Climate Policies, Labor Markets, and Macroeconomic Outcomes in Emerging Economies

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Abstract

We study the labor market and macroeconomic effects of a carbon tax in the energy sector in emerging economies. We build a macro-search model with pollution externalities, endogenous green-energy adoption, salaried-firm entry, and endogenous self-employment. The carbon tax increases green technology adoption in the energy sector, the share of green energy, and energy prices; it reduces salaried firm creation, formal employment, and formal firms; it increases self-employment and unemployment; and it generates output and welfare losses. We show that green technology adoption significantly limits the magnitude of these losses, but the prevalence of self-employment amplifies these losses, thereby partly offsetting the insular benefits of greater green technology adoption. A plausible joint carbon tax-firm formality policy can generate a transition to a lower-carbon economy with minimal output costs.

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1 Introduction

We study the labor market and macroeconomic effects of introducing a carbon tax in the energy sector in small emerging economies (EMEs).[1]

The combined annual CO_2 emissions of small EMEs represent almost 10 percent of global annual emissions, making this group of EMEs the largest carbon dioxide emitter after China, the US, and the EU-28. Moreover, while the contribution of this group of EMEs to global GDP has remained roughly unchanged in the last twenty years, its combined contribution to global CO_2 emissions has risen steadily. Indeed, economic growth in EMEs continuing to be associated with growing domestic carbon emissions. In contrast, starting in the mid-2000s, advanced economies (AEs) have experienced a clear decoupling between their economic growth and the growth in their emissions (see Figure 1 in Section 2). Against this backdrop, WEO (2022) suggests that EMEs may need to reduce their carbon emissions in order to limit the rising economic damages from unmitigated climate change.[2] With recent evidence for AEs showing that carbon taxation reduces emissions, encourages the adoption of green energy technologies and green innovation, and has non-trivial revenue potential for some economies (Andersson, 2019; Pigato et al., 2020; World Bank, 2020; IFC, 2021; Timilsina, 2022; Känzig, 2023), carbon pricing schemes have gained traction in EMEs.[3] However, a major policy concern behind the introduction or expansion of carbon taxes is the potential adverse effects that these taxes may have on firms, job creation, employment, and economic activity. This concern is amplified in EMEs, whose distinct domestic employment and firm structure—specifically, shares of self-employment that are *three times larger* than those in AEs, higher barriers to firm formality reflected in a large universe of informal (unregistered) firms, and large productivity differentials between formal and informal firms (La Porta and

[1]Following the EME macro literature, we focus on the group of small EMEs comprised of: Argentina, Brazil, Chile, Colombia, Indonesia, Malaysia, Mexico, Peru, the Philippines, South Africa, Thailand, and Turkey. While being geographically dispersed, as we note below, these economies exhibit a very similar firm and employment structure characterized by high self-employment shares and high labor and firm informality compared to advanced economies. Both China and India are considered large EMEs and are excluded from our EME group due to their own distinct characteristics.

[2]For quantitative work on the consequences of global warming for the world economy, see Desmet and Rossi-Hansberg (2015) and Cruz and Rossi-Hansberg (2024), among others.

[3]Data from OECD (2022) suggests that revenue potential from carbon reforms, which captures the potential revenue raised from reforms to fossil fuel subsidies and carbon taxes, stands at roughly 3.7 percent of GDP in EMEs compared to only 1 percent of GDP in AEs.

Shleifer, 2014; Ulyssea, 2020)—represents an important growth barrier. Importantly, the latter could be further exacerbated by carbon taxes and therefore raise the potential economic costs of the green transition in these economies.

Studying the link between carbon taxes, emissions, labor markets, and macroeconomic outcomes in EMEs poses an empirical challenge: despite a clear intent to adopt carbon pricing, implementation (if any) of carbon taxation schemes in these economies remains limited. As an imperfect alternative, we first exploit data on CO_2 emissions, which have been shown to respond to carbon taxes in AEs, and document a negative and significant relationship between the annual growth in carbon emissions and annual changes in both the share of self-employment and the unemployment rate in EMEs. Critically, we find that the negative link between the growth in carbon emissions and changes in the share of self-employment in EMEs not only continues to hold after we control for GDP growth but is effectively non existent in AEs. To the extent that carbon taxes reduce emissions, these facts suggest that carbon taxes may affect the structure of EME labor markets in a distinct way and, given the importance of self-employment in these economies, reshape the macroeconomic impact of carbon taxes in EMEs. To study this issue, we build a macro model with equilibrium unemployment and self-employment, salaried-firm entry and selection into formality, and negative pollution externalities in the energy sector. Our model is meant to capture key features of the employment and firm structure of EMEs in a tractable way.[4]

In our framework, energy producers can choose between a regular (polluting) or green (emissions-free) production technology subject to fixed costs. This choice delivers an endogenous share of energy producers that adopt green technologies and allows the technological and emissions structure of energy production to adjust in response to changes in policy—a central element of discussions of the green transition. In turn, labor search frictions allow us to characterize the effects of climate policies on unemployment—a second element at the core of policy discussions regarding the transition. While we abstract from modeling specific industries to keep our baseline framework tractable, carbon emissions emanating from the (endogenous) polluting energy sector can be interpreted as encompassing all energy-related

[4]See Ulyssea (2020) for a framework focusing on salaried-firm informality and firm dynamics that abstracts from labor market (unemployment) dynamics and self-employment.

emissions in the economy.[5] Calibrating the model to match the average firm and employment structure and the polluting-green energy mix in our EME group, we quantitatively characterize the transition and long-run effects of introducing a carbon tax on emissions from polluting energy producers. Our quantitative analysis considers a carbon tax that reduces long-run emissions by 25 percent relative to baseline—in line with current policy proposals (WEO, 2022). As part of our analysis, we quantify the role of self-employment and green technology adoption by comparing our EME findings to those from variants of our model without self-employment and with self-employment held at its pre-carbon-tax level. We also characterize how different carbon-tax revenue-recycling schemes affect our quantitative results.

We establish a baseline by first showing that in the long run, the carbon tax increases the share of green energy and the share of energy producers that use green technologies. Despite the policy-induced shift in the energy structure towards green technologies, the adverse impact on energy production by polluting energy producers is strong enough to generate higher energy prices.[6] The increase in energy input prices reduces new salaried-firm creation, the number of salaried firms and formal firms, salaried job creation, and the share of formal employment. In response to fewer salaried jobs, households shift their members' job search towards self-employment. The carbon tax therefore shifts the composition of employment and production towards greater self-employment, ultimately reducing consumption, GDP, and welfare, and increasing both the unemployment rate and labor informality (mainly via greater self-employment). Importantly, the shift away from searching for salaried jobs and towards self-employment takes place even as the incentive to become self-employed is reduced due to higher energy prices, which affect household consumption and job search choices across all categories: in *relative* terms, searching for self-employment still becomes a better option than searching for reduced salaried-employment options. Despite the long-term output and

[5]For example, transportation generates a non-trivial share of emissions in EMEs through the use of fossil fuels produced/supplied by the energy sector, though this is changing as electric-vehicle sales expand rapidly due to government policies and the price of Chinese electric vehicles (see https://www.iea.org/reports/global-ev-outlook-2025/trends-in-electric-car-markets-2). A similar claim applies to manufacturing if the electricity used as part of the production process comes from fossil fuels. Ultimately, some of the emissions from transport, manufacturing, and other industries outside of the energy sector are rooted in the use of energy-related inputs, and therefore a function of energy and electricity production by the energy sector.

[6]Using data from the European carbon market, Känzig (2023) shows that carbon pricing leads to higher energy prices but also spurs green innovation.

welfare losses from the tax, the transition to a lower-emissions equilibrium is characterized by a short-term increase in consumption, formal employment, and formal firms, and by a temporary decline in the unemployment rate. These short-term positive effects along the transition path are driven by the carbon-tax-induced reduction in the demand for capital among polluting energy producers, which frees up resources that benefit goods-producing firms that use capital.

With these baseline results in mind, our main findings are threefold. First, we show that for the same reduction in emissions, energy producers' ability to adopt green technologies—an extensive margin of adjustment that is absent in most macro-climate models—plays a critical role in significantly limiting the long-term adverse effects of the carbon tax on equilibrium energy prices and on economic activity, with the absence of green technology adoption generating output and welfare losses that are almost twice as large compared to the benchmark model. Thus, green technology adoption significantly limits the economic and welfare costs of the tax.

Second, the rise in self-employment induced by the carbon tax significantly amplifies the output and welfare losses from the policy. The carbon tax shifts resources from more productive salaried firms (both formal and informal) toward less productive self-employment, thereby deepening the output contraction. Simultaneously, lower salaried job creation prompts workers to seek self-employment opportunities, which raises labor force participation but reduces welfare. A counterfactual experiment that abstracts from self-employment reveals that in the long run, the presence of self-employment increases output and welfare losses from the carbon tax by more than 60 percent compared to an environment without self-employment. Self-employment therefore plays an important role in shaping the quantitative effects of carbon taxation in EMEs. Because the increase in self-employment magnifies the output and welfare losses from the carbon tax, it partially offsets the protective effects of green technology adoption identified in our second finding. More broadly, this result suggests that existing macro-environmental models for AEs, which abstract from modeling self-employment, may yield inaccurate quantitative assessments of the labor market and aggregate effects of carbon taxation if applied directly to EMEs and other economies that have large shares of self-employment.

Third, guided by our second finding above, we consider a joint policy that combines the same carbon tax with a data-disciplined reduction in the (regulatory) cost of becoming a formal firm. This joint policy significantly limits the adverse labor market, aggregate, and welfare effects of the carbon tax, both in the long run and along the transition path to the lower-emissions equilibrium, *even as the joint policy also yields higher equilibrium energy prices*. The reason behind this result is simple: the reduction in the cost of firm formality amid a carbon tax fosters greater salaried-firm entry and leads to an equilibrium net increase in both the number of formal firms and in the overall number of salaried (formal and informal) firms. In turn, these firms expand salaried job creation, which bolsters formal employment and limits the extent to which individuals want to search for self-employment opportunities. In doing so, the joint policy prevents the reallocation of resources away from salaried firms and into self-employment, and ultimately delivers small quantitative output and welfare gains. Critically, these net gains materialize only if energy producers have a choice over green technology adoption, which further highlights the importance of this margin. We interpret the results from this joint-policy experiment solely as highlighting the fact that carbon taxation jointly implemented with other structural reforms that address informality—and not carbon taxation in isolation—may be particularly important for EMEs if the policy objective is to foster a green transition with limited economic costs.

Our work is closest to the literature on the labor market and macroeconomic consequences of climate policies and the macro-climate literature on technology adoption, both of which have focused primarily on AEs.[7] Studies that go beyond these economies and incorporate key

[7]For empirical evidence on the employment and macroeconomic consequences of carbon taxes in AEs, see Metcalf and Stock (2020, 2023). For evidence on carbon pricing, energy prices, and green innovation in Europe, see Känzig (2023). For standard one-sector macro models with pollution externalities applied to the US or Europe, see Fischer and Springborn (2011); Heutel (2012); Annicchiarico and Di Dio (2015); Annicchiarico and Dio (2017); Annicchiarico, Correani and Dio (2018). For two-country (US-Europe) models, see Annicchiarico and Diluiso (2019); Ferrari Minesso and Pagliari (2023). For two-sector models with representative polluting-green firms and equilibrium unemployment applied to the US, see Hafstead and Williams (2018); Fernández Intriago (2020). Aubert and Chiroleu-Assouline (2019); Hafstead and III (2019) consider the distributional effects of environmental policy on US workers. Castellanos and Heutel (2024) focus on the impact of a carbon tax on US unemployment amid worker mobility across sectors. For theoretical work on models with green innovation, technology adoption, and the impact of carbon taxes and innovation subsidies in the US, see Acemoglu et al. (2016); Fried (2018*a*). For work on the choice over energy technologies amid carbon taxes and climate policies, see Barrett (2021); Adão, Narajabad and Temzelides (2024), or Jondeau et al. (2022) for the role of carbon taxation and the creation of emissions-abatement goods. See Finkelstein Shapiro and Metcalf (2023) for the role of green technology adoption in shaping the labor market and macroeconomic effects of introducing a carbon tax in the US. Appendix A provides a more extensive

domestic characteristics of EMEs into standard macro-climate models are relatively scarce.

Bento, Jacobsen and Liu (2018) use a frictionless macro model with polluting energy as an input, a manufacturing sector, and a services sector with formal and informal salaried labor to analyze how the presence of an informal sector modifies the effects of an energy tax on the composition of labor and on economic activity. In their model, shifting the tax structure away from goods production and towards energy in a revenue-neutral way reduces informal labor, the size of the informal sector, and the costs of environmental policy. Reidt (2021) uses a search model with salaried formal and informal employment, self-employment as a last resort, and polluting energy use and shows that an energy tax whose revenue is used to facilitate formal-sector hiring can reduce emissions and raise welfare in the context of India. Fernández Intriago and MacDonald (2022) build a framework where informal workers can work in the informal sector or in formal firms with informal contracts and show that in the context of Mexico, using the revenue from a carbon tax to reduce formal-sector taxes bolsters formal job creation. Finally, using a static multi-sector model with input-output linkages, skill heterogeneity, and a representative energy sector with polluting and green energy applied to the US, Brazil, and China, Cavalcanti, Hasna and Santos (2021) show that a country's production and worker skill structure play important roles in shaping the distributional and aggregate effects of the tax.

We contribute to this literature in three ways. First, we move beyond the effects of climate policies on the allocation of inputs alone and characterize how these policies alter both the composition of firms—and hence the endogenous technological and productivity profile of the economy—and the technological (polluting-green) energy-production structure as the economy transitions to a lower-carbon environment. In doing so, we highlight the role of green-technology adoption by energy producers in significantly limiting the adverse labor market and aggregate effects of a carbon tax. Second, our analysis characterizes the long-run effects of carbon taxes and climate policies, but also the transition path to a lower-carbon environment and how this transition is related to long-run outcomes. Finally, in an

review of research on AEs. Taking a cross-country focus, Fried (2018*b*) uses a neoclassical growth model with fossil energy and studies how differences in capital-labor ratios across countries and the potential mismatch between production technologies and the energy intensity of capital shape the effectiveness of carbon taxes and cap-and-trade systems. This issue is relevant for EMEs, where the mismatch between technologies and energy intensity may be particularly salient.

environment where self-employment is a broader household choice regarding labor allocation as opposed to employment of last resort (Maloney, 2004), we show that the response of this core employment category in EMEs provides alternative employment options for household members amid policy-induced lower salaried job creation, but amplifies the adverse effects of carbon taxes on economic activity and negates part of the cost-reduction benefits of green technology adoption. As a result, a key message from our work is that self-employment plays a critical role in shaping the labor market and aggregate effects of climate policies in EMEs compared to AEs.

The rest of the paper is structured as follows. Section 2 summarizes how the link between the growth in carbon emissions, economic growth, and the change in the green energy mix differs in EMEs compared to AEs, and offers new facts on the differential relationship between the growth in carbon emissions (which are affected, among other things, by carbon taxes and other climate policies) and changes self-employment shares and unemployment rates in these two country groups. Section 3 describes the model. Section 4 presents our quantitative findings and discusses the main economic mechanisms behind. Section 5 concludes.

2 Carbon Emissions, Economic Activity, Green Energy Shares, and Labor Markets in EMEs and AEs

As noted in the Introduction, we focus on the group of small EMEs commonly studied in the EME macro literature: Argentina, Brazil, Chile, Colombia, Indonesia, Malaysia, Mexico, Peru, the Philippines, South Africa, Thailand, and Turkey. We exclude China and India from consideration since they are large EMEs with their own distinct characteristics. Our group of EMEs shares a similar employment and firm structure, with high shares of self-employment and informal firms that distinguishes them from AEs; they account for the bulk of carbon emissions in their respective regions after excluding AEs and large EMEs; and they differ from lower income economies by having significantly smaller shares of agricultural employment and production, which we do not model.[8] These economies either do not have

[8]For example, in Africa, South Africa is the largest emitter of carbon dioxide. In Asia, Indonesia, Thailand, and Malaysia combined emit the most carbon dioxide after China, India, and Japan. In North

carbon pricing schemes in place and are considering their implementation, or have very low and/or limited (coverage-wise) carbon taxes and are considering their expansion. Indeed, the average effective carbon tax in our EME group is only 0.24 euros per ton of CO_2 equivalent compared to almost 25 euros in AEs (OECD, 2022).

In what follows, we focus on the period 2000-2019 since the year 2000 is often considered the starting point for the increased adoption of green technologies in AEs followed by a marked acceleration in 2010 (Gerarden, Reguant and Xu, 2025), and the COVID-19 pandemic had very distinct effects on carbon emissions and labor markets in EMEs.

Growth in Carbon Emissions, Economic Activity, and Green Energy Shares in EMEs and AEs– Figure 1 shows that in the last 20 years, AEs experienced a decoupling of their economic growth from growth in their carbon emissions, with this decoupling becoming entrenched in 2010 and continuing onward (right panel of Figure 1). In contrast, over the same time period, carbon emissions in EMEs grew more or less in lockstep with economic growth (left panel of Figure 1). These differences between EMEs and AEs continue to hold if we consider consumption-based measures of carbon emissions, which adjust for the potential offshoring of pollution-generating production. Another important difference between these two country groups lies in the changes in their low-carbon energy shares. To see this in the context of carbon emissions and economic activity, the right axis of each panel of Figure 1 plots the percentage-point change in the share of low-carbon energy relative to year 2000 (shown in dark green).

The decoupling between economic growth and growth in emissions in AEs starting around 2005 coincides with a consistent increase in the share of low-carbon energy in these economies—a trend that is partly rooted in the development and increased adoption of green technologies, and the steady increase in carbon taxation in select AEs (not shown). Over the same time span, the share of low-carbon energy in EMEs exhibits a reduction relative to its year-2000 level, though this pattern starts to reverse in 2017 onward. Indeed, starting in 2017, the share of low-carbon energy finally surpasses its year-2000 level and continues an upward trajectory as EMEs increasingly adopt green technologies. World Bank (2023);

and South America combined, Argentina, Brazil, Chile, Mexico, and Peru emit the most carbon dioxide after the US and Canada (Global Carbon Project).

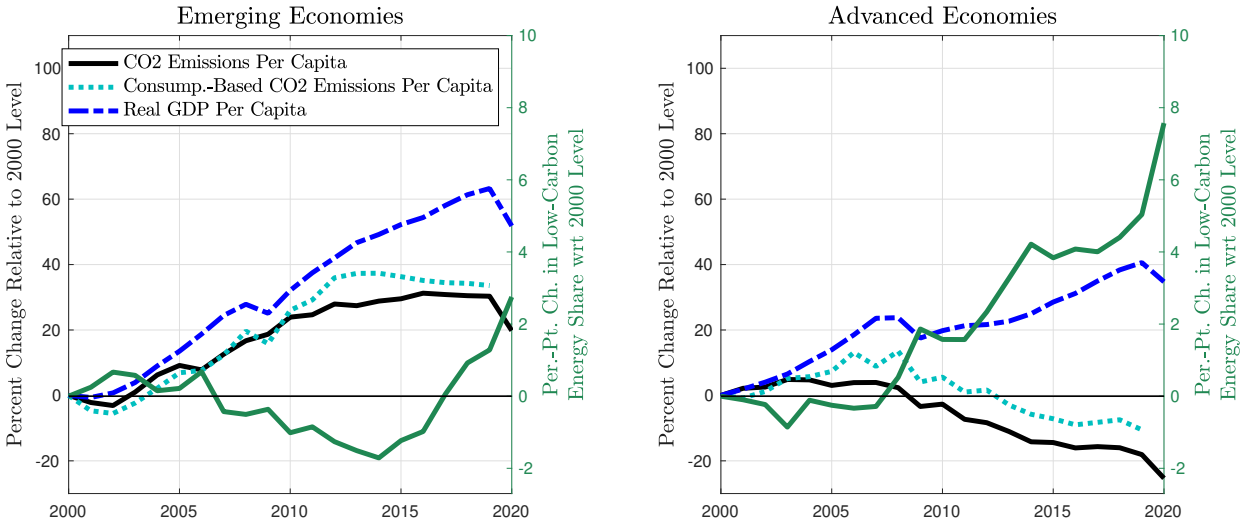


Figure 1: Growth in Carbon Dioxide Emissions, Economic Activity, and Green Energy Shares—AEs vs. EMEs

Source: Data from World Bank and Global Carbon Project via Our World in Data.
Notes: Each variable represents the average for each country group (EME or AE). Real GDP Per Capita is expressed in PPP Constant 2017 international dollars. Consump.-Based CO_2 Emissions Per Capita denotes consumption-based CO_2 emissions, which are adjusted for trade and therefore for production offshoring. Low-carbon energy is given by the sum of renewables (hydropower, wind, solar, bioenergy, geothermal, wave, and tidal) and nuclear energy. The group of AEs is comprised of: Australia, Austria, Belgium, Canada, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Japan, Latvia, Lithuania, Luxembourg, Malta, Netherlands, New Zealand, Norway, Portugal, Singapore, Slovakia, Slovenia, South Korea, Spain, Sweden, Switzerland, United Kingdom, and the US. The group of EMEs is listed at the beginning of Section 2.

United Nations (2023) provide evidence on green technology adoption and highlight specific examples of such adoption in EMEs.[9]

Growth in Emissions and Changes in Self-Employment and Unemployment in EMEs and AEs– The fact that the correlation between economic growth and the growth in carbon emissions in EMEs differs so dramatically from what is observed in AEs suggests that these differences may extend to changes in labor market outcomes as well, especially given the well-known link between self-employment and economic development (Gollin, 2008; La Porta and Shleifer, 2014) and the fact that the average self-employment share in our EME group is close to 40 percent of total employment—almost three times larger than in AEs per ILO data. Thus, in what follows we focus on two main labor market outcomes: the share of

[9]See Reidt (2021) for a summary of the link between economic growth and carbon emissions. For empirical evidence on the link between environmental policies and innovation in renewable energy, see Bettarelli et al. (2023).

self-employment in total employment and the unemployment rate.

To provide a more formal characterization of the link between changes in carbon emissions and changes in these two labor market outcomes, we consider the following simple panel specification:

$$\Delta O_{it} = \alpha_0 + \alpha_1 G_{CO_2,it} + \alpha_2 G_{CO_2,it} \times \text{EME}_i + \alpha_3 X_{it} + \alpha_4 A_i + \alpha_5 B_t + \varepsilon_{it},$$

where subscript it refers to country i in year t. ΔO_{it} represents the change in the outcome variable between period t and period $t-1$—the two outcome variables being either the share of self-employment in total employment (SE Share) or the unemployment rate. $G_{CO_2,it}$ denotes the growth rate in CO_2 emissions between periods t and $t-1$, and the interaction term $G_{CO_2,it} \times \text{EME}_i$ captures the heterogeneity in the impact of the growth rate in CO_2 emissions in EMEs *vis-à-vis* AEs. X_{it} is a set of time-varying country characteristics, A_i is a country-fixed effect, B_t is a year-fixed effect, and ε_{it} is the error term. Coefficient α_2 is our main coefficient of interest.

Table 1 shows that the annual growth rate in carbon emissions is negatively related to the annual change in the share of self-employment in EMEs. Critically for our interest in the labor market structure of EMEs, this result is robust to controlling for GDP growth. Similarly, as shown in Table 2, there is a negative relationship between the annual growth rate in emissions and the annual change in the unemployment rate, both in EMEs and in AEs, though this relationship is sensitive to controlling for GDP growth. Taken together, Tables 1 and 2 illustrate that self-employment in EMEs exhibits a distinct pattern compared to AEs in the context of carbon emissions, and that self-employment appears to behave differently from unemployment.

For completeness, Tables 1 and 2 also consider the change in the share of low-carbon energy as a control since the change in this share can affect energy prices and therefore shape changes in labor market outcomes. Of note, the interaction term between the growth in emissions and the EME dummy variable (and not the growth rate of emissions itself) is significant, suggesting that the negative link between the growth in emissions and the change in our two labor market variables does not appear to be present in AEs (see Appendix B for

Table 1: Changes in Self-Employment Shares and Growth in Carbon Emissions

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	Δ SE Share$_{it}$					
$G_{CO_2,it} \times$ EME$_i$	-2.189	-2.138	-1.970	-1.933	-1.754	-1.694
	(0.863)	(0.869)	(0.860)	(0.866)	(0.860)	(0.865)
$G_{CO_2,it}$	-0.484	-0.476	-0.346	-0.350	-0.325	-0.284
	(0.419)	(0.439)	(0.418)	(0.438)	(0.416)	(0.436)
Δ Low-Carbon Energy Share$_{it}$		0.0999		0.0633		0.0757
		(0.121)		(0.120)		(0.119)
Δ Unempl. Rate$_{it}$			0.0777	0.0768		
			(0.0218)	(0.0220)		
RGDP Growth$_{it}$					-4.424	-4.853
					(1.015)	(1.053)
Observations	940	915	940	915	940	915
R-Squared	0.054	0.056	0.067	0.070	0.074	0.079
No. of Countries	47	46	47	46	47	46
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Robust standard errors are shown in parentheses. ΔLow-Carbon Energy Share$_{it}$ denotes the change in the share of low-carbon energy between period t and $t-1$, ΔUnempl. Rate$_{it}$ denotes the change in the unemployment rate between period t and $t-1$, and RGDP Growth$_{it}$ denotes the growth rate in real GDP between period t and $t-1$. All specifications include a constant term, country-fixed effects and year-fixed effects. SE Share represents the share of self-employment in total employment. EMEs represent 12 out of the 47 economies in our sample. The list of AEs is included in Figure 1.

additional robustness checks).

To the extent that carbon taxes reduce carbon emissions—as suggested by existing evidence for select AEs with carbon taxes in place—it is plausible that carbon taxes may have a larger impact on both the share of self-employment and the unemployment rate in EMEs relative to AEs. In the absence of panel data on carbon taxes for EMEs that would allow us to explicitly analyze the impact of these taxes on labor market and macroeconomic outcomes in these economies, we build a model that incorporates key aspects of the domestic firm, employment, and energy-mix structure of EMEs.

Table 2: Changes in Unemployment Rate and Growth in Carbon Emissions

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	Δ Unemployment Rate$_{it}$					
$G_{CO_2,it} \times$ EME$_i$	-2.821	-2.665	-2.416	-2.269	-0.247	-0.113
	(1.331)	(1.351)	(1.327)	(1.347)	(1.110)	(1.109)
$G_{CO_2,it}$	-1.778	-1.633	-1.689	-1.545	-0.839	-0.531
	(0.646)	(0.683)	(0.643)	(0.679)	(0.537)	(0.560)
Δ Low-Carbon Energy Share$_{it}$		0.477		0.458		0.338
		(0.187)		(0.186)		(0.153)
Δ SE Share$_{it}$			0.185	0.185		
			(0.0519)	(0.0530)		
RGDP Growth$_{it}$					-26.21	-27.91
					(1.309)	(1.351)
Observations	940	915	940	915	940	915
R-Squared	0.242	0.249	0.253	0.260	0.481	0.501
No. of Countries	47	46	47	46	47	46
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Robust standard errors are shown in parentheses. Δ Low-Carbon Energy Share$_{it}$ denotes the change in the share of low-carbon energy between period t and $t-1$, Δ SE Share$_{it}$ denotes the change in the self-employment share between period t and $t-1$, and RGDP Growth$_{it}$ denotes the growth rate in real GDP between period t and $t-1$. All specifications include a constant term, country-fixed effects, and year-fixed effects. EMEs represent 12 out of the 47 economies in our sample. The list of AEs is included in Figure 1.

3 The Model

The baseline economy is closed and comprised of households, goods-producing firms, and energy producers.[10] The labor market features search frictions that deliver equilibrium unemployment and endogenous labor force participation. Total output is a composite of output from salaried firms whose entry is endogenous and who choose between two possible categories (salaried formal or informal) that differ in their technologies and costs of operation, and from self-employed workers who operate owner-only firms. Energy producers choose between a polluting or green technology, where the use of the polluting technology generates TFP-reducing carbon emissions—a negative pollution externality—that are subject to a carbon tax while the use of the green technology is emissions-free but subject to a fixed cost. Households consume goods, energy, and make labor force participation decisions for both salaried and self-employed household members.

[10] Assuming a small open economy environment does not change any of the model's mechanisms or the conclusions from our quantitative analysis.

3.1 Production Structure

Total output is $Y_t = \left[Y_{s,t}^{\frac{\phi_y - 1}{\phi_y}} + Y_{o,t}^{\frac{\phi_y - 1}{\phi_y}} \right]^{\frac{\phi_y}{\phi_y - 1}}$, where $Y_{s,t}$ is the output of salaried firms, $Y_{o,t}$ is the output of self-employed (own-account) firms, and $\phi_y > 1$ dictates the substitutability between $Y_{s,t}$ and $Y_{o,t}$. Assuming a perfectly competitive total output aggregator with real profits $\Pi_{y,t} = [P_t Y_t - P_{s,t} Y_{s,t} - P_{o,t} Y_{o,t}]$ where P_t is the aggregate price index and $P_{s,t}$ and $P_{o,t}$ are the nominal prices of $Y_{s,t}$ and $Y_{o,t}$, respectively, it is straightforward to show that the demand functions for each category of output are $Y_{s,t} = (p_{s,t})^{-\phi_y} Y_t$ and $Y_{o,t} = (p_{o,t})^{-\phi_y} Y_t$, where $p_{s,t} \equiv P_{s,t}/P_t$ and $p_{o,t} \equiv P_{o,t}/P_t$. Given these demand functions, the aggregate price index can be expressed as $1 = \left[p_{s,t}^{1-\phi_y} + p_{o,t}^{1-\phi_y} \right]^{\frac{1}{1-\phi_y}}$.

3.1.1 Salaried Firms

There is an endogenous measure of monopolistically competitive salaried firms whose entry is subject to sunk entry costs as in Bilbiie, Ghironi and Melitz (2012). Based on their realized idiosyncratic productivity upon entry, these firms adopt one of two categories of intermediate goods as inputs, where the two categories differ in the technologies with which they are produced. Using intermediate goods produced with a given technology is equivalent to adopting that technology.[11]

More specifically, while the production technologies of both intermediate goods use salaried labor subject to search frictions, physical capital, and energy as inputs, one of the technologies has higher exogenous productivity and is more capital intensive. The adoption of the intermediate goods produced with the more productive and capital-intensive technology is subject to a fixed cost, and only salaried firms with realized idiosyncratic productivity above an endogenous threshold pay the fixed cost to adopt these intermediate goods. In the model, this fixed cost embodies the cost that firms must incur to register and operate as formal firms. As such, firms and inputs (including workers) associated with the production and use of these intermediate goods are denoted by f for formal. Salaried firms with idiosyn-

[11]The separation between intermediate goods producers and firms that use these intermediate goods as inputs and face sunk entry costs is expositional and follows the separation that is often adopted in New Keynesian models, where input decisions are made by intermediate-goods producers while pricing decisions are made by firms that use these intermediate goods as inputs. Similar to Finkelstein Shapiro and Metcalf (2023), the separation we adopt allows us to describe technology choices and input choices in a clearer way. We adopt a similar separation in the description of energy producers in Section 3.1.2 below.

cratic productivity below the endogenous threshold adopt the intermediate goods produced with the less productive and less capital-intensive technology with zero fixed costs. The firms and the inputs (including workers) that produce and use these intermediate goods are denoted by i for informal. The choice over firm formality generates endogenous productivity differentials between formal and informal firms, where these differentials are a salient feature of firm informality in EMEs.[12]

Intermediate Goods Production– A representative perfectly competitive firm produces two categories of intermediate goods $j \in \{f, i\}$. The firm chooses job vacancies $v_{j,t}$, desired salaried employment $n_{j,t}$, physical capital demand $k_{j,t}$, and energy demand $e_{j,t}$ for each category j to maximize $\sum_{t=0}^{\infty} \Xi_{t|0} \Pi_{s,t}$ subject to

$$\begin{aligned}\Pi_{s,t} = &[mc_{f,t} D(x_t) z_{f,t} H(n_{f,t}, k_{f,t}, e_{f,t}) - w_{f,t} n_{f,t} - r_{k,t} k_{f,t} - \psi_f v_{f,t} - \rho_{e,t} e_{f,t}] \\ &+ [mc_{i,t} D(x_t) z_{i,t} F(n_{i,t}, k_{i,t}, e_{i,t}) - w_{i,t} n_{i,t} - r_{k,t} k_{i,t} - \psi_i v_{i,t} - \rho_{e,t} e_{i,t}],\end{aligned}$$

and the perceived evolution of each category of salaried employment $j \in \{f, i\}$

$$n_{j,t} = (1 - \rho_s) n_{j,t-1} + v_{j,t} q_{j,t}, \tag{1}$$

where $\Xi_{t|0}$ is the household's stochastic discount factor. $H(n_{f,t}, k_{f,t}, e_{f,t})$ and $F(n_{i,t}, k_{i,t}, e_{i,t})$ are Cobb-Douglas production functions associated with the f and i technologies, and $z_{f,t}$ and $z_{i,t}$ are the exogenous productivity levels, respectively. We assume that $z_f > z_i$ and that

[12]See Amin and Okou (2019). For tractability, we abstract from modeling informal employment within formal firms. The literature on informality often considers labor and income taxation as one of several factors that shape the breadth of firm and labor informality. Ultimately, productivity and technology differentials between formal and informal firms are the most relevant factors that ultimately shape the implications of firm informality for macroeconomic outcomes. Conditional on keeping labor and income tax rates unchanged, introducing these taxes only changes the levels of select variables in the baseline calibration of our model but does not change any of our model mechanisms or findings regarding the impact of climate policies in our framework. As such, without loss of generality, we abstract from incorporating these taxes and focus only on carbon taxation. A similar comment applies to including firing costs and other more explicit compliance and enforcement costs associated with being formal. Finally, additional characteristics of firm formality that, for tractability, we abstract from modeling explicitly include improved access to formal finance, more energy-efficient technologies, and basic legal/institutional protections, all of which facilitate greater investment in capital or more cutting-edge technologies and improve firm productivity. However, we note that the assumption in our model that an endogenous subset of firms can access a more productive and capital-intensive technology in the model after incurring a fixed cost and becoming formal can be seen as embodying, in a reduced-form way, the benefits of access to formal finance, institutions, and better production technologies (including more energy-efficient ones) that characterize the formal sector.

$H(\cdot)$ is more capital intensive than $F(\cdot)$. Of note, as stated earlier, it is possible that the technology used by salaried f firms may be more energy efficient compared to the technology used by salaried i firms.[13] Given that we adopt Cobb-Douglas production functions, in our framework, this possibility would ultimately be reflected in z_f being greater than z_i, which we already adopt as a baseline assumption that embodies some of the characteristics of firm formality.[14] Following the macro-climate literature, $D(x_t)$ is a standard damages function that depends on the stock of pollution x_t such that $D(0) = 1$ and $D'(x_t) < 0$, and is taken as given by the intermediate-goods producer (see Nordhaus, 2008). That is, for a given set of production inputs and exogenous productivity levels, an increase in the pollution stock adversely affects the production of intermediate goods via lower productivity.[15] For each intermediate goods category j, $mc_{j,t}$ is the real price of intermediate goods, $w_{j,t}$ is the real wage, and $\psi_j > 0$ is the flow vacancy posting cost. Physical capital is perfectly mobile between intermediate goods with common real price $r_{k,t}$, and the real price of energy $\rho_{e,t}$ is the same across the two categories. Turning to the evolution of salaried employment, $0 < \rho_s < 1$ is the exogenous job separation probability and $0 < q_{j,t} < 1$ denotes the endogenous job-filling probability in salaried employment category j (a function of category-specific market tightness).

The intermediate goods producer's optimal choices yield standard job creation conditions for each salaried-employment category j, given by

$$\frac{\psi_f}{q_{f,t}} = mc_{f,t} D(x_t) z_{f,t} H_{n_f,t} - w_{f,t} + (1-\rho_s)\Xi_{t+1|t}\left(\frac{\psi_f}{q_{f,t+1}}\right), \tag{2}$$

$$\frac{\psi_i}{q_{i,t}} = mc_{i,t} D(x_t) z_{i,t} F_{n_i,t} - w_{i,t} + (1-\rho_s)\Xi_{t+1|t}\left(\frac{\psi_i}{q_{i,t+1}}\right), \tag{3}$$

[13] See Lanteri and Rampini (2025) for evidence using data on the shipping industry that larger firms (which tend to be formal) use equipment that is more energy efficient compared to smaller firms (which are more likely to be informal).

[14] Introducing endogenous energy efficiency whereby the intermediate-goods producer can invest resources to use energy more efficiently and reduce overall energy demand (akin to endogenous capital utilization) does not change our main conclusions. This applies to versions of the model where energy efficiency applies to both f and i intermediate goods or only to f goods.

[15] See Kalkuhl and Wenz (2020) for evidence that greater temperature levels (linked to climate change) are associated with lower productivity levels. The authors find no link between changes in temperature and permanent changes in the growth rate of productivity.

by capital demand conditions $mc_{f,t}D(x_t)z_{f,t}H_{k_f,t} = r_{k,t}$ and $mc_{i,t}D(x_t)z_{i,t}F_{k_i,t} = r_{k,t}$, and by energy demand conditions $mc_{f,t}D(x_t)z_{j,t}H_{e_f,t} = \rho_{e,t}$ as well as $mc_{i,t}D(x_t)z_{i,t}F_{e_i,t} = \rho_{e,t}$, which equate the marginal benefit of a unit of energy to the real price of energy. We describe further below how a carbon tax in the energy sector shapes the price of energy ρ_e and, in doing so, affects energy demand, capital demand, and salaried job creation.

Profits, Optimal Pricing, and Technology Choices– Turning to the salaried firms that use these intermediate goods as inputs, in the general spirit of Ghironi and Melitz (2005), a given salaried firm $\zeta \in Z$ incurs a sunk cost $\varphi_s > 0$ to enter the market, where Z represents the potential measure of salaried firms. Total salaried-firm output is given by $Y_{s,t} = \left(\int_{\zeta \in Z} y_{s,t}(\zeta)^{\frac{\varepsilon-1}{\varepsilon}} d\zeta\right)^{\frac{\varepsilon}{\varepsilon-1}}$, where $y_{s,t}(\zeta)$ is firm ζ's output and $\varepsilon > 1$ is the elasticity of substitution parameter. Upon entry, firm ζ draws its idiosyncratic productivity a_s from a common distribution $G(a_s)$ with support $[a^s_{\min}, \infty)$. The firm maintains its realized idiosyncratic productivity level until it exits with exogenous probability $0 < \delta_s < 1$. In what follows, we denote a given salaried firm ζ by its idiosyncratic productivity a_s.[16]

A salaried firm with idiosyncratic productivity a_s below an endogenous threshold $\overline{a}_{s,t}$ uses intermediate goods i to produce—that is, it adopts the i production technology and is therefore categorized as informal. Its real profits are

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

where $\rho^i_{s,t}(a_s)$ is the real output price of firm a_s using the i technology and $mc_{i,t}/a_s$ is the effective real marginal cost. In turn, a salaried firm with idiosyncratic productivity $a_s \geq \overline{a}_{s,t}$ uses intermediate goods f to produce—that is, it adopts the f production technology and is categorized as formal. Using these intermediate goods entails a fixed resource cost $\varphi_f > 0$.

[16]We abstract from endogenous firm exit and focus instead on policy-induced changes in overall salaried firm creation and the distribution between f and i firms. Endogenizing salaried firm exit would strengthen the response of self-employment to carbon taxes in the benchmark model as salaried firm exit not only reduces overall salaried job creation but also implies the destruction of existing salaried jobs—both of which push households to search for more self-employment opportunities—thereby keeping the model's main economic mechanisms and overall conclusions unchanged.

Its individual real profits are

$$\pi_{f,t}(a_s) = \left[\rho^f_{s,t}(a_s) - \frac{mc_{f,t}}{a_s}\right] y_{f,t}(a_s) - \varphi_f.$$

Noting that the demand function for firm a_s's output in category j is $y_{j,t}(a_s) = \left(\rho^j_{s,t}(a_s)/p_{s,t}\right)^{-\varepsilon} Y_{s,t}$, it is straightforward to show that optimal pricing for each category is $\rho^j_{s,t}(a_s) = [\varepsilon/(\varepsilon-1)]\,(mc_{j,t}/a_s)$. In turn, the threshold productivity level $\overline{a}_{s,t}$ is pinned down by condition $\pi_{i,t}(\overline{a}_{s,t}) = \pi_{f,t}(\overline{a}_{s,t})$. Intuitively, at the threshold $\overline{a}_{s,t}$, a firm is indifferent between the two production technologies.

Evolution and Salaried-Firm Averages– Denoting the measure of new salaried firms by $A_{s,t}$ and the measure of incumbent salaried firms by $N_{s,t}$, the evolution of salaried firms is given by $N_{s,t} = (1-\delta_s)\,(N_{s,t-1} + A_{s,t-1})$. Given the threshold productivity level $\overline{a}_{s,t}$, the measure of informal and formal salaried firms are $N_{i,t} = G(\overline{a}_{s,t})N_{s,t}$ and $N_{f,t} = [1 - G(\overline{a}_{s,t})]\,N_{s,t}$, respectively.

The average idiosyncratic productivity of a salaried firm in category i is

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

while the corresponding average productivity of a salaried firm in category f is $\widetilde{a}^f_{s,t} = \left[\left(\frac{1}{1-G(\overline{a}_{s,t})}\right)\int_{\overline{a}_{s,t}}^{\infty} a_s^{\varepsilon-1} dG(a_s)\right]^{\frac{1}{\varepsilon-1}}$. Then, we define the following average prices and quantities: $\widetilde{\rho}^j_{s,t} = \rho^j_{s,t}(\widetilde{a}^j_{s,t})$, $\widetilde{y}_{j,t} = y_{j,t}(\widetilde{a}^j_{s,t})$. Finally, building on Ghironi and Melitz (2005), we can define average real salaried-firm profits as $\widetilde{\pi}_{s,t} = (N_{i,t}/N_{s,t})\,\pi_{i,t}(\widetilde{a}^i_{s,t}) + (N_{f,t}/N_{s,t})\,\pi_{f,t}(\widetilde{a}^f_{s,t})$.

3.1.2 Energy Producers

There is a continuum of monopolistically competitive energy producers with a fixed measure normalized to one. Energy producers draw their idiosyncratic productivity a_e from a common distribution $G(a_e)$ with support $[a^e_{min}, \infty)$. Similar to the setup of salaried firms, based on their idiosyncratic productivity, energy producers choose to adopt one of two available intermediate energy inputs that differ in their production technologies: a regular (r) polluting technology that generates harmful carbon dioxide emissions as a byproduct of producing energy, or a green (g) technology that produces emissions-free energy. The emissions gener-

ated by the production of intermediate energy inputs with the r technology are subject to a carbon tax $\tau_{e,t}$, but an endogenous share of those emissions can be abated by incurring convex abatement costs. In contrast, the production of the intermediate energy inputs using the g technology is not subject to the carbon tax, but energy producers adopting these inputs face a fixed adoption cost $\varphi_e > 0$. As such, only energy producers that have an idiosyncratic productivity level above an endogenously-determined threshold $\overline{a}_{e,t}$ end up adopting the intermediate energy inputs that use the g technology while the remaining energy producers use those produced with the r technology.

The total amount of energy produced is $E_t = \left(\int_{a^e_{min}}^{\infty} e_t(a_e)^{\frac{\varepsilon_e-1}{\varepsilon_e}} da_e\right)^{\frac{\varepsilon_e}{\varepsilon_e-1}}$, where $\varepsilon_e > 1$ and $e_t(a_e)$ is the individual energy output of a given energy producer a_e. Given an endogenous idiosyncratic productivity threshold $\overline{a}_{e,t}$ (characterized further below), we can write $E_t = \left(\int_{a^e_{min}}^{\overline{a}_{e,t}} e_{r,t}(a_e)^{\frac{\varepsilon_e-1}{\varepsilon_e}} da_e + \int_{\overline{a}_{e,t}}^{\infty} e_{g,t}(a_e)^{\frac{\varepsilon_e-1}{\varepsilon_e}} da_e\right)^{\frac{\varepsilon_e}{\varepsilon_e-1}}$, where $e_{r,t}(a_e)$ and $e_{g,t}(a_e)$ denote the energy output produced by a given energy producer a_e using intermediate energy inputs produced with the r and the g technology. It is straightforward to show that the nominal price of total energy E_t is $P_{e,t} = \left(\int_{a^e_{min}}^{\infty} p_{e,t}(a_e)^{1-\varepsilon_e} da_e\right)^{\frac{1}{1-\varepsilon_e}}$, where $p_{e,t}(a_e)$ is the nominal price of energy producer a_e's output. Given the two production technologies, we can write $P_{e,t} = \left(\int_{a^e_{min}}^{\overline{a}_{e,t}} p^r_{e,t}(a_e)^{1-\varepsilon_e} da_e + \int_{\overline{a}_{e,t}}^{\infty} p^g_{e,t}(a_e)^{1-\varepsilon_e} da_e\right)^{\frac{1}{1-\varepsilon_e}}$, where $p^r_{e,t}(a_e)$ and $p^g_{e,t}(a_e)$ denote the nominal prices of energy producers associated with the r and the g technologies, respectively. For future reference, we can define $\rho^r_{e,t}(a_e) = p^r_{e,t}(a_e)/P_t$ and $\rho^g_{e,t}(a_e) = p^g_{e,t}(a_e)/P_t$, and the relative price of total energy $\rho_{e,t} \equiv P_{e,t}/P_t$.

Similar to the description of salaried firms, we separate the description of energy producers into two: the production of two categories of intermediate energy inputs and the pricing and technology adoption decisions of energy producers. An energy producer's choice over a particular category of intermediate energy inputs is equivalent to a choice over the adoption of the energy-production technology associated with that same category.

Emissions, Carbon Taxes, and Emissions Abatement– There is a perfectly competitive producer of two types of intermediate energy inputs—r and g—which are used by energy producers. The production of each intermediate energy input uses only physical capital.[17]

[17]ILO data shows that employment specific to energy production and heat generation in EMEs represents only between 0.6 and 1.2 percent of total employment (the share of employment in sectors that use said energy as an input—that is, sectors that indirectly contribute to carbon emissions through energy demand

Moreover, while the production of the r intermediate energy input uses the same physical capital that salaried firms use, the production of the g intermediate energy input relies on physical capital that is specific to the g technology and whose real price is assumed to be exogenous.[18] Real profits from the production of these intermediate energy inputs are given by

$$\Pi_{e,t} = \left[mc^r_{e,t} D(x_t) z^r_{e,t} k^r_{e,t} - r_{k,t} k^r_{e,t} - \tau_{e,t} em_t - \Gamma_t\right] + mc^g_{e,t} D(x_t) z^g_{e,t} k^g_{e,t} - r^g_{k,t} k^g_{e,t},$$

where $mc^r_{e,t}$ is the real price of the intermediate energy input produced with the r technology, $z^r_{e,t}$ is exogenous productivity, $k^r_{e,t}$ is the physical capital used to produce r intermediate energy inputs, $r_{k,t}$ is the real price of that capital, em_t denotes net emissions from the production of these inputs, $\tau_{e,t} \geq 0$ is the exogenous carbon tax, and Γ_t is the total cost of emissions abatement. In turn, $mc^g_{e,t}$ is the real price of the intermediate energy input produced with the g technology, $z^g_{e,t}$ is exogenous productivity, $k^g_{e,t}$ is the physical capital used to produce g intermediate energy inputs, and $r^g_{k,t}$ is the real price of capital $k^g_{e,t}$. Similar to salaried firms, pollution damages $D(x_t)$ affect the production of intermediate energy inputs and are taken as given by these intermediate-energy-input producers. Following the macro-climate literature, $\Gamma_t = \gamma \mu^\eta_{e,t} D(x_t) z^r_{e,t} k^r_{e,t}$ is the total abatement cost, where μ_t is the endogenous abatement rate, $\gamma > 0$, and $\eta > 1$. Carbon emissions are $em_t = (1 - \mu_{e,t}) \left[D(x_t) z_t k^r_{e,t}\right]^{1-\nu_e}$, where $0 < \nu_e \leq 1$ (Heutel, 2012; Annicchiarico and Di Dio, 2015). Finally, emissions add to the pollution stock $x_t = \rho_x x_{t-1} + em_t + em^{row}_t$, where $0 < \rho_x < 1$

and use—is, of course, much larger and embodied in the goods-producing sector in our model). Given this very small share of employment and the fact that we use search frictions to model the labor market, we abstract from introducing labor as an input. We also abstract from modeling commodities and other natural resources used in the production of energy in order to focus on the labor market and firm formality margins amid green technology adoption. Introducing a fixed endowment of natural resources in the production of polluting energy alongside physical capital would not change our main findings.

[18] This assumption captures in a reduced-form way the fact that EMEs tend to obtain green technologies and their inputs from AEs via imports given AEs' technological edge on the green-energy front. As such, the global price of these inputs and technologies is often supply-driven and is not affected by demand from any given EME. See Barrett (2021) for recent work on the international diffusion of technologies and their role in addressing climate change. We abstract from explicitly modeling an open economy with an import margin for green technologies and physical inputs to avoid additional complexity. Endogenizing the price of green capital $k^g_{e,t}$, as would be the case if capital were imported in an open-economy setting, does not change our main conclusions. Finally, EMEs are known for having fossil-fuel and other polluting-energy subsidies. Introducing these subsidies in the model does not change the main model mechanisms or conclusions of the model.

determines the persistence of past pollution and em_t^{row} are exogenous emissions from the rest of the world.

The optimal choices of the intermediate energy input producer are characterized by a standard demand condition for capital associated with the g technology (which equates the marginal benefit of a unit of capital to its marginal cost)

$$mc_{e,t}^{g} D(x_t) z_{e,t}^{g} = r_{k,t}^{g}, \tag{4}$$

an optimal emissions abatement decision (which equates the marginal cost of abating one unit of emissions to its marginal benefit, affected by the carbon tax $\tau_{e,t}$)

$$\eta\gamma\mu_{e,t}^{\eta-1} = \tau_{e,t}\left[D(x_t) z_{e,t}^{r} k_{e,t}^{r}\right]^{-\nu_e}, \tag{5}$$

and a demand condition for capital associated with the r technology (which equates the marginal benefit of a unit of capital used with the technology to its marginal cost)

$$mc_{e,t}^{r} D(x_t) z_{e,t}^{r} = r_{k,t} + \left[(1-\nu_e)\,\tau_{e,t}(1-\mu_{e,t})\left[D(x_t) z_{e,t}^{r} k_{e,t}^{r}\right]^{-\nu_e} + \mu_{e,t}^{\eta}\right] D(x_t) z_{e,t}^{r}, \tag{6}$$

where the latter includes the price of capital, the marginal carbon-tax burden net of emissions abatement, and the marginal increase in abatement expenditures.

Profits, Optimal Pricing, and Technology Choices– Turning to the energy producers that use the intermediate energy inputs described above, if energy producer a_e uses the energy inputs produced with the r technology, its individual real profits are

$$\pi_{e,t}^{r}(a_e) = \left[\rho_{e,t}^{r}(a_e) - \frac{mc_{e,t}^{r}}{a_e}\right] e_{r,t}(a_e).$$

If producer a_e uses the energy inputs produced with the g technology, its individual real profits are

$$\pi_{e,t}^{g}(a_e) = \left[\rho_{e,t}^{g}(a_e) - \frac{mc_{e,t}^{g}}{a_e}\right] e_{g,t}(a_e) - \varphi_e,$$

where $\rho_{e,t}^{r}(a_e)$ and $\rho_{e,t}^{g}(a_e)$ denote producer a_e's relative price of energy produced with the r technology and with the g technology, respectively, and $mc_{e,t}^{r}/a_e$ and $mc_{e,t}^{g}/a_e$ are the re-

spective effective real marginal costs. It follows that an energy producer a_e is indifferent between the two technologies if $\pi^r_{e,t}(\overline{a}_{e,t}) = \pi^g_{e,t}(\overline{a}_{e,t})$. This condition pins down the endogenous idiosyncratic productivity level above which the energy producer decides to adopt the g technology $\overline{a}_{e,t}$. Noting that the individual energy producers' demand functions for the r technology is $e_{r,t}(a_e) = \left(\rho^r_{e,t}(a_e)/\rho_{e,t}\right)^{-\varepsilon_e} E_t$, it follows that the optimal relative prices of energy for each category are $\rho^r_{e,t}(a_e) = \left[\varepsilon_e/\left(\varepsilon_e - 1\right)\right]\left(mc^r_{e,t}/a_e\right)$, and $\rho^g_{e,t}(a_e) = \left[\varepsilon_e/\left(\varepsilon_e - 1\right)\right]\left(mc^g_{e,t}/a_e\right)$, respectively.

Average Productivities, Total Energy Production, and Energy Prices– The average idiosyncratic productivity of an energy producer using technology r is $\widetilde{a}^r_{e,t} = \left[\frac{1}{G(\overline{a}_{e,t})}\int_{a^e_{min}}^{\overline{a}_{e,t}} a_e^{\varepsilon_e - 1} dG(a_e)\right]^{\frac{1}{\varepsilon_e - 1}}$. The corresponding average productivity of an energy producer using technology g is $\widetilde{a}^g_{e,t} = \left[\left(\frac{1}{1-G(\overline{a}_{e,t})}\right)\int_{\overline{a}_{e,t}}^{\infty} a_e^{\varepsilon_e - 1} dG(a_e)\right]^{\frac{1}{\varepsilon_e - 1}}$. We define $\widetilde{\rho}^r_{e,t} = \rho^r_{e,t}(\widetilde{a}^r_{e,t})$, $\widetilde{e}_{r,t} = e_{r,t}(\widetilde{a}^r_{e,t})$ and $\widetilde{\pi}^r_{e,t} = \pi^r_{e,t}(\widetilde{a}^r_{e,t})$, similarly for g. For future reference, we denote average total energy producers' profits by $\widetilde{\pi}_{e,t} \equiv G(\overline{a}_{e,t})\widetilde{\pi}^r_{e,t} + (1 - G(\overline{a}_{e,t}))\,\widetilde{\pi}^g_{e,t}$. Finally, we can write average total energy production E_t and the average real price of total energy $\rho_{e,t}$ as

$$E_t = \left\{G(\overline{a}_{e,t})\widetilde{e}_{r,t}^{\frac{\varepsilon_e - 1}{\varepsilon_e}} + [1 - G(\overline{a}_{e,t})]\,\widetilde{e}_{g,t}^{\frac{\varepsilon_e - 1}{\varepsilon_e}}\right\}^{\frac{\varepsilon_e}{\varepsilon_e - 1}}, \text{ and} \tag{7}$$

$$\rho_{e,t} = \left\{G(\overline{a}_{e,t})\left(\widetilde{\rho}^r_{e,t}\right)^{1-\varepsilon_e} + [1 - G(\overline{a}_{e,t})]\left(\widetilde{\rho}^g_{e,t}\right)^{1-\varepsilon_e}\right\}^{\frac{1}{1-\varepsilon_e}}. \tag{8}$$

Note that $G(\overline{a}_{e,t})$ represents the endogenous measure of energy producers that use the r technology, and therefore $[1 - G(\overline{a}_{e,t})]$ represents the endogenous measure of energy producers that use the g technology. The carbon tax (as well as other climate policies) ultimately shapes the average price of energy $\rho_{e,t}$ through changes in the intensive margin (capital use by energy producers) and the extensive margin (sub-measures of energy producers) of energy production.

Carbon Tax, Energy Prices, and Composition of Energy Producers– Using condition (6), it is easy to show that, all else equal, an increase in the carbon tax leads to an increase in the marginal cost of r intermediate energy inputs, which in turn increases $\widetilde{\rho}^r_{e,t}$ (per optimal pricing) and exerts upward pressure on $\rho_{e,t}$. By increasing marginal costs,

the increase in the carbon tax also makes it more attractive for energy producers using the r technology to incur the fixed cost and switch to the g technology, which is reflected in a reduction in the endogenous threshold $\overline{a}_{e,t}$. The latter increases the share of energy producers that adopt the g technology $G(\overline{a}_{e,t})$, which in turn shifts the composition of energy production towards green energy per condition (7) and reduces the influence of $\widetilde{\rho}^{r}_{e,t}$ on $\rho_{e,t}$ per condition (8). Since firms and households use energy, changes in the price of energy not only affect capital demand and salaried job creation but also, as we show further below, households' decisions to send members to search for salaried jobs and self-employment opportunities.

3.2 Households and Self-Employment

A representative household has a unit mass of members and owns all producers and firms. The household derives utility from consuming final goods c_t and energy $e_{h,t}$ and derives disutility from its members' labor market participation across the three employment categories: formal (salaried) employment (f), informal salaried employment (i), and (informal) self-employment (o).[19]

Formally, the household chooses consumption, energy, the desired number of salaried firms $N_{s,t+1}$ and the associated number of new salaried firms $A_{s,t}$ to reach that target, total physical capital accumulation k_{t+1}, the measures of searchers for formal and informal salaried employment, $s_{f,t}$ and $s_{i,t}$, the measure of searchers for self-employment, $s_{o,t}$, and the associated desired measures of workers in those categories, $n_{f,t}$, $n_{i,t}$, and $n_{o,t}$, to maximize $\sum_{t=0}^{\infty}\beta^t[\mathbf{u}(c_t, e_{h,t}) - \mathbf{h}(\text{lfp}_{f,t}, \text{lfp}_{i,t}, \text{lfp}_{o,t})]$ subject to the budget constraint

$$\begin{aligned} c_t + \varphi_s A_{s,t} + \rho_{e,t} e_{h,t} + inv_t = \; & w_{f,t} n_{f,t} + w_{i,t} n_{i,t} + p_{o,t} D(x_t) z_{o,t} n_{o,t} + r_{k,t} k_t \\ & + \widetilde{\pi}_{s,t} N_{s,t} + \Pi_{a,t} + T_t, \end{aligned}$$

the evolution of total salaried employment in each salaried-firm category $j \in \{f, i\}$ and of self-employment

$$n_{j,t} = (1-\rho_s) n_{j,t-1} + s_{j,t}\varrho_{j,t}, \quad \text{and} \quad n_{o,t} = (1-\rho_o) n_{o,t-1} + s_{o,t}\phi_o, \tag{9}$$

[19] It is well known in the literature on informality that the majority of self-employment in EMEs is considered informal employment (Maloney, 2004).

and the evolution of salaried firms

$$N_{s,t+1} = (1 - \delta_s)\,(N_{s,t} + A_{s,t})\,, \tag{10}$$

where $inv_t = k_{t+1} - (1-\delta)\,k_t$ denotes total physical capital investment. The function $\mathbf{u}(c_t, e_{h,t})$ is increasing and concave in each of its arguments while the function $\mathbf{h}(\text{lfp}_{f,t}, \text{lfp}_{i,t}, \text{lfp}_{o,t})$ is increasing and convex in each of its arguments. In the budget constraint, $\Pi_{a,t} \equiv \Pi_{s,t} + \Pi_{e,t} + \widetilde{\pi}_{e,t} + \Pi_{y,t}$ is the sum of intermediate-goods producers' profits $\Pi_{s,t}$, intermediate-energy-input producers' profits $\Pi_{e,t}$, total energy producers' profits $\widetilde{\pi}_{e,t}$, and profits from output aggregation $\Pi_{y,t}$. T_t denotes lump-sum transfers from the government. The term $p_{o,t} D(x_t) z_{o,t} n_{o,t}$ denotes total real earnings from having a measure $n_{o,t}$ of household members working in self-employment, where $z_{o,t}$ is the exogenous productivity level of a self-employed individual. Similar to salaried-firm production and energy production, self-employment production is also adversely affected by pollution damages via $D(x_t)$. Turning to the evolution of employment, $0 < \varrho_{j,t} < 1$ is the endogenous job-finding probability in salaried category j (a function of category-specific market tightness), $0 < \phi_o < 1$ is the exogenous probability that household members searching for self-employment opportunities successfully transition to self-employment, and $0 < \rho_o < 1$ is the exogenous probability that a self-employed individual exits self-employment.[20]

In the household's disutility of labor market participation, $\text{lfp}_{f,t} = n_{f,t} + (1 - \varrho_{f,t})\, s_{f,t}$, $\text{lfp}_{i,t} = n_{i,t} + (1 - \varrho_{i,t})\, s_{i,t}$, and $\text{lfp}_{o,t} = n_{o,t} + (1 - \phi_o)\, s_{o,t}$ denote, respectively, labor force participation in the formal (salaried) sector, in the informal salaried sector, and in self-employment. As such, total labor force participation is $\text{lfp}_t = \text{lfp}_{f,t} + \text{lfp}_{i,t} + \text{lfp}_{o,t}$ and we can define the total unemployment rate as $ur_t = \left[(1 - \varrho_{f,t})\, s_{f,t} + (1 - \varrho_{i,t})\, s_{i,t} + (1 - \phi_o)\, s_{o,t}\right] / \text{lfp}_t$.

The household's optimal choices are characterized by an energy demand optimality condition that equates the marginal benefit of a unit of energy to its marginal cost

$$\mathbf{u}_{e_h,t} = \rho_{e,t} \mathbf{u}_{c,t}, \tag{11}$$

[20]The fact that $0 < \phi_o < 1$ implies that entry into self-employment is not guaranteed. This captures in a reduced-form way the frictions that may prevent entry into self-employment. For tractability, we do not explicitly model these frictions but note that our results would not change if we model frictions associated with input access (for an example of such frictions, see Finkelstein Shapiro, 2018).

by standard optimal salaried firm creation and physical capital accumulation conditions

$$\varphi_s = (1-\delta_s)\Xi_{t+1|t}\left[\widetilde{\pi}_{s,t+1} + \varphi_s\right] \quad \text{and} \quad 1 = \Xi_{t+1|t}\left[r_{k,t+1} + (1-\delta)\right], \tag{12}$$

by an optimal lfp decision for each type of salaried worker $j \in \{f, i\}$

$$\frac{\mathbf{h}_{\text{lfp}_{j,t}}}{\mathbf{u}_{c,t}} = \varrho_{j,t}\left[w_{j,t} + (1-\rho_s)\Xi_{t+1|t}\left(\frac{1-\varrho_{j,t+1}}{\varrho_{j,t+1}}\right)\left(\frac{\mathbf{h}_{\text{lfp}_{j,t+1}}}{\mathbf{u}_{c,t+1}}\right)\right], \tag{13}$$

and by an optimal lfp decision for self-employment

$$\frac{\mathbf{h}_{\text{lfp}_{o,t}}}{\mathbf{u}_{c,t}} = \phi_o\left[p_{o,t}D(x_t)z_{o,t} + (1-\rho_o)\Xi_{t+1|t}\left(\frac{1-\phi_o}{\phi_o}\right)\left(\frac{\mathbf{h}_{\text{lfp}_{o,t+1}}}{\mathbf{u}_{c,t+1}}\right)\right], \tag{14}$$

where $\Xi_{t+1|t} \equiv \beta\mathbf{u}_{c,t+1}/\mathbf{u}_{c,t}$ is the household's stochastic discount factor. The lfp conditions equate the marginal cost of participating to the expected marginal benefit of doing so for each employment category, where the marginal benefit is comprised of the individual's contemporaneous real earnings and the continuation value associated with remaining employed in the same category in the next period.

Self-Employment Decisions and Energy Prices– Our baseline model abstracts from explicitly including energy as an input in the production technology used by the self-employed. We stress that this baseline assumption does *not* mean that the self-employed are not adversely impacted by an increase in energy prices. Indeed, since households both consume energy and choose the measure of household members who search for self-employment opportunities, changes in the price of energy *explicitly* affect the household's decisions over salaried work *and also* self-employment, thereby shaping self-employment entry decisions. Then, changes in energy prices affect both salaried firms and the relative attractiveness of moving to self-employment.

To see this explicitly, using the optimal demand for energy by the household $\mathbf{u}_{e_h,t} = \rho_{e,t}\mathbf{u}_{c,t}$ alongside the definition of $\Xi_{t+1|t}$, we can rewrite expression (14) as follows:

$$\frac{\mathbf{h}_{\text{lfp}_{o,t}}}{\mathbf{u}_{e_h,t}} = \phi_o\left[\frac{p_{o,t}D(x_t)z_{o,t}}{\rho_{e,t}} + (1-\rho_o)\beta\left(\frac{1-\phi_o}{\phi_o}\right)\left(\frac{\mathbf{h}_{\text{lfp}_{o,t+1}}}{\mathbf{u}_{e_h,t}}\right)\right], \tag{15}$$

Then, an increase in $\rho_{e,t}$ *all else equal* reduces the contribution of marginal revenue from self-employment $p_{o,t}D(x_t z_{o,t})$ to the marginal benefit of having an additional household member enter self-employment (the right-hand side of expression (15), thereby pushing the household to reduce their search for self-employment in response to the increase in $\rho_{e,t}$. Of course, following similar steps using expression (13), we can show that the marginal benefit of searching for salaried jobs is similarly affected by higher energy prices. However, in the case of salaried employment, an increase in energy prices also leads to fewer salaried job vacancies (effectively, a reduction in labor demand) by making energy inputs for salaried firms more expensive. The resulting reduction in salaried job creation further lowers the household's incentive to send its members to search for salaried jobs *relative to self-employment opportunities*. In other words, the increase in energy prices makes searching for any category of employment less attractive in absolute terms, but searching for self-employment becomes more attractive than searching for salaried jobs *in relative terms* because the outcome from searching for a salaried job depends not only on household search decisions (as is the case for self-employment) but also on salaried firms' job creation decisions. Then, on net, higher energy prices shift search away from salaried jobs towards self-employment opportunities. Finally, we note that assuming that the self-employed use energy explicitly as an input alongside labor (similar to salaried firms) and abstracting from household energy consumption (whose inclusion would double-count the impact of energy prices on the factors influencing entry into self-employment) delivers the same conclusions as our baseline framework.[21]

3.3 Matching Processes and Real Wages

The matching function $m(s_{j,t}, v_{j,t})$ for salaried category $j \in \{f, i\}$ is constant-returns-to-scale and takes as arguments salaried searchers $s_{j,t}$ and job vacancies $v_{j,t}$ in its respective employment category. The job-finding and job-filling probabilities are $\varrho_{j,t} = \varrho(\theta_{j,t}) = m(s_{j,t}, v_{j,t})/s_{j,t}$ and $q_{j,t} = q(\theta_{j,t}) = m(s_{j,t}, v_{j,t})/v_{j,t}$, respectively, where market tightness is $\theta_{j,t} = v_{j,t}/s_{j,t}$. Following the literature, real wages are determined via bilateral Nash bargaining between the intermediate-goods producer and salaried workers, where $0 < \nu_n < 1$ is the worker bargaining power. Amid endogenous lfp, it is straightforward to show that the real Nash wages

[21] See results in Appendix E for more details.

for salaried workers are

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

and

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

3.4 Symmetric Equilibrium and Market Clearing

As a baseline, we assume that any carbon-tax revenue is transferred lump-sum to households, so that the government budget constraint is $T_t = \tau_{e,t} em_t$. Following the literature, we focus on a symmetric equilibrium. Market clearing in the two salaried-firm categories is then given by $D(x_t)\widetilde{a}^f_{s,t} z_{f,t} H(n_{f,t}, k_{f,t}, e_{f,t}) = N_{f,t}\widetilde{y}_{f,t}$ and $D(x_t)\widetilde{a}^i_{s,t} z_{i,t} F(n_{i,t}, k_{i,t}, e_{i,t}) = N_{i,t}\widetilde{y}_{i,t}$. Similarly, market clearing in the energy sector is given by $D(x_t)\widetilde{a}^r_{e,t} z^r_{e,t} k^r_{e,t} = G(\overline{a}_{e,t})\widetilde{e}_{r,t}$ and $D(x_t)\widetilde{a}^g_{e,t} z^g_{e,t} k^g_{e,t} = [1 - G(\overline{a}_{e,t})]\, e_{g,t}$. In equilibrium, total energy and total physical capital are given by $E_t = e_{h,t} + e_{f,t} + e_{i,t}$ and $k_t = k_{f,t} + k_{i,t} + k^r_{e,t}$, where recall that $k^g_{e,t}$ differs from the physical capital used by production firms and r energy producers and therefore is not included as part of k_t. Finally, the resource constraint is

$$Y_t = c_t + inv_t + \psi_f v_{f,t} + \psi_i v_{i,t} + \varphi_s A_{s,t} + \varphi_f N_{f,t} + \varphi_e \left[1 - G(\overline{a}_{e,t})\right] + \Gamma_t + r^g_{k,t} k^g_{e,t},$$

where vacancy posting costs, salaried firm creation costs, the cost of becoming a formal salaried firm, the cost to energy producers of adopting green technologies, abatement expenditures by polluting energy producers, and the total real cost of capital used in the g energy technology are all resource costs.

4 Quantitative Analysis

The presence of a variety effect in macro models with endogenous firm creation implies that model-based quantity variables are not readily comparable to their empirical counterparts, where the latter are based on an empirical aggregate price index that does not incorporate

the variety effect (see Bilbiie, Ghironi and Melitz, 2012). Following this literature, for any model quantity variable λ_t^m based on the model's aggregate price index, $\lambda_t^d = \lambda_t^m \Theta_t$ is a model-based quantity variable that is data-consistent—that is, comparable to its empirical counterpart—where $\Theta_t = \left(N_{s,t}^{\frac{1-\phi_y}{1-\varepsilon}} + 1 \right)^{\frac{1}{1-\phi_y}}$ eliminates the variety effect from the model's aggregate price index (see Appendix D for more details). Unless otherwise noted, all quantity variables we discuss below are expressed in data-consistent terms.

4.1 Baseline Calibration

In what follows, we describe the baseline calibration of the model. Results from a host of robustness experiments are summarized in Section 4.2.

Functional Forms– Utility from consumption and energy is standard and given by $\mathbf{u}(c_t, e_{h,t}) = \frac{\left[(c_t)^{1-\sigma_e}\left(e_{h,t}\right)^{\sigma_e}\right]^{1-\sigma_c}}{1-\sigma_c}$, where $0 < \sigma_e < 1$ and $\sigma_c > 0$.[22] In turn, the disutility from labor force participation is given by $\mathbf{h}\left(\text{lfp}_{f,t}, \text{lfp}_{i,t}, \text{lfp}_{o,t}\right) = \frac{\left[\kappa_f(\text{lfp}_{f,t}) + \kappa_i(\text{lfp}_{i,t}) + \kappa_o(\text{lfp}_{o,t})\right]^{1+1/\chi_n}}{1+1/\chi_n}$, where $\kappa_f, \kappa_i, \kappa_o > 0$ and $\chi_n > 0$ shapes the elasticity of lfp. The matching functions are constant-returns-to-scale and given by $m(s_{j,t}, v_{j,t}) = (s_{j,t} v_{j,t}) / \left(s_{j,t}^{\xi} + v_{j,t}^{\xi} \right)^{1/\xi}$ for $j \in \{f, i\}$, where $\xi > 0$ (den Haan, Ramey and Watson, 2000). Intermediate goods production is Cobb-Douglas: $H(n_{f,t}, k_{f,t}, e_{f,t}) = (n_{f,t})^{1-\alpha_f-\alpha_e}(k_{f,t})^{\alpha_f}(e_{f,t})^{\alpha_e}$, $F(n_{i,t}, k_{i,t}, e_{i,t}) = (n_{i,t})^{1-\alpha_i-\alpha_e}(k_{i,t})^{\alpha_i}(e_{i,t})^{\alpha_e}$, where $0 < \alpha_f + \alpha_e < 1$ and $0 < \alpha_i + \alpha_e < 1$. Intermediate energy inputs are produced using linear production technologies in their respective physical capital.

Following the macro literature on endogenous firm entry, we adopt Pareto distributions for the idiosyncratic productivities of salaried firms and energy producers, so that $G(a_s) = \left[1 - (a_{min}^s / a_s)^{k_p^s}\right]$ and $G(a_e) = \left[1 - (a_{min}^e / a_e)^{k_p^e}\right]$ where $k_p^s > \varepsilon - 1$ and $k_p^e > \varepsilon_e - 1$. As such, the average salaried idiosyncratic productivities are $\widetilde{a}_{s,t}^i = \widetilde{a}_{s,t}^f \left[\frac{\overline{a}_{s,t}^{k_p^s - (\varepsilon-1)} - \left(a_{min}^s\right)^{k_p^s-(\varepsilon-1)}}{\overline{a}_{s,t}^{k_p^s} - \left(a_{min}^s\right)^{k_p^s}} \right]^{\frac{1}{\varepsilon-1}} a_{min}^s$ and $\widetilde{a}_{s,t}^f = \left[\frac{k_p^s}{k_p^s - (\varepsilon-1)} \right]^{\frac{1}{\varepsilon-1}} \overline{a}_{s,t}$ while the average idiosyncratic productivities of energy producers are $\widetilde{a}_{e,t}^r = \widetilde{a}_{e,t}^g \left[\frac{\overline{a}_{e,t}^{k_p^e - (\varepsilon_e-1)} - \left(a_{min}^e\right)^{k_p^e-(\varepsilon_e-1)}}{\overline{a}_{e,t}^{k_p^e} - \left(a_{min}^e\right)^{k_p^e}} \right]^{\frac{1}{\varepsilon_e-1}} a_{min}^e$ and $\widetilde{a}_{e,t}^g = \left[\frac{k_p^e}{k_p^e - (\varepsilon_e-1)} \right]^{\frac{1}{\varepsilon_e-1}} \overline{a}_{e,t}$.

Following the macro-climate literature, we assume that the damages function is $D(x_t) =$

[22] Assuming that consumption and energy are weak complements, as in Känzig (2023), does not change our main conclusions.

$exp\left[-D_0(x_t - \overline{x})\right]$ where $D_0 > 0$ determines the extent of the pollution externality and $\overline{x} = D_1 x$ is a parameter that represents the pre-industrial atmospheric concentration of carbon dioxide with $D_1 < 1$ and x is steady-state pollution.[23] In turn, recalling that the production of intermediate energy-input producers is the only source of harmful emissions in the model, total abatement costs Γ_t are linear in these producers' total output: $\Gamma_t = \gamma \mu_t^{\eta} D(x_t) z_{e,t}^r k_{e,t}^r$, where $\gamma > 0$ and $\eta > 1$ (Annicchiarico, Correani and Dio, 2018).

Parameters from Literature– Table 3 summarizes the baseline calibration of the model. A period is a quarter. We normalize the exogenous productivity of formal salaried firms to $z_f = 1$. Similarly, we set the exogenous productivities in the energy sector to $z_e^r = z_e^g = 1$.[24] We set the capital shares of salaried production firms to $\alpha_f = 0.32$ and $\alpha_i = 0.22$, which captures the fact that f firms are more capital intensive than i firms. This choice also generates an outcome where, consistent with available data, the majority of the capital stock is held by f firms (Busso, Fazio and Levy Algazi, 2012). As a baseline, the energy share in salaried-firm production is $\alpha_e = 0.05$ (Adão, Narajabad and Temzelides, 2024). We set the subjective discount factor $\beta = 0.985$, the CRRA utility parameter $\sigma_c = 2$, the capital depreciation rate and salaried firm exit rate $\delta = \delta_s = 0.025$, and the elasticity of substitution parameter associated with salaried-firm output $\varepsilon = 4$, all of which are standard values in the EME literature. Based on available evidence, we set the salaried job and self-employment separation probabilities to $\rho_s = 0.05$ and $\rho_o = 0.03$, and the probability of entering self-employment to $\phi_o = 0.15$ (Bosch and Maloney, 2008). Following the search and matching literature, we set the bargaining power of salaried workers to $\nu_n = 0.50$.

As a baseline, we set the elasticity of lfp $\phi_n = 0.26$, the elasticity of substitution between salaried and self-employment output $\phi_y = 4$, the elasticity of substitution between energy producers $\varepsilon_e = 4$, and the Pareto parameters $k_p^s = k_p^e = 4.2$, which satisfy the Pareto distribution requirements that $k_p^s > \varepsilon - 1$ and $k_p^e > \varepsilon_e - 1$.[25] Robustness checks confirm

[23] See Cai and Lontzek (2019); Hambel, Kraft and Schwartz (2021) for the relevance of convexities in the damages function.

[24] Recall that our framework features *endogenous* average productivity differentials between (1) production-firm categories f and i and (2) energy producers using the r and the g technologies. As such, this normalization is innocuous. Our main conclusions remain unchanged if we calibrate z_e^r and z_e^g to match other relevant data targets associated with the energy sector.

[25] Existing evidence suggests that the elasticity of substitution between polluting and green energy inputs

that our main findings remain unchanged if we consider alternative values (see Table A14 in Appendix E). Following the macro literature on endogenous firm entry, without loss of generality, we set the minimum levels of idiosyncratic productivity for salaried production firms and energy producers to $a^s_{min} = a^e_{min} = 1$. We also set the sunk entry cost faced by salaried firms to $\varphi_s = 1$ and confirm that calibrating this parameter does not change our conclusions (see Table A16 in Appendix E).

Turning to the parameters associated with the environmental side, we set the carbon tax $\tau_e = 0$ as a baseline since most EMEs do not have a nationwide carbon tax in the energy sector.[26] Absent specific estimates for select parameters associated with the damages and abatement-cost functions for EMEs, we borrow parameter values from existing literature and conduct robustness checks. Specifically, in the abatement cost function, we set the elasticity parameter $\eta = 2.8$ (Nordhaus, 2008) and assume a weight of $\gamma = 1$ (Hafstead and Williams, 2018) as baseline. We also set the parameter that dictates the sensitivity of emissions to changes in the production of energy using the r technology to $\nu_e = 0.304$ (implying an elasticity of 0.696) and the persistence of the pollution stock to $\rho_x = 0.9979$ (Heutel, 2012). Robustness checks confirm that our conclusions remain unchanged under alternative values. Finally, we set $D_1 = 0.6983$, which represents the ratio of the level of CO_2 concentration at the onset of the industrial era to the level of concentration in the mid 2010s. This value allows us to match the pre-industrial atmospheric concentration of CO_2, which enters the pollution damages function $D(x_t)$ (Annicchiarico, Correani and Dio, 2018).

Calibrated Parameters– As a baseline, we assume the same vacancy posting costs for f and i firms so that $\psi_f = \psi_i$. The remaining parameters σ_e, D_0, $\psi_f (= \psi_i)$, φ_f, φ_e, em^{row}, κ_f, κ_i, κ_o, ξ, z_i,z_o, r^g_k, and $\bar{x}$ are calibrated to match a set of first-moment targets based on averages for the 12 EMEs in Section 2 using the latest available data or, when appropriate, related empirical studies on EMEs.

The targets we use are: an average share of household energy consumption in total energy consumption of 0.26 (Narayan and Doytch, 2017); an average ratio of pollution damages to

is greater than 1 (see Papageorgiou, Saam and Schulte, 2017).

[26] Setting a baseline carbon tax that is positive does not change our main conclusions since we are interested in the effects of a ^{27} in the carbon tax relative to baseline.

GDP of 1.25 percent (Roson and Sartori, 2016);[28] a ratio of total vacancy-posting costs to output of 3 percent (in line with the search and matching literature); an average cost of becoming a formal firm (the cost of business-startup procedures, which includes the cost of registering a firm with local government and tax authorities) of 8 percent of gross national income per capita (World Bank Enterprise Surveys); a real cost of a unit of green capital k_e^g that is 90 percent of the real cost of a unit of regular capital k_e^r (Gormsen, Huber and Oh, 2024),[29] a ratio of carbon dioxide emissions from the rest of the world to total world emissions of 0.90 (Global Carbon Project); an average lfp rate of 0.63 (ILO); an average ratio of formal employment to total employment of 0.542 (ILO); an average ratio of self-employment to total employment of 0.36 (ILO); an average unemployment rate of 8.15 percent (ILO); a share of formal-firm output in total output of 70 percent (World Bank Informal Economy Database); an average ratio of formal to informal wages of 1.25 (ILO); a share of polluting (regular) energy production in total energy of 0.84 (IEA); and the condition that parameter $\bar{x} = D_1 x$ where D_1 was set based on the macro-climate literature and x is steady-state pollution.

The resulting calibrated parameter values that match these targets are: $\sigma_e = 0.0135$, $D_0 = 0.0000043511$, $\psi_f (= \psi_i) = 0.1441$, $\varphi_f = 0.3475$, $\varphi_e = 0.8485$, $em^{row} = 17.8826$, $\kappa_f = 1.2247$, $\kappa_i = 0.9741$, $\kappa_o = 1.1079$, $\xi = 0.3937$, $z_i = 0.4078$, $z_o = 2.672$, $r_k^g = 0.0362$, and $\bar{x} = 6606.683$. Of note, given the endogenous productivity components of salaried firms $\widetilde{a}_s^f$ and $\widetilde{a}_s^i$, in our baseline calibration, the overall average productivity component of f firms ($z_f \widetilde{a}_s^f$) ends up being greater than the overall productivity component of both informal salaried firms ($z_i \widetilde{a}_s^i$) and self-employed individuals (z_o). This is an outcome of the calibration consistent with the well-known fact that in EMEs, formal salaried firms have higher productivity relative to both informal salaried firms and the self-employed.

[28] These costs are at the lower end of what more recent studies document (Kalkuhl and Wenz, 2020). However, higher or lower damages do not change the model mechanisms or main conclusions.

[29] Empirical evidence on the differential cost between green capital and regular capital in EMEs is scant or non-existent. As such, we rely on available evidence for AEs. The resulting value for r_k^g implies that the quarterly depreciation rate of green capital is 2.1 percent vs. 2.5 percent for regular capital.

Table 3: Parameter Description and Baseline Values in Benchmark Model

Parameters from Literature and Baseline Parameter Values			
Parameter	Value	Parameter Description	Source
α_f	0.32	Capital share, formal firms	EME literature
α_i	0.22	Capital share, informal firms	Baseline assumption
α_e	0.05	Energy share, firms	Baseline assumption
β	0.985	Discount factor	EME literature
δ	0.025	Capital depreciation rate	EME literature
δ_s	0.025	Salaried firm exit prob.	EME literature
σ_c	2	CRRA parameter	EME literature
ϕ_n	0.26	Elasticity of LFP	Chetty et al. (2011, 2013)
ε	4	Elast. substit. firm output	Average markup in EMEs
ε_e	4	Elast. substit. energy prod.	Baseline assumption
k_p^s	4.2	Pareto shape param.	Baseline assumption, $k_p^s > \varepsilon - 1$
k_p^e	4.2	Pareto shape param.	Baseline assumption, $k_p^e > \varepsilon - 1$
a_{min}^s	1	Min. idiosync. prod.	Normalization
a_{min}^e	1	Min. idiosync. prod., energy	Normalization
ρ_s	0.05	Salaried job separation prob.	Bosch and Maloney (2008)
ρ_o	0.03	Self-empl. separation prob.	Bosch and Maloney (2008)
ν_n	0.50	Worker bargaining power	Search and matching literature
D_1	0.6983	Parameter damages function	Annicchiarico, *et al.* (2018)
η	2.8	Elasticity of abatement	Nordhaus (2008)
γ	1	Weight abate. cost function	Hafstead and Williams (2018)
ν_e	0.304	Elast. parameter, emissions	Heutel (2012)
ρ_x	0.9979	Persistence of pollution stock	Heutel (2012)
Calibrated Baseline Parameter Values			
Parameter	Value	Parameter Description	Target
σ_e	0.0135	Utility param., HH energy	$e_h/E = 0.26$
D_0	0.000004510981	Damages function parameter	Pollution damages/GDP = 0.0125
$\psi_f\,(=\psi_i)$	0.1441	Salaried vacancy posting cost	$(\psi_f v_f + \psi_i v_i)/Y = 0.03$
φ_f	0.3475	Fixed cost of firm formality	$\varphi_f/Y = 0.08$
φ_e	0.8485	Fixed cost of g tech. adopt.	Share of r energy prod. = 0.84
e^{row}	17.8826	Emissions rest of world	$em^{row}/(em + em^{row}) = 0.90$
κ_f	1.2247	LFP disutility param. for f	$lfp = 0.63$
κ_i	0.9741	LFP disutility param. for i	$(n_f)/(n_f + n_i + n_o) = 0.542$
κ_o	1.1079	LFP disutility param. for o	$(n_o)/(n_f + n_i + n_o) = 0.36$
ξ	0.3937	Matching elasticity param.	Unempl. rate of 8.15 percent
z_i	0.4078	i-firm exog. prod.	$w_f/w_i = 1.25$
z_o	2.672	Self-employed exog. prod.	Total f-firm output share = 0.70
r_k^g	0.0362	Cost of green capital k_e^g	$r_k^g = 0.90 r_k$
$\bar{x}$	6006.683	Pre-indust. pollution stock	$\bar{x} = D_1 x$

4.2 The Effects of a Carbon Tax on Long-Run Outcomes and Transitional Dynamics

We characterize both the long run (steady state) changes and the transition path of the economy in response to an increase in the carbon tax that reduces long-run emissions by 25

percent relative to their baseline level—a reduction in line with the climate policy experiments in WEO (2022). Then, we dissect the main forces and mechanisms behind our findings in Section 4.3 by highlighting (1) the quantitative role of green technology adoption; (2) the relevance of self-employment; and (3) the potential benefits of combining other policies with a carbon tax.[30]

A Note on the Carbon Tax Level in the Model– Before describing our main findings, we note that a simple back-of-the-envelope calculation suggests that the carbon tax in the model is roughly US$6 per unit of emissions. This tax may seem low compared to the average carbon tax of roughly US$40 per unit of emissions in the EU, a region with a long-standing carbon pricing scheme that has been extensively studied in the carbon-tax literature. However, we stress that EMEs and the EU differ non-trivially in their levels of economic development. As such, when expressed in dollar terms in the model, the carbon tax in EMEs may naturally differ since emissions in the model are a function of the level of polluting-energy production, and the latter ultimately depends on the level of total output. Then, a more appropriate comparison of the carbon tax stemming from the model with existing carbon taxes in the EU is to compare the level of the carbon tax *adjusted by GDP per capita between EMEs and AEs*. Adopting this comparison suggests that the model's adjusted carbon tax for an average EME is, in fact, broadly in line with the average carbon tax in the EU.

Summary of Long Run Effects– Table 4 shows the long run effects of the carbon tax on key labor market and macroeconomic variables in the benchmark model. We also show the impact of the tax on the total measure of salaried firms, the measure and share of formal salaried firms, the contribution of formal salaried firms to total output, the share of energy producers using green technologies, the share of green energy in total energy production, and welfare.[31]

[30] Given our interest in the effects of a carbon tax, we abstract from considering market-driven reductions in the cost of green-technology inputs—one example being the cost of solar panels produced in China (Gerarden, Reguant and Xu, 2025)—in our policy analysis.

[31] Building on the macro literature, we assess the welfare effects of the policy in the steady state:

$$\mathbf{u}\left[\left(1+\frac{\Delta_W}{100}\right)c^{base},e_h^{base}\right]-\mathbf{h}\left(\text{lfp}_f^{base},\text{lfp}_i^{base},\text{lfp}_o^{base}\right)=\mathbf{u}\left(c^{\tau},e_h^{\tau}\right)-\mathbf{h}\left(\text{lfp}_{f,t}^{\tau},\text{lfp}_i^{\tau},\text{lfp}_o^{\tau}\right),$$

The carbon tax leads to a reduction in total output and consumption of roughly 0.75 and 0.50 percent, respectively. The mechanism is as follows: by generating an equilibrium increase in the price of energy of almost 11 percent, the carbon tax pushes incumbent formal and informal salaried firms to reduce their energy, labor, and capital demand, and ultimately their output.[32] The reduction in salaried labor demand is reflected in an equilibrium reduction in real wages of almost 0.35 percent. Despite this fact, total employment increases by almost 0.35 percent which, as we describe below, is driven by the increase in self-employment. By increasing incumbent firms' marginal costs, the tax also reduces expected firm profits and therefore the incentive to create new salaried firms. This is reflected in a contraction of almost 3 percent in the measure of salaried firms, which stems from a reduction in the measures of both f and i firms. Both the formal-informal composition of salaried firms—reflected in the average idiosyncratic productivity of each salaried firm category and, in turn, in the share of f firms N_f/N_s—and the economy's average salaried-firm productivity remain virtually unaffected by the carbon tax.[33] Instead, the policy-induced adjustment along the formality margin takes place via changes in (1) the composition of output and employment and (2) labor force participation. This particular finding is driven

where the superscript *base* denotes variables in the baseline (no-carbon-tax) scenario, the superscript τ denotes variables under the policy (carbon-tax) scenario, and Δ_W represents the welfare impact of the policy (expressed as a percent of steady-state consumption). If $\Delta_W > 0$, the policy generates a welfare gain. Conversely, if $\Delta_W < 0$, the policy generates a welfare loss (see Finkelstein Shapiro and Metcalf, 2023, for a similar welfare computation). Of note, this measure of welfare assumes that emissions and pollution affects households primarily via a reduction in earnings as greater pollution reduces aggregate productivity (the standard pollution externality in macro-climate models). Assuming that pollution also directly affects household utility implies that the welfare cost of the carbon tax would be somewhat smaller since a reduction in pollution bolsters household utility. However, the main model mechanisms and overall conclusions, especially regarding the role of self-employment, would remain unchanged.

[32] As shown in Table 4, the adverse effects of the carbon tax on GDP do not appear to be as dramatic given the non-trivial 25-percent reduction in carbon emissions. As we discuss further below, the fact that the contraction in GDP is not as dramatic stems partly from green technology adoption in the energy sector. Moreover, for the same reduction in emissions, the impact of a carbon tax has much larger adverse effect on total output compared to an economy without self-employment, where the absence of self-employment is in line with existing models for AEs.

[33] The fact that the share of formal salaried firms in the universe of salaried firms is unaffected is sensitive to the assumption that both formal and informal salaried firms have the same energy intensity. In EMEs, formal firms are more capital intensive and are likely to also be more energy intensive (though this energy intensity may be accompanied with greater energy efficiency as well since formal firms are able to access external finance and finance more energy-efficient technologies; given our constant-returns-to-scale assumption, this feature of formal firms is partly reflected, in a reduced-form way, in $z_f > z_i$). Assuming that salaried i firms are less intensive in energy than salaried f firms would deliver a reduction in the share of f firms in response to the carbon tax, alongside an increase in the share of self-employment as observed in our baseline model.

by the adverse impact of the carbon tax on overall salaried firm creation: in the absence of salaried firm entry, the share of i firms would increase and average salaried-firm productivity would fall (see Table A15 in Appendix E). This result highlights the relevance of accounting for salaried firm creation in the analysis of carbon taxation.

Table 4: Long Run Effects of Carbon Tax (25-Percent Reduction in Emissions)—Benchmark Model

Variable	Model Values (Levels)		Percent Change
	Baseline (No Tax)	After Tax	Relative to Baseline
Total Output	1.693	1.680	-0.747
Consumption	1.280	1.274	-0.497
Capital Investment	0.117	0.108	-7.703
Total Employment (Level)	0.579	0.581	0.343
Real Wage f	1.605	1.599	-0.343
Real Wage i	1.284	1.280	-0.340
Salaried Firms (N_s)	15.886	15.461	-2.673
f Firms (N_f)	0.575	0.560	-2.624
i Firms (N_i)	15.311	14.901	-2.674
f Ave. Idiosync. Prod. ($\widetilde{a}_s^f$)	3.346	3.345	-0.012
i Ave. Idiosync. Prod. ($\widetilde{a}_s^i$)	1.305	1.305	-0.002
Ave. Salaried Firm Prod.	0.634	0.634	0.004
Price of Energy	0.014	0.015	10.846
Welfare Gain (% Consumption)	–	-1.771	-1.771
	Model Values (Rates or Shares)		Perc.-Pt. Change
	Baseline (No Tax)	After Tax	Relative to Baseline
Share of f Firms (N_f/N_s)	3.62 %	3.62 %	0.002
Share of f Output in Total Output	70.00 %	69.25 %	-0.749
f Employment Share	54.20 %	53.21 %	-0.992
i Salaried Employment Share	9.80 %	9.60 %	-0.200
Self-Employment Share	36.00 %	37.19 %	1.192
Unemployment Rate	8.15 %	8.29 %	0.141
lfp Rate	63.00 %	63.31 %	0.313
Emissions Abate. Rate (μ_e)	0.00 %	4.09 %	4.087
Share of e Producers Using g Tech.	0.06 %	0.23 %	0.164
Share of Green Energy	16.00 %	30.70 %	14.700
Tax Revenue-Output Ratio	0.00 %	0.37 %	0.375

Notes: Average salaried firm productivity (Ave. Salaried Firm Prod.) is defined as $(N_f/N_s)\, z_f \widetilde{a}_s^f + (N_i/N_s)\, z_i \widetilde{a}_s^i$. The formal employment share, $(n_f)\,/\,(n_f + n_i + n_o)$, is the mirror image of the informal employment share. The self-employment share is defined as $(n_o)\,/\,(n_f + n_i + n_o)$. lfp is labor force participation. All real variables are expressed in data-consistent terms. Values are rounded to three decimal places.

In particular, the share of formal-sector output falls by roughly 0.75 percentage points while the share of formal (f) salaried employment in total employment falls by 1 percentage point. Note that since this share is the mirror image of the informal employment share, the

share of labor informality increases. To understand the equilibrium rise in labor informality, note that the reduction in salaried labor demand across firm categories pushes household members to increase their search for self-employment opportunities—an outside option for salaried workers—even as the rise in energy prices affects the incentive to search for employment across categories. This ultimately leads to an increase in the share of self-employment in total employment of 1.20 percentage points relative to baseline.

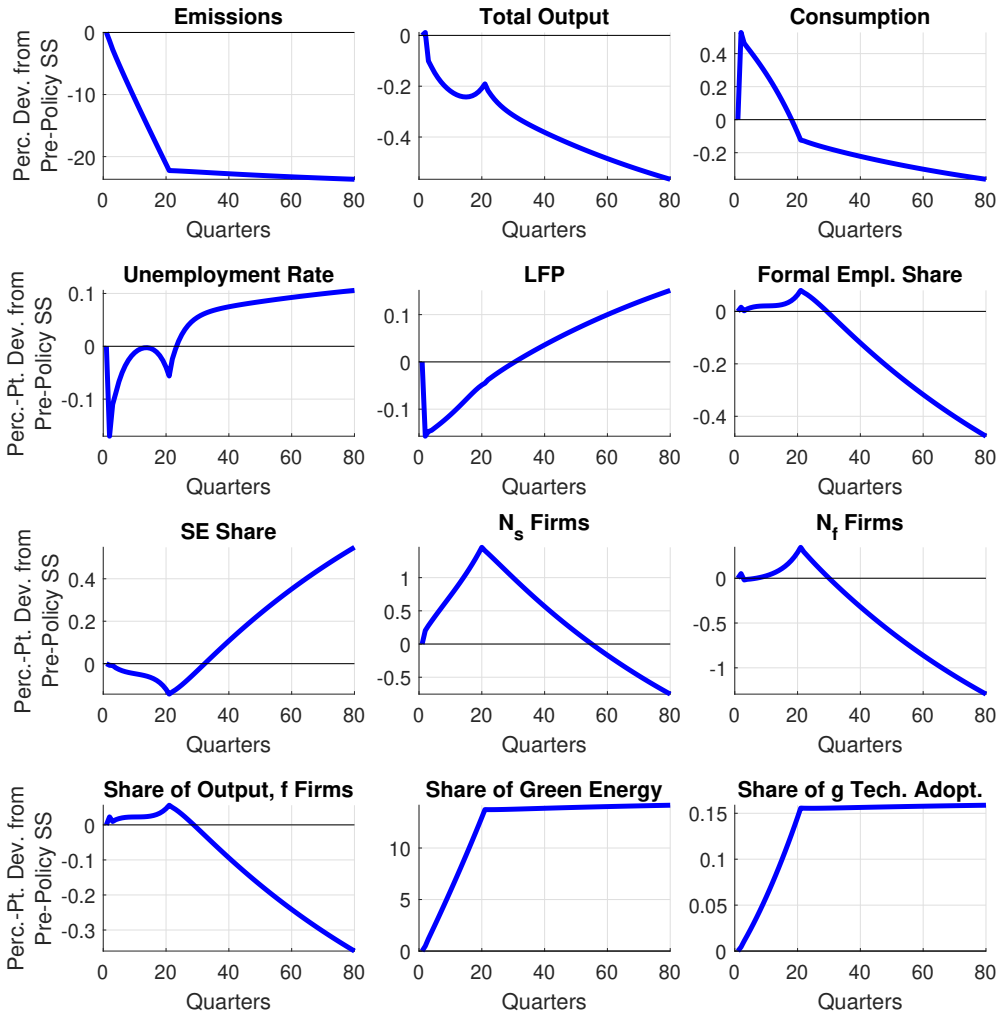
Recalling that total informal employment is the sum of self-employment n_o and informal salaried employment n_i, the increase in self-employment is the main driver of the increase in the share of total informal employment and in the level of total employment. The increase in search for self-employment opportunities and the reduction in salaried-firm hiring put upward pressure on unemployment, resulting in an increase in the unemployment rate of roughly 0.15 percentage points. The response of self-employment puts upward pressure on labor force participation as well, resulting in an increase in participation of roughly 0.30 percentage points. All told, given the carbon-tax-induced reduction in consumption and the increase in labor force participation, the carbon tax reduces steady-state welfare by almost 1.80 percent. We revisit the role of the reallocation of employment away from salaried employment and towards self-employment in shaping the aggregate effects of the carbon tax in Section 4.3.

Finally, turning to the response of the energy sector to the carbon tax, energy producers who choose the r technology incur abatement expenditures to partially offset the tax burden they face from generating emissions, which leads to an increase in the abatement rate of roughly 4 percentage points. More importantly, the tax shifts the endogenous energy-production structure towards green energy: the share of green-energy producers increases by 0.16 percentage points while the share of green energy production in total production increases by 15 percentage points (from 16 to almost 31 percent). Given the carbon tax and its impact on emissions and output, the tax revenue-output ratio increases by almost 0.40 percentage points.

Transition Path to Lower-Carbon Economy– Figure 2 plots the transition path as we increase the carbon tax gradually and in uniform steps over the course of 8 years (32

quarters) to achieve the long run reduction in emissions of 25 percent.

Figure 2: Gradual Increase in Carbon Tax and Transitional Dynamics



Notes: The formal employment share, $n_f/(n_f+n_i+n_o)$, is the mirror image of the informal employment share. The self-employment share is defined as $n_o/(n_f+n_i+n_o)$. Perc. Dev. denotes percent deviations and Perc.-Pt. Dev. denotes percentage-point deviations. The transition path is obtained by solving the full non-linear model under perfect foresight using the historical algorithm in Juillard (1996).

As the carbon tax increases, r energy producers increase their abatement expenditures and also reduce their demand for physical capital. This reduction in demand is strong enough to reduce overall physical capital investment (not shown). At the same time, the tax makes the adoption of green technologies increasingly attractive, which leads to a steady increase in both the share of green energy and the share of energy producers using the g technology. The contraction in physical capital investment frees up existing resources that can be used

for salaried firm creation and for consumption, which explains the *temporary* increase in both consumption and the measure of salaried firms for the first 5 years. As the tax reaches its long run level, these variables eventually fall back and converge to their lower long-run levels.

The reduction in capital use by r energy producers also has important implications for the labor market. Specifically, this reduction initially exerts downward pressure on the price of capital, which not only makes capital more attractive to salaried firms across both categories but also incentivizes greater salaried firm entry.[34] As more salaried firms enter and demand capital, they bolster salaried job creation, thereby reducing household members' incentive to search for self-employment opportunities that ultimately leads to a temporary reduction in the self-employment share. The decline in self-employment search is also powerful enough to generate a decline in unemployment and labor force participation. These short-term transitional dynamics highlight the importance of self-employment for the labor market and macroeconomic effects of carbon taxation in EMEs—a point that we revisit in detail in Section 4.3. Despite the initial expansion of both salaried firm categories, their output response is not strong enough to offset the decline in self-employment output. Hence the decline in total output as the carbon tax increases gradually.

Once emissions reach their lower long-run level, given the higher long-run carbon tax, r energy producers also stabilize their capital demand. Since the carbon tax causes a long-lasting drop in investment, salaried firms begin to cut back on capital and job creation, ultimately pushing household members to search for self-employment opportunities. The resulting increase in search for self-employment exerts upward pressure on labor force participation and ultimately pushes the unemployment rate above its pre carbon-tax level. These medium-term transitional dynamics end up putting downward pressure on household income and lead to a reduction in consumption and a further contraction in output. Eventually, all variables converge to the long run levels shown in Table 4. Convergence to the new steady state is slow due to the presence of frictional labor markets and the costly nature of salaried

[34]These results continue to hold even if we assume that r energy producers use a type of capital that is different from the capital that salaried production firms use. What ultimately matters is that the reduction in input demand by r energy producers frees up resources that can be allocated elsewhere, including to salaried firms.

firm creation.

The Role of Capital Adjustment Costs in the Transition– Capital adjustment costs—which embody the potential frictions associated with capital reallocation—can alter the transition path and modify the transition costs associated with the policy-induced emissions reduction above and beyond the presence of other frictions in the economy. There are no reliable empirical measures of capital adjustment costs that we can use to fully discipline these costs in the model. However, for completeness, Figure A1 in Appendix E shows the transition path in a version of the model where the capital used to produce intermediate goods faces convex adjustment costs. The presence of these costs induces a more rapid transition to the new lower-emissions steady state and therefore limits the short-term positive effects of the carbon tax on unemployment, formal firms, and formal employment shown in Figure 2. As a result, the economy experiences a more rapid increase in informality and a more rapid reduction in output along the transition path compared to an environment with no capital adjustment costs.

Robustness Analysis and Additional Experiments– We consider the following alternative calibrations and parameterizations of the benchmark model: (1) a higher baseline share of green energy in total energy; (2) higher vacancy posting costs for f firms compared to i firms; (3) a lower physical capital share and a higher energy share in the production function of both salaried firms; (4) greater baseline pollution damages as a share of GDP; (5) a higher elasticity of emissions with respect to r energy production; (6) greater producer concentration in the energy sector; (7) a higher energy share among f firms; (8) and lower and higher baseline values for the salaried-firm sunk entry cost. We also consider modified versions of the baseline model where: (9) the damages function is held constant (this allows us to focus on the costs of the carbon tax while keeping the environmental benefits of the policy, reflected in lower productivity damages, fixed); (10) the cost of becoming an f firm depends on the firm's real marginal cost and can therefore change with policy; (11) the self-employed use their own labor and energy as inputs in production alongside household energy use; (12) regular capital is used alongside green capital in the production of green

energy; (13) labor force participation is held fixed at its baseline.[35] Table A9 in Appendix E summarizes the main conclusions of our robustness analysis while results for each exercise are presented in Tables A10 through A17.

4.3 Main Economic Mechanisms

Relative to existing models for EMEs, our framework has two novel features that are important for quantifying and understanding the labor market and macroeconomic effects of carbon taxes in the energy sector in these economies. First, we endogenize the adoption of green technologies by energy producers, which makes the polluting-green (extensive-margin) structure endogenous.[36] Second, we endogenize entry into self-employment amid frictional labor markets where, consistent with evidence for EMEs and the recent literature on labor informality, self-employment is a choice and not considered as employment of last resort.

Green Technology Adoption Limits the Tax-Induced Increase in Energy Prices and its on Economic Activity– Table 5 compares the impact of the carbon tax in a version of the model where the two categories of energy producers each have a fixed measure and can adjust their inputs but they cannot change their technologies (column (1)) to the impact of the tax in the benchmark model (column (2)). In both versions, the carbon tax revenue is transferred lump-sum to the household. A comparison of columns (1) and (2) shows that, for the same reduction in emissions from the carbon tax, green technology adoption significantly limits the extent of the policy-induced quantitative increase in the price of energy. As a result, the quantitative reductions in salaried firm entry, formal firms, formal salaried employment, and total formal-firm output, and the quantitative increase in self-employment are all smaller, all of which limit the adverse effect of the tax on labor income, consumption, output, and welfare.

To illustrate the key role of green technology adoption in affecting the change in equilib-

[35] To introduce energy use in self-employment production, we assume a constant-returns-to-scale production that combines self-employment labor and energy. We assume the same energy intensity in self-employment production as salaried firms even though self-employment production is likely to be less energy intensive to show results under an upper bound for energy intensity in self-employment production.

[36] For a model that introduces an endogenous polluting-green structure in the goods sector in the context of the US, see Finkelstein Shapiro and Metcalf (2023).

rium energy prices due to the carbon tax in a clear way, Table 5 shows results for versions of the benchmark model with alternative tax-revenue recycling scenarios where, instead of transferring the carbon-tax revenue to the household—our baseline revenue-recycling assumption—the revenue is used to subsidize the fixed cost of green-technology adoption φ_g (column (3)) or the cost of green capital r_k^g (column (4)). Both scenarios lead to a larger equilibrium increase in green technology adoption and in the green energy share. This, in turn, contributes to a smaller carbon-tax-induced increase in the price of energy and in the self-employment share, and to a smaller reduction in the shares of formal employment and formal-firm output, in total output, and in welfare relative to the baseline case. Quantitatively, across the three tax-revenue-recycling scenarios, using the revenue to subsidize the cost of green technology adoption or the price of green capital delivers a similar increase in the green energy share. However, subsidizing the price of green capital bolsters green-energy production and limits the reduction in total energy output because of the tax (not shown). As a result, this revenue-recycling assumption generates the smallest increase in the price of energy across scenarios which, combined with greater green technology adoption, leads to a net increase in total output and welfare.[37]

The Response of Self-Employment Exacerbates the Adverse Macro and Welfare Effects of the Carbon Tax– As noted in the Introduction, the share of self-employment in EMEs is almost three times larger than the share in AEs. As we show next, the quantitative response of self-employment to carbon taxation has significant policy relevance for the labor market and beyond.

To highlight the importance of accounting for self-employment in the quantitative analysis of carbon taxes in EMEs, Table 6 compares the effects of a simpler version of the benchmark model that abstracts from self-employment (column (1)) and a version of the benchmark model where we hold the share of self-employment fixed at its baseline level (column (2)) to the findings in the benchmark model (column (3)).[38] Across all scenarios, we consider the

[37]Our main focus is on analyzing the labor market and aggregate effects of an increase in carbon taxes that generate a given reduction in emissions considered in policy circles. As such, we leave the analysis of optimal carbon taxes and optimal subsidy rates for green technology adoption for future work.

[38]To keep these experiments comparable, we maintain the same calibration targets as those of the benchmark model. For column (1), we simply drop the calibration target associated with the self-employment share and assign the share of self-employed individuals to be workers in salaried i firms. This guarantees

Table 5: Long Run Effects of Carbon Tax (25-Percent Reduction in Emissions) and the Role of Green Technology Adoption

Variable	No Green	Benchmark Model with Carbon Tax		
	Tech. Adopt. Choice (1)	Rev. Transfer to HH (2)	Rev. Subsid. Lower φ_g (3)	Rev. Subsid. Lower r_k^g (4)
	Percent Change Relative to Baseline			
Total Output	-1.370	-0.747	0.148	0.466
Consumption	-0.695	-0.497	-0.336	-0.170
Capital Investment	-8.222	-7.703	-7.062	-6.675
Total Employment (Level)	0.512	0.343	0.171	0.060
Real Wage f	-0.596	-0.343	0.004	0.159
Real Wage i	-0.590	-0.340	0.004	0.158
Salaried Firms (N_s)	-4.707	-2.673	0.168	1.223
f Firms (N_f)	-4.618	-2.624	0.154	1.188
i Firms (N_i)	-4.711	-2.674	0.169	1.224
f Ave. Idiosync. Prod. ($\widetilde{a}_s^f$)	-0.022	-0.012	0.003	0.008
i Ave. Idiosync. Prod. ($\widetilde{a}_s^i$)	-0.005	-0.002	0.001	0.002
Ave. Salaried Firm Prod.	0.007	0.004	-0.001	-0.003
Price of Energy	17.735	10.846	2.262	-1.093
Welfare Gain (% Consumption)	-2.846	-1.771	-0.438	0.201
	Percentage Point Change Relative to Baseline			
Share of f Firms (N_f/N_s)	0.003	0.002	-0.001	-0.001
Share of f Output in Total Output	-1.295	-0.749	-0.030	0.242
f Employment Share	-1.708	-0.992	-0.037	0.328
i Salaried Employment Share	-0.346	-0.200	-0.001	0.073
Self-Employment Share	2.054	1.192	0.038	-0.401
Unemployment Rate	0.242	0.141	0.003	-0.049
lfp Rate	0.490	0.313	0.110	0.004
Emissions Abate. Rate (μ_e)	4.908	4.087	2.616	2.704
Share of e Producers Using g Tech.	-	0.164	1.001	0.284
Share of Green Energy	9.032	14.700	22.506	22.742
Tax Revenue-Output Ratio	0.530	0.375	0.164	0.173

Notes: Average salaried firm productivity (Ave. Salaried Firm Prod.) is defined as $(N_f/N_s)\, z_f \widetilde{a}_s^f + (N_i/N_s)\, z_i \widetilde{a}_s^i$. In the absence of self-employment, the formal employment share is $(n_f)\,/\,(n_f + n_i)$. In the benchmark model, the formal employment share is $(n_f)\,/\,(n_f + n_i + n_o)$ and is the mirror image of the informal employment share. The self-employment share is defined as $(n_o)\,/\,(n_f + n_i + n_o)$. lfp is labor force participation. All real variables are expressed in data-consistent terms. Values are rounded to three decimal places.

same 25-percent reduction in emissions, where the carbon-tax revenue is transferred to the household lump-sum.

that all model versions have the same baseline share of formal employment and share of formal output in total output, among other data targets. To perform the experiment in column (2), when we increase the carbon tax, we adjust the exogenous productivity of self-employment accordingly so as to keep the share of self-employment at its baseline (pre-carbon-tax) level.

Table 6: Long Run Effects of Carbon Tax (25-Percent Reduction in Emissions), the Role of Self-Employment, and Joint Policies

Variable	Model	Benchmark Model		
	Without SE (1)	SE Share at Baseline (2)	Baseline Results (3)	Baseline Carbon Tax + Exog. $\downarrow \varphi_f$ (4)
	Percent Change Relative to Baseline			
Total Output	-0.437	-0.455	-0.747	0.240
Consumption	-0.546	-0.482	-0.497	0.189
Capital Investment	-6.675	-7.011	-7.703	-7.132
Total Employment (Level)	0.179	-0.032	0.343	-0.107
Real Wage f	-0.648	-0.603	-0.343	0.150
Real Wage i	-0.637	-0.600	-0.340	0.149
Salaried Firms (N_s)	-0.654	-0.897	-2.673	0.420
f Firms (N_f)	-0.658	-0.901	-2.624	10.044
i Firms (N_i)	-0.654	-0.897	-2.674	0.058
f Ave. Idiosync. Prod. ($\widetilde{a}_s^f$)	0.001	0.001	-0.012	-2.156
i Ave. Idiosync. Prod. ($\widetilde{a}_s^i$)	0.000	0.000	-0.002	-0.442
Ave. Salaried Firm Prod.	0.000	0.000	0.004	0.732
Price of Energy	10.436	10.475	10.846	10.242
Welfare Gain (% Consumption)	-1.093	-1.019	-1.771	0.229
	Percentage Point Change Relative to Baseline			
Share of f Firms (N_f/N_s)	0.000	0.000	0.002	0.347
Share of f Output in Total Output	-0.001	-0.116	-0.749	0.381
f Employment Share	0.003	-0.001	-0.992	0.405
i Salaried Employment Share	-0.003	0.001	-0.200	-0.275
Self-Employment Share	-	-	1.192	-0.131
Unemployment Rate	0.030	0.218	0.141	-0.018
lfp Rate	0.133	0.129	0.313	-0.080
Emissions Abate. Rate (μ_e)	4.175	4.165	4.087	4.234
Share of e Producers Using g Tech.	0.176	0.175	0.164	0.185
Share of Green Energy	15.413	15.335	14.700	15.907
Tax Revenue-Output Ratio	0.490	0.385	0.375	0.392

Notes: Average salaried firm productivity (Ave. Salaried Firm Prod.) is defined as $(N_f/N_s)\, z_f \widetilde{a}_s^f + (N_i/N_s)\, z_i \widetilde{a}_s^i$. In the absence of self-employment, the formal employment share is $(n_f)\,/\,(n_f + n_i)$. In the benchmark model, the formal employment share is $(n_f)\,/\,(n_f + n_i + n_o)$ and is the mirror image of the informal employment share. The self-employment share is defined as $(n_o)\,/\,(n_f + n_i + n_o)$. In the absence of self-employment, the formal employment share is $(n_f)\,/\,(n_f + n_i)$. All real variables are expressed in data-consistent terms. Values are rounded to three decimal places. A * denotes a targeted change.

In the absence of self-employment and for the same long-run reduction in emissions, the carbon tax has a significantly smaller adverse impact on the number of salaried firms in each category and, as a result, smaller adverse effects on total output and welfare. To understand why the presence and adjustment of self-employment amplifies the adverse effects of the carbon tax on the labor market and on total output, recall that by increasing firms'

marginal costs via higher energy prices, the carbon tax reduces the incentive of salaried firms to create jobs, thereby lowering salaried job creation, salaried-firm output, total output, and ultimately welfare. More specifically, in the benchmark model, the household responds to the reduction in salaried-job opportunities by not only reducing the measure of members searching for salaried jobs, but by redirecting these members towards searching for self-employment opportunities. This reallocation of searchers towards self-employment further reduces the potential salaried-worker pool from which salaried f and i firms can hire compared to an environment without self-employment.

This "second-round" effect on the pool of potential salaried workers, which occurs solely because of the presence and response of self-employment to the carbon tax, puts additional upward pressure on the expected marginal cost of filling a vacancy (via a reduction in the job-filling probability), thereby pushing salaried firms to reduce job creation, input demand, and production *by more relative to an environment without self-employment*. The larger reduction in salaried production ultimately contributes to a larger equilibrium reduction in total output, *even as self-employment production expands* since total self-employment output accounts for a smaller share of total output compared to total salaried output. Finally, the increase in self-employment is primarily responsible for raising overall labor force participation, which contributes to a larger reduction in welfare compared to a setting without self-employment. The results from the experiment in column (2) effectively convey the same message: when self-employment does not respond to the carbon tax—either because it is not an available margin of adjustment (column (1)) or because it is not allowed to adjust to the tax (column (2))—the output and welfare losses are considerably smaller compared to the benchmark model.[39]

A Joint Carbon-Formality Policy Can Limit The Adverse Effects of Greater Self-Employment– Given the above findings, column (4) of Table 6 presents results from a *joint policy* in the benchmark model that increases the carbon tax to achieve a long-run

[39]Yet another way of highlighting the relevance of self-employment for the output and welfare losses from the carbon tax is to consider a baseline calibration with a higher baseline probability that a household member searching for self-employment opportunities successfully transitions to self-employment. This effectively means that the self-employment outside option is more accessible for a given level of search effort. In this alternative calibration, the carbon tax generates larger output and welfare losses from the tax compared to our benchmark findings due to the larger response of self-employment to carbon taxation.

reduction in emissions of 25 percent while simultaneously lowering the cost to salaried firms of being formal, φ_f. Reducing φ_f is a natural policy to consider since it can be implemented at a relatively low cost via plausible government reforms.[40]

Before we describe this model experiment, we stress that its objective is to showcase and convey a simple but important broader message: *considering joint policies in the context of the green transition in EMEs may significantly limit the economic costs that would otherwise arise from the implementation of carbon taxes in isolation.*

With this in mind, World Bank data on the most recent changes in the average cost that firms face to become formal in our group of EMEs show a reduction in this cost of 8.35 percent. Therefore, we reduce φ_f by 8.35 percent relative to its baseline value.[41] This

[40]Existing evidence on the impact of reductions in the cost of firm registration on informality and firm outcomes recently summarized in Ohnsorge and Yu (2021) suggests that such reforms can bolster formal firm entry and reduce output informality: one benefit of firm registration to firms is access to VAT refunds, which can offset other costs associated with firm formality and may deliver net benefits for firms (greater revenue or labor productivity) that make formality more attractive. In such cases, reducing barriers to firm formality may be effective. See, for example, Klapper, Lewin and Delgado (2011); for positive effects of these reforms on employment in Mexico, see Bruhn (2011). Of course, other reforms—improved governance, more flexible labor market regulations, a reduced burden from tax compliance, and lower corporate and labor income taxes, among others—can also reduce firm informality. Some reforms, such as those that reduce corporate and labor income taxes, can be more effective than reductions in the cost of firm registration in improving firm outcomes (revenue, productivity), though unlike reforms that reduce firm entry costs, reforms that reduce taxes must balance the benefits of greater formality with the potential adverse fiscal effects if the firm productivity gains stemming from the reform are insufficient to offset the loss in government revenue.

[41]From a practical standpoint, a reduction in the cost of firm formality φ_f can be achieved by implementing reforms that cut excessive red tape, or more plausibly by implementing e-government initiatives that make use of existing digital technologies (whose adoption by firms and individuals has dramatically increased in recent years), online payment systems, and e-filing services to reduce firms' effective costs of registration and paperwork compliance (see, for example, the GovTech World Bank initiative at https://www.worldbank.org/en/programs/govtech). One important caveat with this experiment is that these reforms may work in some countries but not in others based on how regulatory barriers to firm informality interact with other barriers and frictions (for example, financial frictions and the tax regime). Our analysis does not consider these interactions, but the latter can be easily incorporated into our framework.

Focusing on our EME group and per World Bank Enterprise Survey data, the cost of business start-up procedures—which includes the cost of firm registration with local government and tax authorities, one of the costs of firm formality—ranges from a low of 0.2 percent of income per capita in South Africa to a high of 23.3 percent in the Philippines, with an EME average and median of 8 and 6.8 percent, respectively, in 2019, which is the latest year of available data (for comparison, the corresponding average cost in AEs in that year is 2.2 percent). The *average* EME cost fell by 8.35 percent between 2018 and 2019, bringing down the cost to roughly 7.3 percent of income per capita in 2019. Note that even after this reduction, the cost is still considerably higher than the average cost in AEs. In our model, becoming a formal firm gives firms access to a more productive, capital-intensive technology. This captures in a reduced-form way the benefits of firm formality stemming from access to formal credit markets, which allows firms to expand their market, adopt better technologies, and bolster firm productivity. Recent evidence suggests that reducing barriers to firm formality (by facilitating access to business registration certificates) and providing information about bank credit can increase firm sales and profits (Campos, Goldstein and McKenzie, 2023).

joint policy not only delivers the intended reduction in emissions (by construction), but as shown in column (4) of Table 6, virtually eliminates the output and welfare losses from the carbon tax, bolsters the share of formal employment, and keeps the unemployment rate from increasing. Importantly, we note that Table A21–Appendix F shows that the same policy experiment in a context where we abstract from green technology adoption still generates output and welfare losses—a result that confirms the quantitative importance of green technology adoption for limiting the adverse impact of the carbon tax.

To understand the reasons behind the net positive effects of the joint policy, note that reducing the cost of firm formality as the carbon tax is introduced limits the extent to which the tax adversely affects the cost and operating profits of incumbent salaried f firms, leading to a change in the composition of firms, employment, and economic activity away from self-employment and towards more productive, salaried f firms. Specifically, as shown in column (4), the joint policy leads to a 0.34 percentage-point *increase* in the share of salaried f firms (a modest increase relative to the magnitude of the reduction in the cost of firm formality), a 0.31 percentage-point *increase* in the share of formal employment, and a 0.34 percentage-point *increase* in the share of output from f firms (per the results from the benchmark model in column (3), all these shares fall with the carbon tax alone). At the same time, by reducing the incentive to search for self-employment opportunities, the joint policy leads to a small decline in labor force participation. Given the relatively larger weight of formal firms in total output compared to salaried i firms in the baseline (no-carbon-tax) economy, the resulting shift in the composition of employment, firms, average salaried firm productivity, and economic activity towards salaried f firms ultimately offsets the output, consumption, and welfare losses that the carbon tax alone otherwise generates, and keeps unemployment from increasing.[42]

[42]Figure A2–Appendix F plots the steady-state change of select labor market and aggregate variables for different changes in the cost of firm formality—ranging from a 5-percent increase to a roughly 13-percent reduction relative to the baseline cost—*all of which take place as the carbon tax achieves a 25-percent reduction in emissions*. Of note, the largest reduction in the cost of firm formality we consider is both plausible and reasonable in a policy context: in our EME group, the *median* reduction in the cost of business start-up procedures—which embody the cost of firm formality—between 2018 and 2019 was roughly 13 percent. For a large enough reduction in the cost of firm formality introduced jointly with the carbon tax—under the baseline model calibration, the carbon-tax-induced reduction in emissions may be accompanied by a clear *increase* in output, welfare, the share of formal employment, the measures of f firms and total salaried firms, and by a *reduction* in the share of self-employment. Of course, our analysis abstracts from

Finally, for completeness, Figure A3–Appendix F shows the transition path for this joint policy while Figure A4 shows a version with capital adjustment costs. A key takeaway from the transition path is that a policy that combines a carbon tax with a reduction in the cost of firm formality can foster greater employment and firm formality and significantly limit—and in some cases fully offset—the economic and welfare losses associated with the transition to a lower-carbon economy, even if the transition takes place amid capital adjustment costs.

5 Conclusion

We study the labor market and macroeconomic effects of climate policies in emerging economies (EMEs) in a framework with pollution externalities from energy production, labor search frictions, endogenous self-employment and salaried firm entry, and firm selection into formality that captures the distinct employment and firm structure of EMEs vis-á-vis advanced economies (AEs). Focusing on the energy sector as the source of harmful carbon emissions that can be taxed, our framework features energy producers that can choose to adopt polluting or green technologies. This choice endogenizes the share of energy producers that adopt green technologies and, more broadly, the technological (polluting-green) composition of energy production.

Focusing on a carbon tax on carbon emissions from the production of polluting energy, we first show that the carbon tax bolsters green technology adoption and increases the share of green energy in the total energy mix, but also leads to higher energy prices that reduce energy demand by firms and households. In doing so, the carbon tax reduces the overall number of salaried firms, the number of formal firms and salaried job creation, and the share of formal employment, and generates an increase in self-employment and in unemployment. From an aggregate standpoint, the policy reduces consumption, GDP, and welfare, and increases labor informality via greater self-employment. Based on these baseline results, we show that energy producers' ability to adopt green technologies significantly limits the adverse effects

the fact that policymakers may be constrained in their ability to significantly reduce the cost of formality for reasons that are beyond the scope of our work. Our joint-policy experiment merely points to a plausible way to offset the adverse effects of carbon taxes via reforms that several EMEs have been considering to promote firm formality.

of the carbon tax on labor markets, firms, and aggregate economic activity. Critically, we also highlight how the carbon-tax-induced increase in self-employment—a core component of the labor market structure of EMEs—plays an important role in amplifying the adverse effects of the carbon tax on labor market and macroeconomic outcomes.

Given this last finding, we show that achieving the targeted reduction in emissions with a carbon tax need not generate output and welfare losses under a joint policy that combines the carbon tax with an empirically-plausible reduction in the cost of firm formality. The results from this joint policy suggest a way in which EMEs may be able to exploit joint policies in order to promote a carbon tax-based transition to a low-carbon economy with minimal short- and long-term economic costs. While our framework captures key features of the employment and firm structure of EMEs, it abstracts from household heterogeneity and imperfect risk sharing. Given the asymmetric effect that carbon taxation has on salaried and self-employment, a carbon tax is likely to have non-trivial heterogeneous welfare effects across households. More research is needed to assess the quantitative magnitude of these effects.

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