\left[-D_0(x_t - \bar{x})\right]$
- $D_0 > 0$ dictates strength of pollution externality and $\bar{x} = D_1 x$ denotes pre-industrial atmospheric carbon dioxide concentration, with $0 \leq D_1 < 1$
- Can then calibrate D_0 to match pollution damages-GDP ratio and choose D_1 to reflect growth in atmospheric stock of GHG since beginning of Industrial era

Back

Computing Welfare

Following Fried (2018) and Finkelstein Shapiro and Metcalf (2022), the welfare effects of the policy are determined by:

$$\left[\mathbf{u}\left(\left(1+\frac{\Delta}{100}\right)c^{base}, e_h^{base}\right)-\mathbf{h}\left(lfp_f^{base}, lfp_i^{base}, lfp_o^{base}\right)\right]$$
$$=\left[\mathbf{u}\left(c^{\tau}, e_h^{\tau}\right)-\mathbf{h}\left(lfp_{f,t}^{\tau}, lfp_i^{\tau}, lfp_o^{\tau}\right)\right],$$

where the superscript *base* denotes variables in the baseline (no-carbon-tax) scenario, the superscript τ denotes variables under the carbon-tax scenario, and Δ represents the welfare gain from the policy (expressed as a percent of steady-state consumption)

Back

Parameters from Literature, Baseline Parameter Values

Back

Parameter	Value	Description	Source
α_f	0.32	Capital share, f firms	EME lit.
α_i	0.22	Capital share, i firms	Baseline
α_e	0.05	Energy share, firms	Baseline
β	0.985	Discount factor	EME lit.
δ	0.025	Capital depreciation rate	EME lit.
δ_s	0.025	Salaried firm exit prob.	EME lit.
σ_c	2	CRRA parameter	EME lit.
ϕ_n	0.26	Elasticity of LFP	Chetty et al. (2011, 2013)
ε	4	Elast. substit. firm output	Ghironi and Melitz (2005)
k_p^s	4.2	Pareto shape param.	Baseline, $k_p^s > \varepsilon - 1$
k_p^e	4.2	Pareto shape param.	Baseline, $k_p^e > \varepsilon - 1$

Parameters from Literature (Continued) ▸ Back

Parameter	Value	Description	Source
a^s_{min}	1	Min. idiosyncratic prod.	Normalization
a^e_{min}	1	Min. idiosyncratic prod.	Normalization
ρ_s	0.05	Salaried job separation prob.	Bosch, Maloney (2008)
ρ_o	0.03	Self empl. separation prob.	Bosch, Maloney (2008)
ν_n	0.50	Worker bargaining power	Search lit.
D_1	0.6983	Parameter damages function	Annicchiarico, et al. (2018)
η	2.8	Elasticity of abatement	Nordhaus (2008)
γ	1	Weight abatement cost	Hafstead, Williams III (2018)
ν	0.304	Elast. parameter, emissions	Heutel (2012)
ρ_x	0.9979	Pollution Persistence	Heutel (2012)

Calibrated Parameters ▸ Back

Parameter	Value	Description	Target
σ_e	0.0139	HH energy share	$e_h / E = 0.26$
D_0	0.00000344	Damages param.	Damages/GDP $= 0.0125$
$\psi_f\ (= \psi_i)$	0.1487	Vacancy posting cost	$(\psi_f v_f + \psi_i v_i) / Y = 0.03$
φ_f	0.3586	Fixed cost f	$\varphi_f / Y = 0.08$
φ_e	0.0363	Fixed cost g	r energy prod. share $= 0.84$
e^{row}	22.5967	Rest of world em.	$em^{row} / (em + em^{row}) = 0.90$
κ_f	1.2450	LFP disutility f	$lfp = 0.63$
κ_i	0.9902	LFP disutility i	$(n_f) / (n_f + n_i + n_o) = 0.542$
κ_o	1.0543	LFP disutility o	$(n_o) / (n_f + n_i + n_o) = 0.36$
ξ	0.3937	Matching elasticity	$ur = 0.0815$
z_i	0.4697	i-firm exog. prod.	$w_f / w_i = 1.25$
z_o	2.5252	SE exog. prod.	Total f output share $= 0.70$
r_k^g	0.0377	Cost g capital k_e^g	$(r_k^g + \varphi_e / k_e^g) - r_k = 0.06$
$\bar{x}$	8348.3	Pre-industrial x stock	$\bar{x} = D_1 x$

Growth in Emissions and Change in SE Share: Model ▸ Back

	Emerging Economy Calibration	**Advanced Economy Calibration**
	$\Downarrow$ Emissions due to Carbon Tax (or $\Downarrow z_e^r$)	$\Downarrow$ Emissions due to Carbon Tax (or $\Downarrow z_e^r$)
Perc. Change in Emissions	**-10**	**-10**
Perc.-Pt. Change in SE Share	0.522 (0.615)	0.202 (0.236)
Perc.-Pt. Change in SE Share Holding Output Growth Constant	0.185 (0.241)	0.078 (0.105)

Note: Advanced Economy calibration has lower baseline SE share, higher baseline f-output share.

Growth in Emissions and Change in SE Share: EMEs
Back

EMERGING ECONOMIES

Δ **SE Share**$_{t,t-1}$	(1)	(2)	(3)	(4)
Perc. Δ CO2 Emissions$_{t,t-1}$	**-0.029*****	**-0.016**	**-0.023****	**-0.014**
	(-2.98)	(-1.58)	(-2.29)	(-1.36)
Perc. Δ RGDP PC$_{t,t-1}$	—	-0.084***	—	-0.084***
		(-3.85)		(-2.88)
Country Fixed Effects	Yes	Yes	Yes	Yes
Time Fixed Effects	No	No	Yes	Yes
Overall R^2	0.04	0.11	0.12	0.17
Obs.	240	240	240	240
No. of Countries	12	12	12	12
Time Span	2000-2019	2000-2019	2000-2019	2000-2019

Sources: World Bank Development Indicators and Carbon Project via Our World in Data. **Note:** *** and ** denote sig. at 1% and 5% levels.

Growth in Emissions and Change in SE Share: AEs

Back

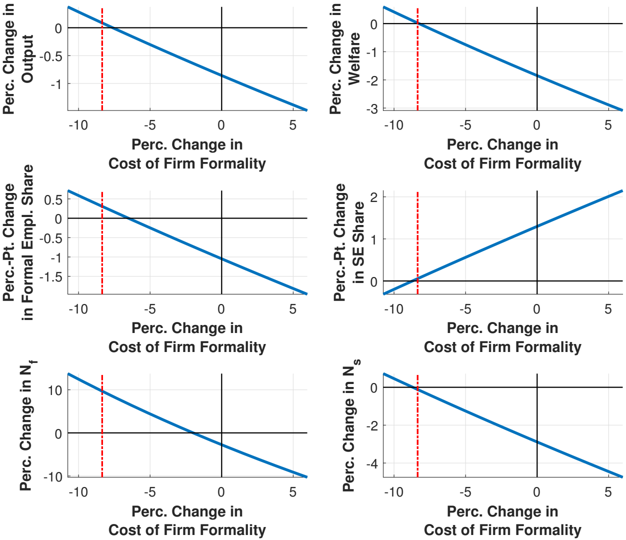
ADVANCED ECONOMIES

Δ SE Share$_{t,t-1}$	(1)	(2)	(3)	(4)
Perc. Δ CO2 Emissions$_{t,t-1}$	-0.007**	-0.003	-0.005	-0.004
	(-1.99)	(-0.77)	(-1.30)	(-0.97)
Perc. Δ RGDP PC$_{t,t-1}$	—	-0.049***	—	-0.046***
		(-5.82)		(-4.10)
Country Fixed Effects	Yes	Yes	Yes	Yes
Time Fixed Effects	No	No	Yes	Yes
Overall R^2	0.01	0.05	0.04	0.06
Obs.	800	780	800	780
No. of Countries	40	39	40	39
Time Span	2000-2019	2000-2019	2000-2019	2000-2019

Sources: World Bank Development Indicators and Carbon Project via Our World in Data. **Note:** *** and ** denote sig. at 1% and 5% levels.

Joint Carbon Tax-Firm Formality Policy

▸ Back



Energy Use in Self-Employment

Variable	Benchmark	Benchmark Higher Base. Green e Share	Benchmark Energy Use in SE
	Percent Δ	Percent Δ	Percent Δ
Total Output (Y)	-0.857	-0.627	-0.666
Consumption (c)	-0.491	-0.345	-0.500
Salaried Firms (N_s)	-2.888	-2.134	-1.713
Welfare Gain (% of c)	-1.848	-1.352	-1.209
	Perc.-Pt. Δ	Perc.-Pt. Δ	Perc.-Pt. Δ
Share of f Firms (N_f/N_s)	0.005	0.004	0.002
Share of f Output in Y	-0.732	-0.542	-0.333
Formal Employment Share	-1.047	-0.778	-0.482
SE Share	1.297	0.964	0.594
Unempl. Rate	0.153	0.114	0.076
LFP Rate	0.368	0.270	0.226
Share of e Prod. Using g Tech.	3.666	2.367	3.647
Share of Green Energy	17.515	15.217	17.722
Tax Rev.-Output Ratio	0.144	0.155	0.150

TRANSITIONAL DYNAMICS

Transition Path to Lower-Emissions Steady State

- Search frictions, costly firm creation, transition to formality, and g tech. adoption ⇒ full, long-term effect of carbon tax may take time to materialize

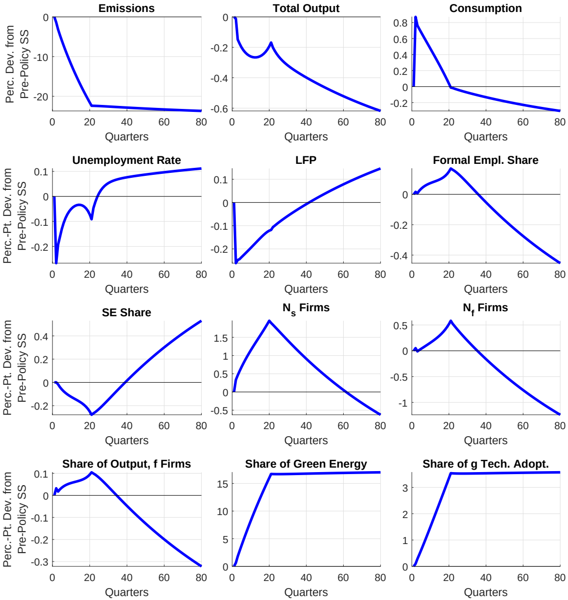
- **Does transition to lower-emissions steady state also entail reductions in output, formal employment? If so, are the transition costs sizable?**

- Consider **gradual, uniform increase in carbon tax** that takes 8 years (32 quarters) to reach its long-term level

Back

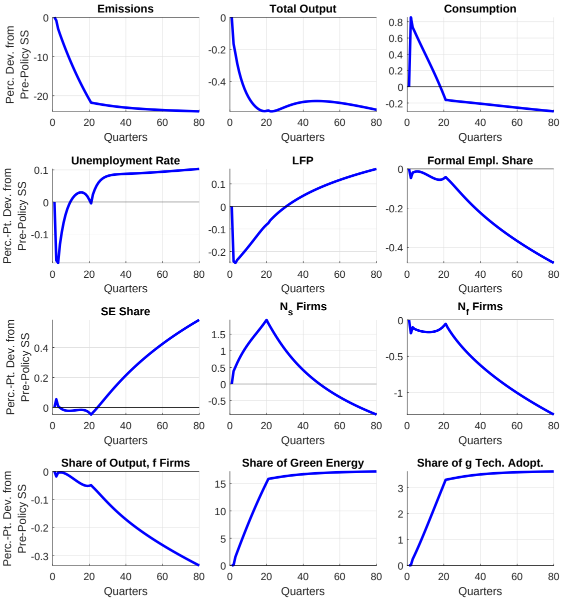
Transitional Dynamics: Carbon Tax

Back



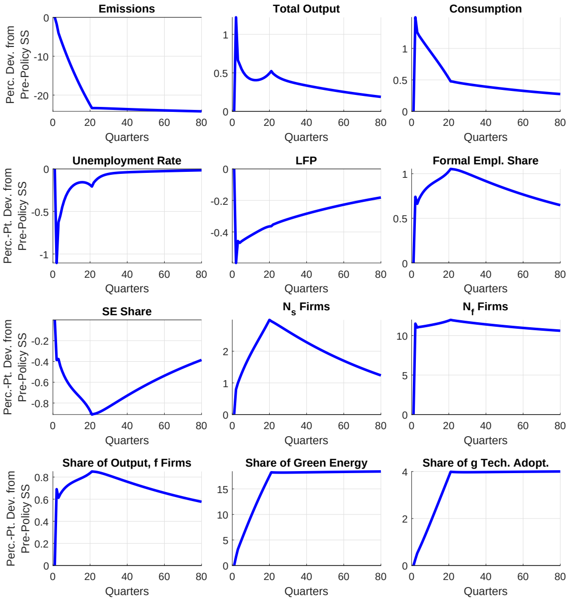
Carbon Tax Amid Capital Adjustment Costs

Back



Transitional Dynamics: Joint Policy

Back



Joint Policy Amid Capital Adjustment Costs

Back