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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 search and matching macro model with pollution externalities from energy production, endogenous green-technology adoption, and salaried-firm entry that incorporates two key elements of the employment and firm structure of these economies: salaried labor and firm informality and self-employment. Calibrating the model to emerging-economy data, we show that a carbon tax increases green-technology adoption and the share of green energy, but also leads to higher energy prices. As a result, the tax reduces salaried firm creation, the number of formal firms, and formal employment, and leads to an increase in self-employment, labor participation, and unemployment—a response that generates long run output and welfare losses. Green-technology adoption limits while self-employment exacerbates the quantitative magnitude of these losses. A joint policy that combines a carbon tax with a reduction in the cost of firm formality can offset the adverse effects of the tax and generate a transition to a lower-carbon economy with minimal economic costs.

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1 Introduction

We study the labor market and macroeconomic effects of a carbon tax and climate policies in the energy sector in emerging economies (EMEs). According to WEO (2022), EMEs face greater climate-driven risk and potential losses and need to join advanced economies in reducing their carbon dioxide emissions in order to successfully limit the costs and damages from climate change.[1] Indeed, the combined annual carbon dioxide emissions of EMEs represent almost 10 percent of global annual emissions, making this group of economies the largest carbon dioxide emitter after China, the United States, and the group of EU-28 countries. In the last twenty years, the contribution of EMEs to global GDP has remained roughly unchanged but their contribution to global carbon emissions has continued to rise. Moreover, in contrast to advanced economies which decoupled their economic growth from emissions in the mid-2000s, economic growth in EMEs continues to be associated with growing emissions (Figure 1 in Section 2).

The adoption of existing green technologies to produce clean energy is seen as an important pathway to reduce emissions. Greater adoption can be fostered with a carbon tax, a policy that is gaining significant interest and traction in policy circles, and that has nontrivial revenue potential (Pigato *et al.*, 2020; World Bank, 2020; IFC, 2021; Timilsina, 2022, Table 1 in section 2). However, a key concern behind the implementation of these policies is their impact on employment, economic activity, and overall growth potential. This concern is deepened in EMEs, which have a distinct employment and firm structure that already limits their growth potential—a structure characterized by high barriers to firm formality, large shares of (informal) self-employment and informal (unregistered) firms amid weak safety nets, and large productivity differentials between formal and informal firms that ultimately translate into lower aggregate productivity (La Porta and Shleifer, 2014; Ulyssea, 2018). Carbon taxation and climate policies may exacerbate these growth barriers and, in doing so, further raise the potential costs associated with the transition to a low-carbon environment.

[1] 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.

What We Do Against this backdrop, we build a general equilibrium labor search and matching model with negative pollution externalities from energy production, labor force participation and self-employment entry, and endogenous salaried-firm creation and selection into formality that captures the employment and firm structure of EMEs. A central element of our model is the inclusion of a green-technology adoption margin whereby energy producers, which supply energy to firms and households, choose between a regular (polluting) or green (emissions-free) production technology amid fixed costs of green-technology adoption. This margin endogenizes the share of energy producers that use green technologies and allows the technological structure of energy production to react to changes in policy and structural factors. In turn, the inclusion of labor frictions is needed to explicitly analyze the impact of climate policies on unemployment and labor force participation—two central elements of the labor market that are at the core of climate policy discussions surrounding the labor market.[2]

We calibrate the model to match the average formal-informal composition of employment, firms, and economic activity, and the polluting-green energy mix using data on a well known group of EMEs. Focusing our baseline quantitative analysis on the average EME as opposed to a specific EME allows us to highlight the core economic mechanisms of the model and dissect the role of informality, where the latter is a defining characteristic of economic activity *across* EMEs. Using the baseline EME calibration as a starting point, we first analyze the transition and long-run effects of a carbon tax on emissions from polluting energy producers that reduces long-run emissions by 25 percent—a reduction that is in line with the carbon policy scenarios considered by WEO (2022). We then compare the effects of the tax to those of alternative climate policies that generate the same long-run reduction in emissions as the tax by lowering the effective costs of green-technology adoption and green-energy inputs. As part of our quantitative analysis, we conduct a battery of robustness experiments, including alternative baseline calibrations of the model to specific EMEs.

Main Findings Our quantitative analysis delivers four results. First, in the long run, the carbon tax increases the share of green energy and the share of energy producers that use

[2] See Ulyssea (2018) for a framework focusing on salaried-firm informality and firm dynamics that abstracts from labor market (unemployment) dynamics and self-employment.

green technologies. Despite the policy-induced shift in the technological structure of energy towards green technologies, the tax has a strong-enough adverse impact on polluting energy producers so as to generate higher energy prices in the new equilibrium.[3] Since energy is an input in production, the increase in energy prices reduces new salaried-firm creation, the numbers of both total salaried firms and formal firms. The adverse impact of the carbon tax on salaried firms reduces salaried job creation and the share of formal employment as formal firms are more sensitive to the increase in energy prices. Amid lower salaried-job opportunities, households shift their members' job search towards self-employment opportunities, leading to greater self-employment entry and production. The carbon tax therefore shifts the composition of employment and production towards greater self-employment. As a result, the tax ultimately reduces consumption, GDP, and welfare, it increases the unemployment rate, and it raises informality (mainly via greater self-employment). Even though the tax generates long-term output and welfare losses, 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 suppresses the price of capital for salaried firms.

Second, energy producers' ability to adopt green technologies plays a critical role in significantly limiting the long-term adverse effects of the carbon tax. Abstracting from this margin while retaining the presence of polluting and green energy—that is, having representative polluting and green energy producers *without* the choice to change production technologies—implies that the output and welfare losses are almost twice as large. Thus, green technology adoption is a fundamental margin that significantly limits the economic and welfare costs of the tax.

Third, the policy-induced increase in self-employment—an employment category that lies at the core of EME labor markets—is an important factor shaping the output and welfare losses from the tax: the reallocation of resources away from more productive salaried

[3]In recent work, Känzig (2023) uses data from the European carbon market to show that carbon pricing leads to higher energy prices and spurs more green innovation.

(formal and informal) firms and towards less productive self-employment exacerbates the reduction in total output that would otherwise take place. In turn, the increase in search for self-employment opportunities amid lower salaried job creation bolsters total labor force participation, which reduces welfare. A counterfactual experiment that abstracts from self-employment shows that in the long run, the increase in self-employment generates output and welfare losses from the carbon tax that are roughly 60 percent greater relative to a model without self-employment. These findings highlight the quantitative role of self-employment in shaping the aggregate effects of carbon taxation and suggest that existing macro-labor-environmental models for advanced economies, which abstract from self-employment, may not provide an accurate quantitative assessment of the labor market and aggregate effects of carbon taxation in an EME context.

Finally, given this third result, we consider a joint policy combining a carbon tax that lowers long-run emissions by 25 percent with a data-disciplined reduction in the (regulatory) cost of becoming a formal firm. This joint policy effectively eliminates 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 if the joint policy also yields higher equilibrium energy prices*. The reason behind this result is simple: the (data-disciplined) reduction in the cost of firm formality amid a carbon tax fosters greater salaried-firm entry and leads to an equilibrium net increase in the number of formal firms and in the overall number of salaried (formal and informal) firms. In turn, these firms generate more salaried jobs, which bolsters formal employment and limits the extent to which individuals would 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 limits the increase in labor force participation that the carbon tax alone would induce via greater self-employment, ultimately delivering small output and welfare gains. Critically, these gains materialize only if energy producers have the choice to adopt green technologies: without an active green-technology adoption margin, the joint policy still generates non-trivial output and welfare losses because the reduction in the cost of firm formality is not strong enough to offset the tax's adverse impact on salaried-firms' entry and hiring decisions stemming from higher energy prices. More broadly, this experiment points to a low-cost and plausible policy that EMEs can implement alongside carbon taxation in order to foster a transition to a lower-carbon economy with minimal short- and long-term economic costs.

Related Literature Our work is closest to the literature on the labor market and macroeconomic consequences of climate policies using quantitative macroeconomic models and the macro-climate literature on technology adoption, both of which have focused primarily on advanced economies.[4] Studies that go beyond these economies and incorporate key features that characterize EMEs into standard macro-climate models are relatively scarce.

Bento *et al.* (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. Intriago and MacDonald (2022) build a framework where informal workers can work in the

[4] For empirical evidence on the employment and macroeconomic consequences of carbon taxes in advanced economies, 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 *et al.* (2018). For two-country (US-Europe) models, see Annicchiarico and Diluiso (2019) and Pagliari and Ferrari Minesso (2021). For two-sector models with representative polluting-green firms and equilibrium unemployment applied to the US, see Hafstead and Williams (2018) and Fernandez Intriago (2020). Aubert and Chiroleu-Assouline (2019) and Hafstead and Williams (2021) consider the distributional effects of environmental policy on US workers. Castellanos and Heutel (2019) 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) and Fried (2018a). For work on the choice over energy technologies amid carbon taxes and climate policies, see Mano *et al.* (2021) and Adao *et al.* (2022), 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.1 provides a more extensive review of these advanced-economy studies. Taking a cross-country focus, Fried (2018b) 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.

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 *et al.* (2021) show that a country's production and worker skill structure plays an important role in shaping the distributional and aggregate effects of the tax.

Our work contributes to the existing literature in three ways. First, given our framework, 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 limiting the adverse labor market and aggregate effects of a carbon tax and other climate policies focused on green energy and technology. Second, our analysis considers both the long-run effects of carbon taxes and climate policies and the transition path to a lower-carbon environment. Finally, in an environment with endogenous labor force participation where self-employment is a choice (Maloney, 2004), we show that the response of this core employment category in EMEs plays a central role in shaping the labor market, welfare, and aggregate effects of climate policies.

The rest of the paper is structured as follows. Section 2 summarizes key facts on the employment and firm structure in EMEs, select characteristics of the energy mix, estimated damages from climate change, the presence of carbon policies, and the reliance of EMEs on existing green technologies from advanced economies. Section 3 describes the model. Section 4 presents our quantitative findings and discusses the main economic mechanisms behind. Section 5 concludes.

2 Key Facts and Motivation for Model Structure

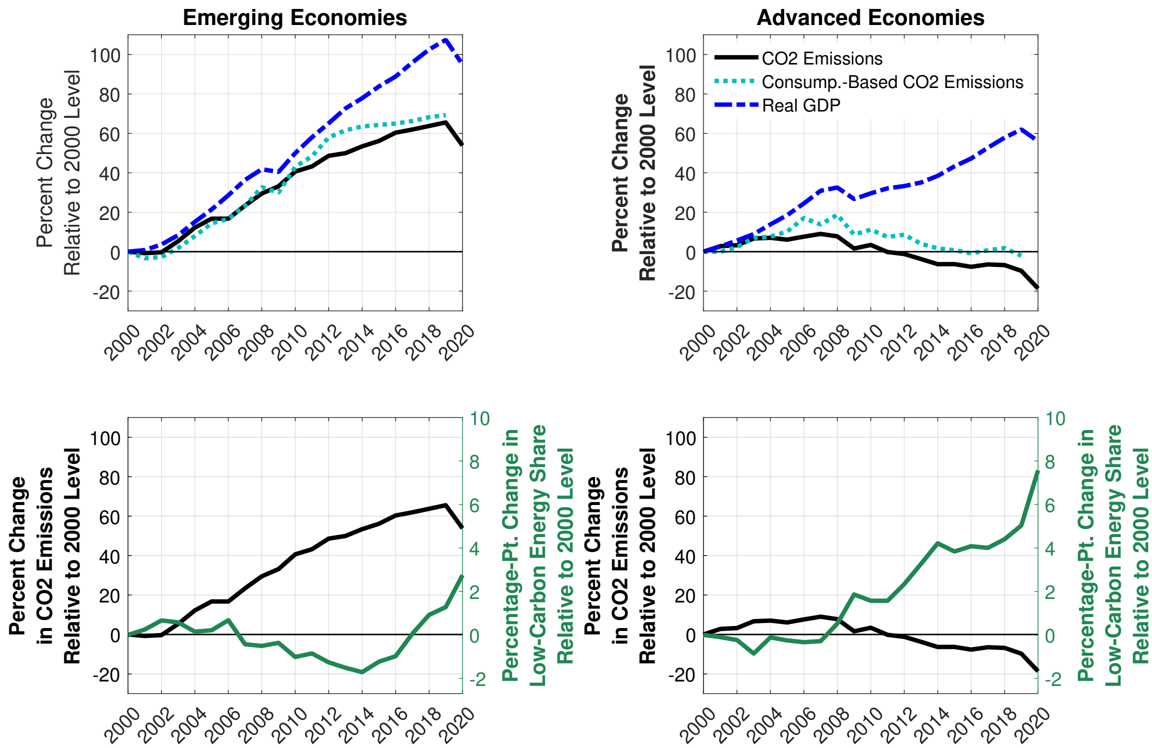
We focus on a group of 12 small open EMEs comprised of: Argentina, Brazil, Chile, Colombia, Indonesia, Malaysia, Mexico, Peru, the Philippines, South Africa, Thailand, and Turkey. These economies are at the center of much of the EME literature; they are much smaller than other EMEs like China and India; and they share a general employment and firm structure that distinguishes them from advanced economies. At the same time, these EMEs differ from lower income economies by having significantly smaller shares of agricultural employment and production, which we abstract from modeling. More broadly, excluding large economies, these 12 EMEs are responsible for the bulk of carbon emissions in their respective regions.[5]

Carbon Emissions and Economic Activity in EMEs Figure 1 shows that in the last 20 years, advanced economies experienced a decoupling of their economic growth from growth in their carbon emissions, with this decoupling becoming entrenched in 2010 and continuing onward (left panel of Figure 1). In contrast, during the same time period, carbon emissions in EMEs continued to increase more or less in lockstep with economic growth (right panel of Figure 1).[6] The right axis of each panel in Figure 1 (shown in dark green) plots the percentage-point change in the share of low-carbon energy relative to year 2000.

[5] For example, in Africa, South Africa is the largest emitter of carbon dioxide. In Asia, Indonesia, Thailand, and Malaysia—all three of which are small open economies—emit the most carbon dioxide after China, India, and Japan. In North and South America combined, Argentina, Brazil, Chile, Mexico, and Peru emit the most carbon dioxide after the US and Canada (Global Carbon Project).

[6] These facts hold even if we consider consumption-based measures of carbon emissions, which adjust for the potential offshoring of pollution-generating production in these economies. Figure A1 in Appendix A.2 presents similar evidence when emissions and real GDP are expressed in per capita terms. See Ritchie (2021) for a summary of the link between economic growth and carbon emissions.

Figure 1: Growth in Carbon Dioxide Emissions Economic Activity, and Green Energy Shares—Advanced Economies vs. Emerging Economies



Sources: Data from World Bank and Global Carbon Project via Our World in Data (https://ourworldindata.org/co2-gdp-decoupling, https://ourworldindata.org/grapher/low-carbon-share-energy). **Note:** Each variable represents the average of that variable in each country group (Emerging or Advanced). Real GDP is expressed in PPP Constant 2017 international dollars. Consump.-Based CO2 Emissions denotes consumption-based CO2 emissions, which are adjusted for trade and therefore for production offshoring (series available until 2019). Low-carbon energy is given by the sum of renewables (hydropower, wind, solar, bioenergy, geothermal, wave and tidal) and nuclear energy. The group of advanced economies is comprised of: Australia, Austria, Belgium, Bulgaria, Canada, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Latvia, Lithuania, Luxembourg, Malta, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Singapore, Slovakia, Slovenia, South Korea, Spain, Sweden, Switzerland, United Kingdom, and the United States.

The clear decoupling between economic growth and emissions in advanced economies starting in 2010 coincides with a consistent increase in these economies' share of low-carbon energy—a trend that is partly rooted in the development and adoption of green technologies. In 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, when the share of low-carbon energy finally surpasses its year-2000 level and exhibits an upward trajectory as EMEs continue to adopt green energy technologies.[7]

Employment and Firm Structure, Energy Sources, and Carbon Policies in EMEs Table 1 compares the average employment and firm structure, composition of energy sources, and stance of current carbon policies of EMEs to that of advanced economies (see Tables A1, A2, and A3 in Appendix A.2 for disaggregated data on these characteristics for each EME in our sample). In particular, Table 1 shows that in EMEs:

1. Self-employment—most of which is categorized as informal—accounts for almost 40 percent of total employment (vs. 14 percent in advanced economies);

2. 72 percent of micro, small, and medium enterprises (MSMEs) are informal (vs. 31 percent in advanced economies), where MSMEs account for 95 percent of all firms;[8]

3. Fossil fuels (coal, gas, and oil) represent almost 83 percent of current energy sources and 63 percent of current electricity sources (vs. 73 percent and 39 percent, respectively, in advanced economies);

4. An increase in temperature of $3°C$ is estimated to reduce GDP in EMEs by an average of 3.7 percent (vs. a 0.70 percent *increase* in advanced economies, driven by tourism; (Roson and Sartori, 2016);

5. Low-carbon technology products are a source of comparative disadvantage (vs. a source of comparative advantage in advanced economies);

6. The share of greenhouse gas emissions that are subject to a positive carbon price, and the carbon price itself, are significantly lower than in advanced economies;

[7]For empirical evidence on the link between environmental policies and innovation in renewable energy, see Bettarelli *et al.* (2023). For evidence on green technology adoption and specific examples of such adoption in EMEs, see World Bank (2023) and United Nations (2023).

[8]Following the International Labour Organization (ILO), informal employment is defined as employment that is not covered, or weakly covered, by labor laws and regulations and social protection schemes. Micro firms are generally defined as having fewer than 10 workers; small firms are generally defined as having between 10 and 50 workers. Formal firms are defined as firms that are registered with their local tax or government authorities. Tables A1, A2, and A3 in Appendix A.2 show each of these characteristics for each of the 12 EMEs we focus on.

7. Carbon reforms that reduce fossil-fuel subsidies and increase carbon prices have 3 times as much revenue potential as similar reforms in advanced economies.

Table 1: Differences between Emerging Economies vs. Advanced Economies—Employment and Firm Structure, Energy Sources, and Carbon Policies

	EME Average	AE Average
1. Employment and Firm Structure		
Self-Employment (% of Total Empl.)	36.4	13.8
Informal MSMEs (% of All MSMEs)*	71.6	30.8
Informal Sector Size (% of GDP)	33.0	17.9
2. Energy Sources, Climate Damages, Low-Carbon Tech.		
Share of Energy from Fossil Fuels (% of Equiv. Primary Energy)	82.5	72.5
Share of Electricity from Fossil Fuels (% of Total Electricity)	62.5	39.2
Impact of 3°C Increase on GDP (% of GDP)	-3.69	0.69
Comparative Advantage in Low-Carbon Tech. Products (Index)	0.51	0.95
3. Carbon Policies		
Share of GHG Emissions Subject to Positive Price (% of Em.)	13.5	53.0
Average Effective Carbon Prices (EUR per tCO2e)	0.46	24.6
Current Carbon Tax Revenue Estimates (% of GDP)	0.04	0.14
Current Net Energy Tax Revenue Estimates (% of GDP)	0.63	1.75
Revenue Potential from Carbon Reforms (% of GDP)	3.70	1.02

Sources: World Bank World Development Indicators, IFC Enterprise Finance Gap 2010, IFC MSME Economic Indicators 2019, Elgin *et al.* (2021)**;** Our World in Data (https://ourworldindata.org/energy-mix), IMF Climate Change Dashboard (https://climatedata.imf.org/), and Roson and Sartori (2016); Figures 2.12, 2.4, 2.8, and 3.1 in OECD (2022). **Note:** Advanced Economies (AEs): Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Japan, Latvia, Lithuania, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Singapore, Slovakia, Slovenia, Spain, Sweden, Switzerland, United Kingdom, and the United States. **1.**MSMEs denotes micro, small, and medium enterprises. The definition of micro and small firms differs across economies, but in general micro firms are defined as firms with fewer than 10 workers while firms are defined as firms having between 10 and 50 workers. Informal firms are defined as firms that are not registered with their local tax authorities. *The latest available data on informal firms is from the 2010 IFC Enterprise Finance Gap database, which relies on census data (collected every 10 years) for several EMEs. The data on self-employment shares is for 2019. Similar facts hold with data for 2010, 2016, 2017. The data on informal sector size is for 2018 (latest observation) **2.** Equivalent primary energy is obtained by using the substitution method. Non-fossil-fuel energy is comprised of renewables and nuclear power. Non-fossil-fuel electricity is comprised of hydro, solar, wind, nuclear, and other renewables. All data are for 2019 unless otherwise noted. Similar facts hold with data for 2020 and 2021. **3.** GHG denotes greenhouse gas. Net energy tax revenue estimates are computed using information on fuel excise revenues, carbon tax revenues, ETS revenues, electricity excise revenues, fossil fuel subsidies, and electricity subsidies. Revenue potential from carbon reforms refers specifically to the potential revenue raised from reforms to fossil fuel subsidies and carbon prices.

The large shares of self-employment and informal firms are particularly relevant from a macroeconomic standpoint given the presence of large productivity differentials between formal and informal firms, which ultimately shape aggregate productivity (La Porta and Shleifer, 2014; Amin and Okou, 2019). Moreover, self-employment only captures one facet of labor informality in EMEs: total informal employment, which considers both self-employed and informal salaried workers, represents more than 50 percent of total employment. Turning to the composition of energy sources, as discussed in Pigato *et al.* (2020), advanced economies have been responsible for the bulk of innovation, development, production, and exports of low-carbon technologies for the last 15 years.[9] As such, any near-term progress by EMEs in increasing their share of green energy and decoupling carbon emissions from their economic growth is likely to rely on (imported) low-carbon technologies from advanced economies and less so on the domestic development and production of these technologies.

Motivated by the EME facts in Table 1, we build a search and matching model with firm entry, endogenous salaried-firm and -employment heterogeneity based on formality status, self-employment, and an energy-production sector where the polluting-green composition of energy production is endogenous and the production of green energy depends on green-technology-specific capital (this capital is meant to reflect its (imported) non-generic nature compared to more standard physical capital).

3 The Model

In what follows, we describe the baseline model and relegate a discussion of alternative assumptions and their implications for our main findings to Section 4.2.4.

The economy is closed and comprised of production firms, households, and energy producers. The labor market features search and matching frictions and endogenous labor force participation. Total output is a composite of output from two categories of production firms:

[9] Advanced economies tend to have a relative advantage in the development of low-carbon technology products. This is confirmed by the IMF Climate Change Dashboard index of comparative advantage in exporting low-carbon technology products, where a value below 1 can be interpreted as a relative disadvantage in the export potential of these products. Advanced economies have an average index of 0.95 (with at least 7 out of 39 advanced economies having an index above 1) while EMEs have an average index of 0.51. See Glachant *et al.* (2013) for related evidence on climate innovation across countries, low-carbon patent inflows, and capital-goods imports in EMEs and Dussaux *et al.* (2017) on the importance of intellectual property rights for the transfer of low-carbon technologies from advanced economies to EMEs.

salaried firms and self-employed (owner-only) firms.

Salaried firms are monopolistically competitive and their entry is endogenous and subject to sunk entry costs as in Bilbiie *et al.* (2012).[10] Based on their productivity upon entry, they choose between two available production technologies. Both technologies use salaried labor (subject to search frictions), physical capital, and energy as inputs, but one technology has higher exogenous productivity and is more capital intensive. However, its adoption is subject to a fixed cost. Only firms with productivity above an endogenous threshold pay the fixed cost to adopt the more productive and capital-intensive technology, where the fixed cost embodies the registration cost that firms must incur to operate formally. This set of firms and their salaried workers are therefore labeled as formal. Salaried firms with productivity below the threshold choose the less productive and capital-intensive technology. This set of firms and their salaried workers are labeled as informal. The choice over formality generates endogenous productivity differentials between formal and informal firms, which is a salient feature of informality.[11]

A representative household derives utility from consuming goods and energy and disutility from its members' participation in the labor market. It makes labor force participation decisions by choosing its members' search behavior across three employment categories: salaried employment in informal firms, salaried employment in formal firms, and self-employment. As such, the creation of self-employed (owner-only) firms is endogenous and equivalent to sending individuals to self-employment. As a baseline, self-employed firms use owner-supplied labor as their sole input.

There is a fixed measure of monopolistically competitive energy producers that use physical capital to produce. Based on their productivity, they choose between two available

[10] For seminal models of firm dynamics with endogenous firm exit, see Hopenhayn (1992) and Hopenhayn and Rogerson (1993).

[11] See Amin and Okou (2019). Productivity and technology differentials between formal and informal firms are also the most relevant features for analyzing the macroeconomic implications of firm formality. Incorporating other relevant aspects that characterize formal firms and employment—payroll and profit/revenue taxation, firing costs, and other compliance, enforcement, and regulatory costs associated with being formal—does not change any of our model mechanisms or findings. Additional characteristics of firm formality that we abstract from for tractability include improved access to formal finance and basic legal/institutional protections, both of which facilitate greater investment in capital or more cutting-edge technologies and improve firm productivity. In this sense, access to a more productive, capital-intensive technology in the model embodies these factors in a reduced-form way.

production technologies. Those with productivity below an endogenous threshold choose to adopt a regular technology that generates harmful carbon dioxide emissions as a by-product. These emissions add to the economy's stock of pollution, which in turn generates damages through reduced aggregate productivity for production firms and energy producers, where these damages are taken as given (a negative environmental externality).[12] Energy producers using this technology face a carbon tax on their emissions and can reduce their carbon-tax burden without changing technologies by incurring abatement expenditures.

Energy producers with productivity above the threshold incur a fixed cost and choose to adopt a green (emissions-free) production technology. Since this technology does not generate emissions, it is not subject to the carbon tax. This energy production structure makes the polluting-green technological composition of energy—and therefore the possibility of a technological transition to a low-carbon economy—endogenous.[13] The energy produced by each endogenous energy-producer category is aggregated and supplied to households and production firms as an aggregate energy bundle.

The literature on informality often considers labor and income taxation as one of several factors that shape the breadth of firm and labor informality. Conditional on keeping labor and income tax rates unchanged, introducing these taxes only changes the levels of select variables in the baseline calibration of the model but does not alter the impact of carbon policies in our framework, where these policies are the main focus of our analysis. As such, we abstract from incorporating these taxes and focus only on carbon taxation.

3.1 Production Structure

3.1.1 Total Output

Total output is given by $Y_t = \left[Y_{s,t}^{\frac{\phi_y - 1}{\phi_y}} + Y_{o,t}^{\frac{\phi_y - 1}{\phi_y}} \right]^{\frac{\phi_y}{\phi_y - 1}}$, where $Y_{s,t}$ is the total output of salaried firms, $Y_{o,t}$ is the total output of self-employed (or own-account) firms, and $\phi_y > 1$ dictates

[12]Following the most common modeling approach in the environmental-macro literature, we assume that pollution affects the economy by reducing aggregate productivity. An alternative approach is to assume that pollution negatively affects household utility (a reduced-form way of capturing the adverse health effects of pollution on household welfare). Assuming that pollution affects household utility delivers the same general conclusions.

[13]See Finkelstein Shapiro and Metcalf (2023) for a US-focused framework without energy production where the endogenous polluting-green technological composition is present at the goods-production level.

the substitutability between $Y_{s,t}$ and $Y_{o,t}$. Writing $\Pi_{y,t} = [P_t Y_t - P_{s,t} Y_{s,t} - P_{o,t} Y_{o,t}]$ 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 $p_{o,t} \equiv P_{o,t}/P_t$, and the aggregate price index can be expressed as $1 = \left[p_{s,t}^{1-\phi_y} + p_{o,t}^{1-\phi_y}\right]^{\frac{1}{1-\phi_y}}$.

3.1.2 Salaried Production

For expositional clarity only, we assume that a representative intermediate-goods producer uses salaried workers, physical capital, and energy to produce two categories of intermediate goods: one is produced with a more productive and more capital-intensive technology while the other is produced with a less productive and less capital-intensive technology. Hiring salaried workers for each technology entails posting costly job vacancies. Depending on their idiosyncratic productivity upon entry, salaried firms decide whether to incur a fixed cost and use intermediate goods produced with the more productive technology or to use intermediate goods produced with the other technology at no additional cost. Using intermediate goods produced with a given technology is equivalent to adopting that technology.[14]

Consistent with the mapping between technology adoption by salaried firms and formality status noted at the beginning of Section 3, we denote the inputs, prices, intermediate goods, and salaried firms associated with the more productive technology with subscript f for formal and those associated with the less productive technology with subscript i for informal.

Intermediate Goods Production The representative intermediate-goods producer chooses job vacancies $v_{j,t}$, desired salaried employment $n_{j,t}$, physical capital demand $k_{j,t}$, and energy

[14] The separation between intermediate goods producers and firms that use these intermediate goods as inputs is *purely expositional* and follows the separation that is often adopted in New Keynesian models, where labor/capital/input decisions are made by intermediate-goods producers while pricing decisions are made by firms that use these intermediate goods as inputs. As is well known from this literature, merging intermediate-goods producers and the firms using these goods as inputs into a single problem delivers *the exact same equilibrium conditions* as those from the setting that separates the two firm problems. The separation we adopt allows to describe technology choices and input choices in a clearer way. We adopt a similar separation when describing the problem of energy producers in Section 3.1.3 below.

demand $e_{j,t}$ for each category $j \in \{f, i\}$ to maximize $\sum_{t=0}^{\infty} \Xi_{t|0}\Pi_{s,t}$ subject to

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

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

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

where $\Xi_{t|0}$ is the household's stochastic discount factor (defined in Section 3.2 below). $H(n_{f,t}, k_{f,t}, e_{f,t})$ and $F(n_{i,t}, k_{i,t}, e_{i,t})$ are constant-returns-to-scale production functions associated with the f and i technologies, respectively, and $z_{f,t}$ and $z_{i,t}$ are the respective exogenous productivity levels. We assume that $z_f > z_i$ and that $H(\cdot)$ is more capital intensive than $F(\cdot)$. Following the macro-climate literature, $D(x_t)$ is a 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 with common real price $r_{k,t}$, and the real price of energy $\rho_{e,t}$ is the same across the two categories.[16] 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 are characterized by standard job

[15] See Kalkuhl and Wenz (2020) for recent 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 productivity growth.

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

creation conditions for each category of salaried employment:

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

and

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

by standard 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 $mc_{f,t}D(x_t)z_{f,t}H_{e_f,t} = \rho_{e,t}$ and $mc_{i,t}D(x_t)z_{i,t}F_{e_i,t} = \rho_{e,t}$, which equate the marginal benefit of a unit of energy to the real price of energy.

Salaried Firms: Profits and Technology Choices There is an endogenous measure of monopolistically competitive salaried firms whose entry is subject to sunk costs. In the general spirit of Ghironi and Melitz (2005), a given 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 between individual firm output.

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 and for notational simplicity, we denote a given salaried firm ζ by its idiosyncratic productivity a_s.

Salaried firms with idiosyncratic productivity a_s below the endogenous threshold $\overline{a}_{s,t}$ use intermediate goods i to produce—that is, they adopt the i production technology and are therefore categorized as informal. Their individual real profits are given by

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

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, salaried firms with idiosyncratic productivity $a_s \geq \overline{a}_{s,t}$ use intermediate goods f to produce—that is, they adopt the f production technology and are therefore categorized as formal. Using these intermediate goods entails a fixed cost $\varphi_f > 0$. Their individual real profits are given by

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

where $\rho^f_{s,t}(a_s)$ is the real output price of firm a_s using the f technology and $mc_{f,t}/a_s$ is the effective real marginal cost.

Noting that the demand function for firm a_s's output operating in category $j \in \{f, i\}$ 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 j is $\rho^j_{s,t}(a_s) = (\varepsilon/\left(\varepsilon - 1\right))\left(mc_{j,t}/a_s\right)$. 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.

Salaried-Firm Evolution and Salaried-Firm Averages Denoting the number of new salaried firms by $A_{s,t}$ and the number of active salaried firms by $N_{s,t}$, the evolution of salaried firms is given by $N_{s,t} = (1 - \delta_s)\left(N_{s,t-1} + A_{s,t-1}\right)$. 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 $N_{f,t} = \left[1 - G(\overline{a}_{s,t})\right] N_{s,t}$, respectively.

The average idiosyncratic productivities of each category of salaried firms are given by $\widetilde{a}^i_{s,t} = \left[\frac{1}{G(\overline{a}_{s,t})}\int_{a^s_{min}}^{\overline{a}_{s,t}} a_s^{\varepsilon-1} dG(a_s)\right]^{\frac{1}{\varepsilon-1}}$ and $\widetilde{a}^f_{s,t} = \left[\left(\frac{1}{1-G(\overline{a}_{s,t})}\right)\int_{\overline{a}_{s,t}}^{\infty} a_s^{\varepsilon-1} dG(a_s)\right]^{\frac{1}{\varepsilon-1}}$. Then, we define the following average prices and quantities: $\widetilde{\rho}^i_{s,t} = \rho^i_{s,t}(\widetilde{a}^i_{s,t})$, $\widetilde{\rho}^f_{s,t} = \rho^f_{s,t}(\widetilde{a}^f_{s,t})$, $\widetilde{y}_{i,t} = y_{i,t}(\widetilde{a}^i_{s,t})$, and $\widetilde{y}_{f,t} = y_{f,t}(\widetilde{a}^f_{s,t})$. Finally, we can define average real salaried-firm profits as $\widetilde{\pi}_{s,t} = \left(N_{i,t}/N_{s,t}\right)\pi_{i,t}(\widetilde{a}^i_{s,t}) + \left(N_{f,t}/N_{s,t}\right)\pi_{f,t}(\widetilde{a}^f_{s,t})$.

3.1.3 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 $[a^e_{min}, \infty)$. The production of energy, which is used by salaried firms and households, is based on a constant-returns-to-scale production function that uses physical capital.[17] Energy producers choose to adopt one of two available

[17]ILO data shows that employment in the energy sector in EMEs represents only between 0.6 and 1.2 percent of total employment depending on the economic activities included in the sector's definition. Given

production technologies based on their idiosyncratic productivity: a regular (r) polluting technology that generates harmful carbon dioxide emissions as a byproduct of producing energy, or a green (g) technology that produces green (emissions-free) energy.

The use of the r technology is subject to a carbon tax $\tau_{e,t}$ on the emissions generated, but energy producers using the r technology can abate a portion of these emissions by incurring convex abatement costs. In contrast, the use of the g technology is not subject to the carbon tax but its adoption entails a fixed 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 g technology while the remaining energy producers use the r technology. Moreover, while the r technology uses the same physical capital that salaried firms use, the g technology relies on physical capital that is specific to the g technology and whose real price is assumed to be exogenous.[18]

Total Energy Production The total amount of energy produced is given by $E_t = \left(\int_{a^e_{min}}^{\infty} e_t(a_e)^{\frac{\varepsilon_e - 1}{\varepsilon_e}} da_e\right)^{\frac{\varepsilon_e}{\varepsilon_e - 1}}$ 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 $\overline{a}_{e,t}$, 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 the r and the g technology, respectively. 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, note that we can write the nominal price of total

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 in the energy sector. 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 advanced economies via imports given advanced economies' 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. Assuming that the price of green capital $k^g_{e,t}$ changes with its demand, 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.

energy as $P_{e,t} = \left(\int_{a^e_{min}}^{\bar{a}_{e,t}} p^r_{e,t}(a_e)^{1-\varepsilon_e} da_e + \int_{\bar{a}_{e,t}}^{\infty} p^g_{e,t}(a_e)^{1-\varepsilon_e} da_e \right)^{\frac{1}{1-\varepsilon_e}}$, where $p^r_{e,t}(a_e)$ and $p^g_{e,t}(a_e)$ denote the nominal prices of energy producers using 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 $\rho_{e,t} \equiv P_{e,t}/P_t$.

For expositional clarity only and similar to the description of salaried firms, we separate the description of energy producers into two parts: the energy production process—which includes the generation of harmful emissions, their taxation, and their potential abatement—and the pricing and technology adoption decisions of energy producers.

Energy Production and 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. Real profits from the production of these intermediate energy inputs are given by

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

where $mc^r_{e,t}$ is the real price of the intermediate energy input produced with the r technology, $z^r_{e,t}$ is an exogenous productivity parameter, $k^r_{e,t}$ 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 an exogenous productivity parameter, $k^g_{e,t}$ is the physical capital used to produce g intermediate energy inputs, and $r^g_{k,t}$ is the real price of capital $k^g_{e,t}$. As noted earlier, the price $r^g_{k,t}$ is assumed to be exogenous. Similar to salaried firms, pollution damages $D(x_t)$ also affect the production of intermediate energy inputs and are taken as given by energy-input producers.

Following the macro-climate literature, the total cost of abatement is $\Gamma_t = \gamma \mu^\eta_{e,t} D(x_t) z^r_{e,t} k^r_{e,t}$, where μ_t is the endogenous abatement rate, $\gamma > 0$, and $\eta > 1$ (Heutel, 2012; Annicchiarico and Di Dio, 2015). In turn, emissions net of abatement are given by $em_t = (1 - \mu_{e,t}) \left[D(x_t) z_t k^r_{e,t} \right]^{1-\nu_e}$, where $0 < \nu_e \leq 1$. Finally, emissions add to the pollution stock

$x_t = \rho_x x_{t-1} + em_t + em_t^{row}$, where $0 < \rho_x < 1$ determines the persistence of past pollution and em_t^{row} denotes 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

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

an optimal emissions abatement decision

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

and a demand condition for capital associated with the r technology

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

Energy Producer Profits, Technology Choices, and Optimal Pricing Turning to energy producers, if energy producer a_e uses the r technology, its individual real profits are given by

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

If producer a_e uses the 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 respective effective real marginal costs. It follows that an energy producer a_e is indifferent between the two technologies if $\pi_{e,t}^r(\overline{a}_{e,t}) = \pi_{e,t}^g(\overline{a}_{e,t})$, where $\overline{a}_{e,t}$ is the endogenous idiosyncratic productivity level above which the energy producer decides to adopt the g technology. Noting that the individual energy producers' demand functions for each technology category are given by $e_{r,t}(a_e) = \left(\rho_{e,t}^r(a_e)/\rho_{e,t}\right)^{-\varepsilon_e} E_t$ and $e_{g,t}(a_e) = \left(\rho_{e,t}^g(a_e)/\rho_{e,t}\right)^{-\varepsilon_e} E_t$, it follows that the optimal relative prices of energy for each category are $\rho_{e,t}^r(a_e) = (\varepsilon_e/(\varepsilon_e - 1))\left(mc_{e,t}^r/a_e\right)$

and $\rho^g_{e,t}(a_e) = (\varepsilon_e/(\varepsilon_e - 1))\left(mc^g_{e,t}/a_e\right)$.

Average Productivities and Total Energy Production The average idiosyncratic productivities of each category of energy producers are $\widetilde{a}^r_{e,t} = \left[\frac{1}{G(\overline{a}_{e,t})}\int_{a^e_{min}}^{\overline{a}_{e,t}} a_e^{\varepsilon_e - 1} dG(a_e)\right]^{\frac{1}{\varepsilon_e - 1}}$ and $\widetilde{a}^g_{e,t} = \left[\left(\frac{1}{1-G(\overline{a}_{e,t})}\right)\int_{\overline{a}_{e,t}}^{\infty} a_e^{\varepsilon_e - 1} dG(a_e)\right]^{\frac{1}{\varepsilon_e - 1}}$. We define $\widetilde{\rho}^r_{e,t} = \rho^r_{e,t}(\widetilde{a}^r_{e,t})$, $\widetilde{\rho}^g_{e,t} = \rho^g_{e,t}(\widetilde{a}^g_{e,t})$, $\widetilde{e}_{r,t} = e_{r,t}(\widetilde{a}^r_{e,t})$, $\widetilde{e}_{g,t} = e_{g,t}(\widetilde{a}^g_{e,t})$, $\widetilde{\pi}^r_{e,t} = \pi^r_{e,t}(\widetilde{a}^r_{e,t})$, and $\widetilde{\pi}^g_{e,t} = \pi^g_{e,t}(\widetilde{a}^g_{e,t})$. Finally, we can write average total energy production E_t as

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

and the average real price of total energy $\rho_{e,t}$ as

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

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. For future reference, we denote average total energy producers' profits by $\widetilde{\pi}_{e,t} \equiv G(\overline{a}_{e,t})\widetilde{\pi}^r_{e,t} + (1 - G(\overline{a}_{e,t}))\,\widetilde{\pi}^g_{e,t}$.

3.2 Households and Self-Employment

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

Formally, the household chooses consumption c_t,energy $e_{h,t}$, 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 $s_{i,t}$, and the measure of searchers for self-employment, $s_{o,t}$, as well as the associated desired measures of workers in those three categories, $n_{f,t}$, $n_{i,t}$, and $n_{o,t}$, to maximize $\sum_{t=0}^{\infty}\beta^t\left[\mathbf{u}(c_t,e_{h,t})-\mathbf{h}(lfp_{f,t},lfp_{i,t},lfp_{o,t})\right]$ subject to the budget constraint

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

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

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

and the evolution of salaried firms

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

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 $\mathbf{h}(lfp_{f,t},lfp_{i,t},lfp_{o,t})$ 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.[19]

[19] Given the very nature of self-employment—there are no firms demanding labor, only labor supply used to produce goods in owner-only firms—we do not model matching externalities in self-employment. 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. We do not explicitly model these frictions for model tractability and note that our results would not change if we model frictions associated with input

In the household's disutility of labor market participation, $lfp_{f,t} = n_{f,t} + (1 - \varrho_{f,t})\, s_{f,t}$, $lfp_{i,t} = n_{i,t} + (1 - \varrho_{i,t})\, s_{i,t}$, and $lfp_{o,t} = n_{o,t} + (1 - \phi_o)\, s_{o,t}$ 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 $lfp_t = lfp_{f,t} + lfp_{i,t} + lfp_{o,t}$ and we can define the total unemployment rate as $ur_t = \left((1 - \varrho_{f,t})\, s_{f,t} + (1 - \varrho_{i,t})\, s_{i,t} + (1 - \phi_o)\, s_{o,t}\right) / lfp_t$.

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, $\mathbf{u}_{e_h,t} = \rho_{e,t}\mathbf{u}_{c,t}$, by standard optimal salaried firm creation and physical capital accumulation conditions

$$\varphi_s = (1 - \delta_s)\Xi_{t+1|t}\left[\widetilde{\pi}_{s,t+1} + \varphi_s\right] \quad \text{and} \quad 1 = \Xi_{t+1|t}\left[r_{k,t+1} + (1 - \delta)\right], \tag{11}$$

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

$$\frac{\mathbf{h}_{lfp_{j,t}}}{\mathbf{u}_{c,t}} = \varrho_{j,t}\left[w_{j,t} + (1 - \rho_s)\Xi_{t+1|t}\left(\frac{1 - \varrho_{j,t+1}}{\varrho_{j,t+1}}\right)\left(\frac{\mathbf{h}_{lfp_{j,t+1}}}{\mathbf{u}_{c,t+1}}\right)\right], \tag{12}$$

and by an optimal labor force participation decision for self-employment

$$\frac{\mathbf{h}_{lfp_{o,t}}}{\mathbf{u}_{c,t}} = \phi_o\left[p_{o,t}D(x_t)z_{o,t} + (1 - \rho_o)\Xi_{t+1|t}\left(\frac{1 - \phi_o}{\phi_o}\right)\left(\frac{\mathbf{h}_{lfp_{o,t+1}}}{\mathbf{u}_{c,t+1}}\right)\right], \tag{13}$$

where $\Xi_{t+1|t} \equiv \beta\mathbf{u}_{c,t+1}/\mathbf{u}_{c,t}$ is the household's stochastic discount factor. The labor force participation 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. Even though we abstract from energy as a production input in self-employment, note that changes in the price of energy can affect the decision to search for self-employment opportunities via changes in the marginal utility of consumption (especially if c_t and $e_{h,t}$ are complements).

access (for an example of such frictions, see Finkelstein Shapiro, 2018).

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 given by $\varrho_{j,t} = \varrho(\theta_{j,t}) = m(s_{j,t}, v_{j,t})/s_{j,t}$ and $q_{j,t} = q(\theta_{j,t}) = m(s_{j,t}, v_{j,t})/v_{j,t}$, respectively, where market tightness is $\theta_{j,t} = v_{j,t}/s_{j,t}$.

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. It is straightforward to show that the real wage for formal salaried workers is

$$w_{f,t} = \nu_n \left(mc_{f,t} D(x_t) z_{f,t} H_{n_f,t} + (1 - \rho_s) \mathbb{E}_t \Xi_{t+1|t} \psi_f \theta_{f,t+1} \right), \tag{14}$$

and the real wage for informal salaried workers is

$$w_{i,t} = \nu_n \left(mc_{i,t} D(x_t) z_{i,t} F_{n_i,t} + (1 - \rho_s) \mathbb{E}_t \Xi_{t+1|t} \psi_i \theta_{i,t+1} \right). \tag{15}$$

3.4 Market Clearing

As a baseline, we assume that the carbon-tax revenue is transferred lump-sum to households. Thus, the government budget constraint is $T_t = \tau_{e,t} em_t$. Following Ghironi and Melitz (2005) and related literature, we focus on a symmetric equilibrium. Market clearing in the two salaried-firm categories is given by

$$D(x_t) z_{f,t} H(n_{f,t}, k_{f,t}, e_{f,t}) = N_{f,t} \left(\frac{\widetilde{y}_{f,t}}{\widetilde{a}^f_{s,t}} \right) \quad \text{and} \quad D(x_t) z_{i,t} F(n_{i,t}, k_{i,t}, e_{i,t}) = N_{i,t} \left(\frac{\widetilde{y}_{i,t}}{\widetilde{a}^i_{s,t}} \right). \tag{16}$$

Similarly, market clearing in the energy sector is given by

$$D(x_t) z^r_{e,t} k^r_{e,t} = G(\overline{a}_{e,t}) \left(\frac{\widetilde{e}_{r,t}}{\widetilde{a}^r_{e,t}} \right) \quad \text{and} \quad D(x_t) z^g_{e,t} k^g_{e,t} = [1 - G(\overline{a}_{e,t})] \left(\frac{\widetilde{e}_{g,t}}{\widetilde{a}^g_{e,t}} \right). \tag{17}$$

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 is therefore not included as part of k_t. Finally, the resource constraint is

$$Y_t = c_t + inv_t + \psi_f v_{f,t} + \psi_i v_{i,t} + \varphi_s A_{s,t} + \varphi_f N_{f,t} + \varphi_e \left[1 - G(\overline{a}_{e,t})\right] + \Gamma_t + r_{k,t}^g k_{e,t}^g, \qquad (18)$$

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, and the cost of capital used in the g technology are all resource costs.

4 Quantitative Analysis

The presence of a variety effect in models with endogenous firm or product 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 (Bilbiie *et al.*, 2012). Following the 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 A.4 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 to an average EME. Conclusions from an extensive robustness analysis (including alternative baseline calibrations to specific EMEs) are summarized in Section 4.2.4.

Functional Forms Household utility from consumption is $\mathbf{u}(c_t, e_{h,t}) = \frac{\left((c_t)^{1-\sigma_e}\left(e_{h,t}\right)^{\sigma_e}\right)^{1-\sigma_c}}{1-\sigma_c}$. The disutility from participation is $\mathbf{h}\left(lfp_{f,t}, lfp_{i,t}, lfp_{o,t}\right) = \frac{\left[\kappa_f(lfp_{f,t})+\kappa_i(lfp_{i,t})+\kappa_o(lfp_{o,t})\right]^{1+1/\chi_n}}{1+1/\chi_n}$, where $0 < \sigma_e < 1$, σ_c,$\kappa_f, \kappa_i, \kappa_o > 0$, and $\chi_n > 0$ shapes the elasticity of labor force participation. 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 *et al.*, 2000). Intermediate-goods producers use Cobb-Douglas production functions $H(n_{f,t}, k_{f,t}, e_{f,t}) = (n_{f,t})^{1-\alpha_f-\alpha_e}(k_{f,t})^{\alpha_f}(e_{f,t})^{\alpha_e}$ and $F(n_{i,t}, k_{i,t}, e_{i,t}) = (n_{i,t})^{1-\alpha_i-\alpha_e}(k_{i,t})^{\alpha_i}(e_{i,t})^{\alpha_e}$, where $0 < \alpha_f + \alpha_e < 1$ and $0 < \alpha_i + \alpha_e < 1$. Recall that intermediate energy inputs are produced using a production function that is linear in 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 modeling approach of pollution damages and abatement expenditures in the macro-climate literature and for comparability with related models, the damages function is $D(x_t) = exp\left[-D_0(x_t - \overline{x})\right]$ 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.[20] 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 *et al.*, 2018).

Parameters from Literature 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 $z_e^r = z_e^g = 1$.[21] 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,

[20] See Cai and Lontzek (2019) and Hambel *et al.* (2021) for the relevance of convexities in the damages function.

[21] 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.

the majority of the capital stock is held by f firms (see, for example, Busso *et al.*, 2012). As a baseline, the energy share in salaried-firm production is $\alpha_e = 0.05$ (see, for example, Adao *et al.*, 2022). 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 for these economies, 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 labor force participation $\phi_n = 0.26$, 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 $k_p^e > \varepsilon_e - 1$.[22] Our main findings remain unchanged if we consider alternative values. 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 $a_{min}^s = 1$ and $a_{min}^e = 1$. We also set the sunk entry cost faced by salaried firms to $\varphi_s = 1$ (calibrating this parameter does not change our conclusions; see Table A14 of Appendix A.7).

Turning to the parameters associated with the environmental side of the model, we set the carbon tax $\tau_e = 0$ as a baseline since most EMEs do not have a nationwide carbon tax. Absent specific estimates for EMEs, we borrow parameter values from existing literature as part of our baseline calibration and conduct robustness checks to confirm that our main conclusions are not driven by the baseline calibration. Specifically, we set the elasticity parameter in the abatement cost function $\eta = 2.8$ (see Nordhaus, 2008) and assume a weight of $\gamma = 1$ in the abatement cost function ((see, for example, Hafstead and Williams, 2018). 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)

[22]Existing evidence suggests that the elasticity of substitution between polluting and green energy inputs is greater than 1 (see, for example, Papageorgiou *et al.*, 2017). Table A12 of Appendix A.7 shows that our main results are robust to alternative values for the Pareto parameters.

and the persistence of the pollution stock to $\rho_x = 0.9979$ (Heutel, 2012). Finally, we set $D_1 = 0.6983$, which represents the ratio of the level of carbon dioxide 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 carbon dioxide, which enters the pollution damages function $D(x_t)$ (Annicchiarico *et al.*, 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_k^g, and $\bar{x}$ are calibrated to match a set of first-moment targets based on averages for the 12 EMEs we focused on in Section 2. These averages are obtained using the latest available data for our EME group or related empirical studies on EMEs.

The data 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 GDP of 1.25 percent (Roson and Sartori, 2016);[23] 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 spread between the effective cost of using the g technology per unit of green capital k_e^g and the per-unit cost of using regular capital k_e^r of 6 percent (Steffen, 2020);[24] a ratio of carbon dioxide emissions from the rest of the world to total world emissions of 0.90 (Global Carbon Project); an average labor force participation 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

[23] These costs are at the lower end of what more recent studies document (see, for example, Kalkuhl and Wenz, 2020).

[24] More specifically, given the presence of a fixed cost of operating the g technology and the cost of capital k_e^g, the effective cost of using the g technology *per unit of green capital* k_e^g is $(r_k^g + \varphi_e/k_e^g)$ while the capital rental rate for regular capital k_e^r is r_k. In our model, r_k also represents the riskless real interest rate of the economy. Based on the availability of data for EMEs, our target for the spread between these two costs is based on the cost of solar (renewable energy) projects relative to LIBOR (see Steffen, 2020, for more details).

in total energy production of 0.84 (IEA); and the condition that $\bar{x} = D_1 x$ where D_1 was set earlier and x is the steady-state stock of pollution.

The resulting parameter values that match these targets are: $\sigma_e = 0.0139$, $D_0 = 0.0000034434$, $\psi_f (= \psi_i) = 0.1487$, $\varphi_f = 0.3586$, $\varphi_e = 0.0363$, $em^{row} = 22.5967$, $\kappa_f = 1.2450$, $\kappa_i = 0.9902$, $\kappa_o = 1.0543$, $\xi = 0.3937$, $z_i = 0.4697$,$z_o = 2.5252$, $r_k^g = 0.0377$, and $\bar{x} = 8348.3$. Table A4 in Appendix A.5 summarizes the baseline calibration of the model. Of note, given the endogenous productivity components of f and i firms $\widetilde{a}_s^f$ and $\widetilde{a}_s^i$, the overall average productivity of f firms ($z_f \widetilde{a}_s^f$) is greater than the overall productivity of both informal salaried firms ($z_i \widetilde{a}_s^i$) and self-employed individuals (z_o). This calibration outcome is 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.

4.2 The Long-Run and Transition Effects of a Carbon Tax

We characterize the long run (steady state) changes and the transition path of the economy in response to a carbon tax that reduces emissions by 25 percent relative to their baseline level. This reduction in emissions is in line with the climate policy experiments in WEO (2022) (of course, the model can be used to consider more ambitious reductions, including a a target of net-zero emissions). Then, we dissect the main forces and mechanisms behind our findings in Section 4.3. In doing so, we highlight (1) the quantitative role of green technology adoption and green energy, (2) the relevance of self-employment, salaried firm creation, and the composition of salaried firms; and (3) the potential benefits of joint policies and alternative climate policies.

4.2.1 Long Run Effects

Carbon Tax Level in the Model A simple back of the envelope calculation suggests that the carbon tax in the model represents roughly 6 US dollars per unit of emissions. At first sight, this number may seem exceedingly low compared to the average carbon tax of roughly 40 dollars per unit of emissions in the European Union, the most extensively studied region of the world with a well-established and long-standing carbon pricing scheme.

However, a more accurate comparison of the carbon tax level stemming from the model to existing carbon taxes in advanced economies is to consider the level of the carbon tax per unit of emissions as a share of GDP per capita: this approach takes into account the fact that EMEs have lower levels of real GDP per capita compared to the European Union and other advanced economies and, as such, EMEs should not be expected to sustain the same carbon price (in dollar terms) per unit of emissions. This alternative comparison suggests that the carbon tax as a share of real GDP per capita in the model is broadly in line with the average carbon tax (also as a share of average real GDP per capita) in the European Union.

Summary of Main Results Table 2 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, formal salaried firms' contribution to total output, the share of energy producers using green technologies, the share of green energy in total energy production, and welfare.[25]

The carbon tax leads to a reduction in total output and consumption of roughly 0.85 and 0.50 percent, respectively. Indeed, by generating an equilibrium increase in the price of energy of almost 12 percent, the carbon tax pushes formal and informal salaried firms to reduce their energy, labor, and capital demand, and ultimately their output.[26] The reduction

[25]We assess the welfare effects of the policy in the steady state by using the following expression:

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

where the superscript *base* denotes variables in the baseline (no-carbon-tax) scenario, the superscript τ denotes variables under the policy (carbon-tax) scenario, and Δ represents the welfare impact of the policy (expressed as a percent of steady-state consumption). If $\Delta > 0$, the policy generates a welfare gain. Conversely, if $\Delta < 0$, the policy generates a welfare loss (see Finkelstein Shapiro and Metcalf, 2023, for a similar computation of welfare). 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 conclusions would remain unchanged.

[26]As shown in Table 2, 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. The magnitude of the policy-induced reduction in GDP amid a significant reduction in emissions is in line with existing studies, which have focused on advanced

in salaried labor demand is reflected in an equilibrium reduction in real wages of almost 0.50 percent. Despite this fact, total employment increases by almost 0.50 percent which, as we describe below, is driven by self-employment. The tax also reduces the incentive to create new salaried firms, which is reflected in a contraction of almost 3 percent in the measure of salaried firms stemming from a reduction in the measures of both f and i firms. Surprisingly, 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 both remain virtually unaffected by the carbon tax. 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 by the adverse impact of the carbon tax on overall salaried firm creation: in the absence of salaried firm entry, the share of i salaried firms would increase and average salaried-firm productivity would fall (see Table A13 in Appendix A.7). This result highlights the relevance of accounting for salaried firm creation in the analysis of carbon taxation.

In particular, the share of formal-sector output falls by roughly 0.70 percentage points while the share of formal (f) salaried employment in total employment falls by more than 1 percentage point. Given that this share is the mirror image of the informal employment share, 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. This ultimately leads to an increase in the share of self-employment in total employment of 1.3 percentage points.

economies, that consider similar quantitative reductions in emissions (see, for example, Annicchiarico *et al.*, 2018). Of note, this does *not* mean that EMEs and advanced economies exhibit the same reduction in GDP in response to a carbon tax: as we discuss in our analysis further below, the impact of a carbon tax has a larger adverse effect on EMEs compared to advanced economies, with one element of the larger reduction in GDP in EMEs tracing back to the prevalence of self-employment in these economies.

Table 2: 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	1.716	1.701	-0.857
Consumption	1.284	1.277	-0.491
Capital Investment	0.130	0.117	-9.467
Total Employment (Level)	0.579	0.581	0.417
Real Wage f	1.627	1.620	-0.402
Real Wage i	1.302	1.296	-0.398
Salaried Firms (N_s)	16.813	16.327	-2.888
f Firms (N_f)	0.570	0.554	-2.751
i Firms (N_i)	16.056	15.116	-5.859
f Ave. Idiosync. Prod. $\left(\widetilde{a}_s^f\right)$	3.400	3.398	-0.034
i Ave. Idiosync. Prod. $\left(\widetilde{a}_s^i\right)$	1.310	1.309	-0.007
Ave. Salaried Firm Prod.	0.709	0.710	0.008
Price of Energy	0.011	0.012	11.628
Welfare Gain (% of Consumption)	–	–	-1.848
	Model Values (Rates or Shares)		**Perc.-Pt. Change**
	Baseline (No Tax)	**After Tax**	Relative to Baseline
Share of f Firms (N_f/N_s)	3.39%	3.39%	0.005
Share of f Output in Total Output	70.00%	69.27%	-0.732
f Employment Share	54.20%	53.15%	-1.047
i Salaried Employment Share	9.80%	9.55%	-0.250
Self-Employment Share	36.00%	37.30%	1.297
Unemployment Rate	8.15%	8.30%	0.153
LFP Rate	63.00%	63.37%	0.368
Emissions Abate. Rate (μ_e)	0.00%	3.46%	3.461
Share of e Producers Using g Tech.	1.03%	4.69%	3.666
Share of Green Energy	16.00%	33.51%	17.515
Tax Revenue-Output Ratio	0.00%	0.14%	0.144

Note: 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.

Recalling that total informal employment is defined as the sum of self-employment n_o and informal salaried employment n_i, the increase in self-employment is therefore the main driver of the increase in the share of total informal employment and, in turn, in the level of total employment.[27] The increase in search for self-employment opportunities and the reduction in salaried-firm hiring both put upward pressure on unemployment, resulting in an increase in the unemployment rate of roughly 0.15 percentage points. Finally, the response of self-employment puts upward pressure on labor force participation as well, resulting in an increase in participation of almost 0.40 percentage points. All told, given the carbon-tax-induced reduction in consumption and increase in labor force participation, the carbon tax reduces steady-state welfare by 1.85 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 3.5 percentage points. More importantly, the tax shifts the endogenous energy-production structure towards green energy: the share of green-energy producers increases by almost 4 percentage points (from 1 percent to almost 5 percent) while the share of green energy production in total production increases by 18 percentage points (from 16 percent to almost 34 percent). Given the carbon tax and its impact on emissions and output, the tax revenue-output ratio increases by almost 0.15 percentage points.

4.2.2 Empirical Validation of Model: Growth in Carbon Emissions and Changes in Self-Employment Share

The results in Table 2 suggest that a reduction in carbon emissions is associated with an increase in the share of self-employment in EMEs. While the reduction in emissions in the model is induced by raising the carbon tax—that is, by a change in policy—the same negative relationship between emissions and self-employment arises when we consider a change in

[27] Even though we assume that the self-employed do not use energy as an input in production, the costs and benefits of searching for self-employment opportunities are influenced by changes in energy prices via households' choices over energy consumption. In particular, given that goods consumption and energy are complements, a change in household energy consumption shapes the marginal utility of consumption $\mathbf{u}_{c,t}$, thereby affecting self-employment participation decisions (see equation (13)). As summarized in Section 4.2.4, assuming that the self-employed also use energy in production does not change the main model mechanisms and delivers the same broad conclusions as our benchmark model.

emissions that stems from changes in non-policy structural parameters.

To show this explicitly, Table A5 in Appendix A.6 shows the relationship between a 10-percent reduction in steady-state emissions and the change in the steady-state self-employment share when the reduction in emissions stems from the carbon tax and when the reduction in emissions stems from a reduction in the exogenous productivity of r energy producers.[28] In both cases, the share of self-employment increases. Moreover, Table A5 shows that when we hold output growth constant, the negative relationship between the change in emissions and the change in the self-employment share becomes quantitatively weaker. Section a. of Table A6 in Appendix A.6 shows results from a simple panel regression with country and time fixed effects using annual data from 2000 to 2019 for the set of EMEs in Section 2. The table confirms a significant negative relationship between the growth of emissions and the change in the self-employment share. Furthermore, when we control for the growth of real GDP per capita, this relationship becomes considerably weaker. Both empirical findings are consistent with the model's predictions.[29]

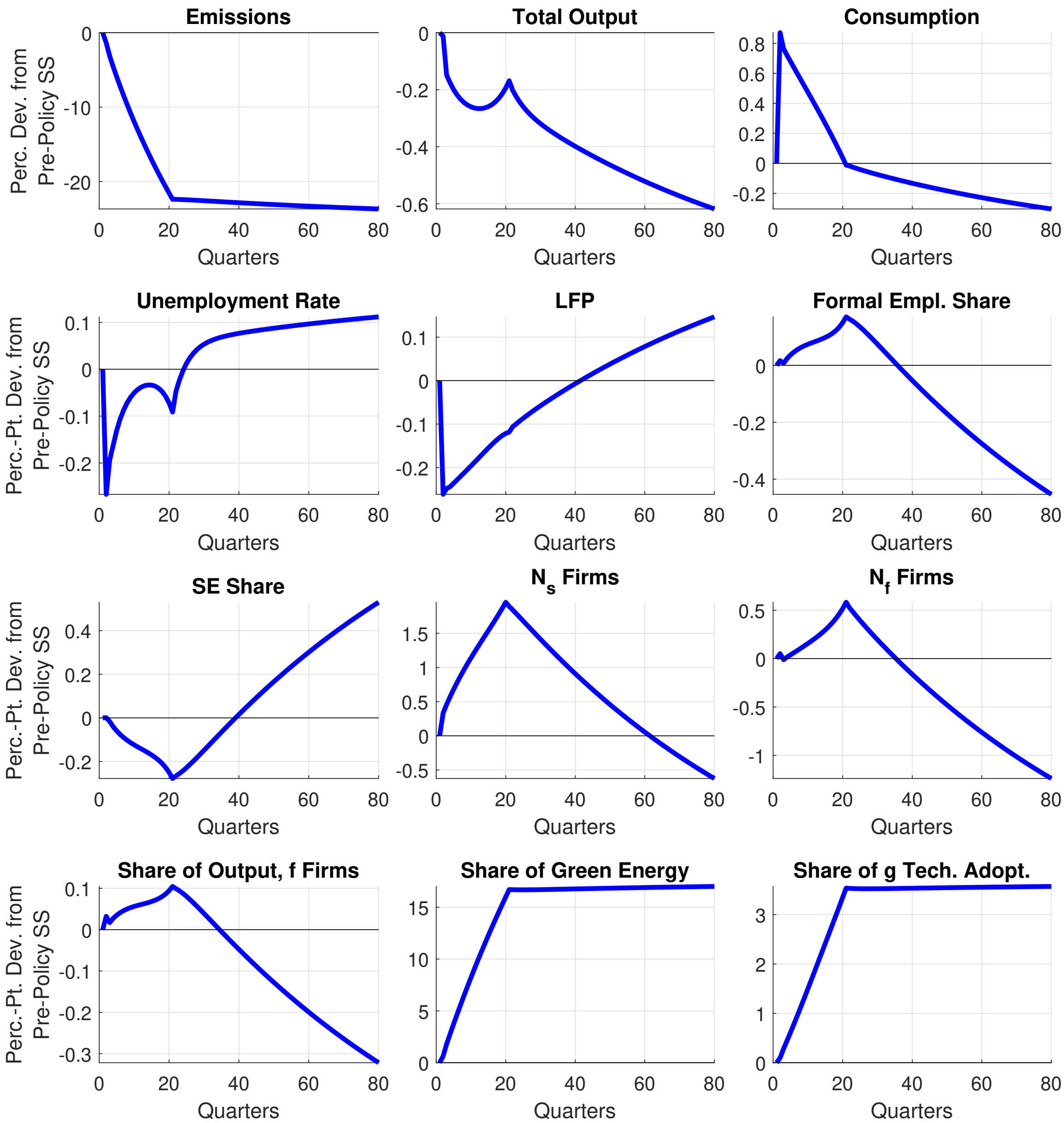
4.2.3 Transition Path to Lower-Carbon Economy

Summary of Main Results Figure 2 plots the transition path as the carbon tax increases gradually and uniformly over the course of 8 years (or 32 quarters) to ultimately achieve the 25-percent reduction in emissions in the long run. This time horizon is broadly consistent with a 2030 target for emissions reductions.

[28]The 10-percent reduction in emissions is merely illustrative, and the same conclusions hold under alternative reductions. Changing the exogenous productivity of r energy producers is a natural exercise to consider given that this parameter directly affects the generation of emissions by changing the production of polluting energy. Similar qualitative findings hold if we consider a reduction in emissions due to lower green-technology-adoption costs.

[29]For completeness and further model validation, Table A5 shows the same experiments in an "advanced economy" baseline calibration of the model—characterized by having a lower baseline self-employment share (14 percent of total employment, which is the average self-employment share in advanced economies, vs. the original 36 percent in EMEs) and a higher baseline share of f-firm output in total output (90 percent, consistent with the average size of the informal sector, vs. the original 70 percent in EMEs). As shown in columns (3) and (4) of Table A5, the advanced-economy calibration generates a much weaker negative relationship between the growth in emissions and the change in the self-employment share compared to the EME calibration. Moreover, the relationship effectively vanishes when output growth is held constant. Using data for advanced economies in a panel setting, Section b. of Table A6 in Appendix A.6 confirms that the model outcomes in the advanced-economy calibration are consistent with the data.

Figure 2: Gradual Increase in Carbon Tax and Transitional Dynamics



Note: 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, emissions steadily decline until they reach their lower long-run level. The tax-induced increase in the price of energy leads to an increase in abatement expenditures and to a reduction in physical capital demand by r energy producers. This reduction in demand is strong enough to reduce 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 green technologies.

The contraction in physical capital investment frees up resources that can be used for salaried firm creation and for consumption, which explains the otherwise surprising result that both consumption and the measure of salaried firms increase temporarily for the first 20 quarters before falling back to their pre-carbon-tax levels and eventually contracting below those levels in the long run.

The reduction in capital use by r energy producers also has important implications for the labor market. Specifically, this reduction 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.[30] As more salaried firms enter and demand more capital, they bolster salaried job creation, thereby reducing household members' incentive to search for self-employment opportunities and generating a reduction in the self-employment share. The decline in self-employment search is also powerful enough to generate a decline in the unemployment and labor force participation rates. 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 we revisit in more detail in Section 4.3. Despite the initial expansion of both salaried firm categories, their output 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 stabilize at their lower long run level, given the 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 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-

[30] 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.

term transitional dynamics eventually put 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 2. Convergence to the new steady state is slow due to the presence of frictional labor markets and the costly nature of salaried firm creation.

The Role of Capital Adjustment Costs for the Transition The presence of 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 steady reduction in emissions above and beyond the presence of other frictions in the economy. For completeness, Figure A2 in Appendix A.7 shows the transition path in a version of the model where i and f firms face convex capital 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. As a result, the economy experiences a more rapid increase in informality and more rapid reduction in output along the transition path.

4.2.4 Robustness Analysis and Additional Experiments

To confirm the robustness of our main results, 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 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) a lower baseline cost of green capital; (9) and lower and higher baseline values for the salaried-firm sunk entry cost. We also consider a version of the model where: (10) 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 via lower damages fixed); (11) a version of the model where the cost of becoming an f firm depends on the firm's real marginal cost and can therefore change with policy;

(12) a version of the model where the self-employed use energy as an input in production; (13) a version of the model where regular capital is used alongside green capital in the production of green energy; and (14) a version of the model where labor force participation is held fixed at its baseline.[31] Table A7 in Appendix A.7 summarizes the main conclusions of the robustness analysis (the results of each exercise are presented in Tables A8 through A15 of the same Appendix). Finally, Table A18 in Appendix A.7 presents results for an exercise where we calibrate the model to Brazil and Mexico, which differ primarily in their share of green energy, costs of firm formalization, and damages from climate change, and compare the impact of a reduction in emissions of the same magnitude in the two countries.

Three results from this robustness analysis are worth highlighting. First, as shown in Table A16 in Appendix A.7, even if we assume that the self-employed use energy to produce (and are therefore adversely affected by the policy-induced increase in the price of energy), the carbon tax still leads to a non-trivial increase in self-employment and reductions in the shares of formal employment and formal-firm output, in the number of formal firms, in total output, and in welfare. Thus, the simplifying assumption that the self-employed do not use energy does not change our main conclusions. Second, a higher energy share in salaried-firm production generates considerably larger output and welfare losses, but the qualitative direction of the changes remain unchanged. Third, the higher the baseline share of energy in the production process, the larger the adverse effect of the carbon tax on GDP for the same reduction in emissions. This result stems from the higher sensitivity of energy demand to energy prices when production is more intensive in energy. A similar comment applies to the baseline shares of self-employment and green energy: the higher the baseline share of self-employment, the larger the reduction in GDP in response to the carbon tax, while the opposite is true under a higher baseline share of green energy (see Tables A8 and A10 in Appendix A.7).

[31] To introduce energy use in self-employment production, we assume a constant-returns-to-scale production that combines self-employment labor and energy. As a baseline, 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. This assumption provides an upper bound for the likely quantitative effects of this alternative assumption about energy use in self-employment.

4.3 Economic Mechanisms

Our framework has two novel features relative to existing models for EMEs. The first feature is the choice by energy producers over which production (polluting or green) technology they use, which makes the polluting-green (extensive-margin) structure of energy production endogenous.[32] The second feature is endogenous entry into self-employment amid frictional labor markets.

Green Technology Adoption Limits the Carbon-Tax-Induced Increase in Energy Prices and the Impact of the Carbon Tax on Economic Activity Table 3 compares the impact of the carbon tax in a version of the model where energy producers cannot choose to adopt the green technology (that is, the two categories of energy producers each have a fixed measure and can adjust their inputs but they cannot change their technologies) (column (1)) and in the benchmark model, where recall that the carbon-tax revenue is transferred lump-sum to the household (column (2)).

A comparison of columns (1) and (2) in Table 3 reveals that green technology adoption limits the extent of the increase in the price of energy caused by the carbon tax. As a result, the reductions in salaried firm entry, formal firms, formal salaried employment, and total formal-firm output and the increase in self-employment are all smaller, which limits the adverse effect of the tax on labor income, consumption, output, and welfare. To further illustrate the role of green technology adoption in affecting energy prices, we consider 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 or the cost of green capital r_k^g (columns (3) and (4), respectively, of Table 3).

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

Table 3: Long Run Effects of Carbon Tax (25-Percent Reduction in Emissions)—Green Technology Adoption Limits the Adverse Impact of Carbon Taxation

Variable	Model	Benchmark Model		
	Without Green Tech. Adopt. Choice	**Carbon-Tax Rev. Transfer to HH**	**Carbon-Tax Rev. Subsid. φ_g Reduction**	**Carbon-Tax Rev. Subsid. r_k^g Reduction**
	(1)	(2)	(3)	(4)
	Percent Δ Rel. to Base.	**Percent Δ** Rel. to Base.	**Percent Δ** Rel. to Base.	**Percent Δ** Rel. to Base.
Total Output	**-1.452**	**-0.857**	**-0.519**	**-0.262**
Consumption	-0.613	-0.491	-0.486	-0.328
Capital Investment	-9.602	-9.467	-9.568	-9.164
Total Employment (Level)	0.585	0.417	0.357	0.235
Real Wage f	-0.641	-0.402	-0.280	-0.146
Real Wage i	-0.635	-0.398	-0.278	-0.145
Salaried Firms (N_s)	-4.729	-2.888	-1.876	-1.038
f Firms (N_f)	-4.499	-2.751	-1.793	-0.994
i Firms (N_i)	-4.737	-5.859	-1.879	-1.040
Ave. Salaried Firm Prod.	0.0133	0.008	0.005	0.003
Price of Energy	**17.760**	**11.628**	**1.263**	**0.827**
Total Energy Output	**-15.968**	**-11.013**	**-8.368**	**-5.606**
Welfare Gain (% of Consumption)	-2.744	-1.848	-1.444	-0.898
	PP Δ Rel. to Base.	**PP Δ** Rel. to Base.	**PP Δ** Rel. to Base.	**PP Δ** Rel. to Base.
Share of f Firms (N_f/N_s)	0.008	0.005	0.003	0.002
Share of f Output in Total Output	**-1.175**	**-0.732**	**-0.502**	**-0.295**
f Employment Share	**-1.675**	**-1.047**	**-0.718**	**-0.422**
i Salaried Employment Share	-0.405	-0.250	-0.167	-0.096
Self-Employment Share	**2.080**	**1.297**	**0.885**	**0.518**
Unemployment Rate	0.245	0.153	0.104	0.061
LFP Rate	0.538	0.368	0.297	0.190
Emissions Abate. Rate (μ_e)	4.910	3.461	2.033	2.540
Share of e Producers Using g Tech.	–	3.666	9.615	5.000
Share of Green Energy	**9.040**	**17.515**	**23.390**	**22.168**
Tax Revenue-Output Ratio	0.270	0.144	0.056	0.082

Note: 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. Percent Δ denotes Percent Change. PP Δ Change denotes Percentage-Point Change. Rel. to Base. denotes Relative to Baseline.

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. 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. As a result, this revenue-recycling assumption generates the smallest increase in the price of energy across scenarios, and therefore the smallest adverse labor market, output, and welfare effects from the carbon tax.

Self-Employment Exacerbates the Adverse Macro and Welfare Effects of the Carbon Tax Given the pervasiveness of self-employment in EMEs, its contribution to labor informality, and the challenges that informality represents for growth (Ohnsorge and Yu, 2021), the quantitative response of self-employment to carbon taxation has significant policy relevance. Table 4 compares our benchmark results (column (2)) to those of a benchmark-model variant without self-employment (column (1)).[33] Across scenarios scenarios, the carbon-tax revenue is transferred to the household lump-sum.

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.

[33]To keep the model versions comparable, we maintain the same calibration targets as those of the benchmark model while dropping the targets associated with self-employment. This implies that the two model versions have the same baseline share of formal employment and share of formal output in total output, among other data targets.

Similar findings to those we describe below for column (1) of Table 4 hold if instead of abstracting from self-employment, we consider a version of the benchmark model where the share of self-employment is artificially held at its baseline, pre carbon-tax level when the carbon tax is introduced (see Table A21 in Appendix A.8).

Table 4: Long Run Effects of Carbon Tax (25-Percent Reduction in Emissions)—Self-Employment Exacerbates the Adverse Effects of the Carbon Tax

Variable	**Model Without Self-Employment**	**Benchmark Model**	
		Carbon Tax	**Carbon Tax + Exog. Reduction in φ_f**
	(1)	**(2)**	**(3)**
	Percent Δ Rel. to Base.	**Percent Δ** Rel. to Base.	**Percent Δ** Rel. to Base.
Total Output	-0.538	-0.857	0.086
Consumption	-0.502	-0.491	0.190
Capital Investment	-8.475	-9.467	-9.076
Total Employment (Level)	0.144	0.417	-0.094
Real Wage f	-0.718	-0.402	0.110
Real Wage i	-0.704	-0.398	0.110
Salaried Firms (N_s)	-0.791	-2.888	-0.116
f Firms (N_f)	-0.788	-2.751	9.680
i Firms (N_i)	-0.791	-5.859	-0.460
Ave. Salaried Firm Prod.	0.001	0.008	0.542
Price of Energy	11.215	11.628	11.130
Welfare Gain (% of Consumption)	-1.079	-1.848	0.022
	PP Δ Rel. to Base.	**PP Δ** Rel. to Base.	**PP Δ** Rel. to Base.
Share of f Firms (N_f/N_s)	0.000	0.005	0.332
Share of f Output in Total Output	0.001	-0.732	0.345
f Employment Share	0.006	-1.047	0.307
i Salaried Employment Share	-0.006	-0.250	-0.362
Self-Employment Share	–	1.297	0.055
Unemployment Rate	0.033	0.153	0.004
LFP Rate	0.114	0.368	-0.057
Emissions Abate. Rate (μ_e)	3.525	3.461	3.556
Share of e Producers Using g Tech.	3.942	3.666	4.081
Share of Green Energy	18.371	17.515	18.790
Tax Revenue-Output Ratio	0.135	0.144	0.148

Note: 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 $(n_f)\,/\,(n_f + n_i)$. LFP is labor force participation. All real variables are expressed in data-consistent terms. Values are rounded to three decimal places. Percent Δ denotes Percent Change. PP Δ Change denotes Percentage-Point Change. Rel. to Base. denotes Relative to Baseline. A * denotes a target.

To understand why self-employment amplifies the adverse effects of the carbon tax, recall that by increasing the costs of production via higher energy prices, the carbon tax reduces salaried firms' incentive to create jobs, thereby lowering salaried job creation, salaried-firm output, and total output. As we explain below, the adjustment of self-employment in response to a reduction in salaried job opportunities for household members acts as an adverse amplification effect that further reduces salaried job creation relative to an environment without self-employment. This, in turn, shapes the extent to which the carbon tax affects welfare.

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 formal and informal 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 of self-employment, 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.* 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.

But a Joint Carbon-Formality Policy Can Offset The Adverse Effects of Greater Self-Employment Given these findings, column (3) of Table 4 presents results from a *joint policy* that increases the carbon tax to achieve a long-run 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.[34]

[34]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

Based on data on the most recent observed change in the average cost that firms face to become formal in our EME group, we reduce φ_f by 8.35 percent relative to its baseline value.[35] As shown in Table 4, this joint policy not only delivers the intended reduction in emissions, but virtually eliminates the output and welfare losses from the carbon tax, bolsters the share of formal employment, and keeps the unemployment rate from rising. For completeness, Table A22 of Appendix A.8 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 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

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firm entry and reduce output informality (see, for example, Klapper *et al.* (2011); for positive effects of these reforms on employment in Mexico, see Bruhn (2011)). As Ohnsorge and Yu (2021) point out, 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. 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.

[35] 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, 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 advanced economies 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 advanced economies). 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 *et al.*, 2023).

f firms' costs and operating profits, leading to a change in the composition of firms, employment, and economic activity away from self-employment and towards more productive, formal firms. As shown in column (3) of Table 4, the joint policy leads to a 0.33 percentage-point *increase* in the share of f firms (a modest increase relative to the magnitude of the reduction in the cost of firm formality), a 0.30 percentage-point *increase* in the share of formal employment, and a 0.35 percentage-point *increase* in the share of output from f firms (per column (2), 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 informal 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 formal firms ultimately offsets the output, consumption, and welfare losses that the carbon tax alone otherwise generates, and keeps unemployment from rising.[36]

For completeness, Figure A4 in Appendix A.8 shows the transition path for this joint policy while Figure A5 in the same Appendix 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.

[36]For completeness, Figure A3 in Appendix A.8 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, a 9-percent reduction in the cost or greater—the carbon-tax-induced reduction in emissions may be accompanied by an *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.

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 employment and firm structure of EMEs. Focusing on the energy sector as the source of harmful emissions, we allow energy producers to choose between 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.

Our analysis delivers four main results. First, a carbon tax on emissions from the production of polluting energy 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. Second, energy producers' ability to adopt green technologies significantly limits the adverse effects of the carbon tax on labor markets, firms, and aggregate economic activity. Third, the carbon-tax-induced increase in self-employment—a core component of EME labor markets—plays an important role in exacerbating the adverse effects of the carbon tax on labor market and macroeconomic outcomes. Given this third 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 becoming a formal firm. The results from this joint policy imply that EMEs may be able 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.

References

Acemoglu, D., Akcigit, U., Hanley, D. and Kerr, W. (2016) Transition to clean technology, *Journal of Political Economy*, **124**, 52 – 104.

Adao, B., Narajabad, B. and Temzelides, T. (2022) Renewable technology adoption costs and economic growth, *Energy Economics*, **129**, 107255.

Amin, M. and Okou, C. (2019) Casting a shadow: Productivity of formal firms and informality, *Review of Development Economics*, **24**, 1610–1630.

Annicchiarico, B., Correani, L. and Dio, F. D. (2018) Environmental policy and endogenous market structure, *Resource and Energy Economics*, **52**, 186–215.

Annicchiarico, B. and Di Dio, F. (2015) Environmental policy and macroeconomic dynamics in a new keynesian model, *Journal of Environmental Economics and Management*, **69**, 1–21.

Annicchiarico, B. and Diluiso, F. (2019) International transmission of the business cycle and environmental policy, *Resource and Energy Economics*, **58**, 1–29.

Annicchiarico, B. and Dio, F. D. (2017) GHG Emissions Control and Monetary Policy, *Environmental & Resource Economics*, **67**, 823–851.

Aubert, D. and Chiroleu-Assouline, M. (2019) Environmental tax reform and income distribution with imperfect heterogeneous labour markets, *European Economic Review*, **116**, 60–82.

Barrett, P. (2021) Can international technological diffusion substitute for coordinated global policies to mitigate climate change?, *IMF Working Papers*.

Bento, A. M., Jacobsen, M. R. and Liu, A. A. (2018) Environmental policy in the presence of an informal sector, *Journal of Environmental Economics and Management*, **90**, 61–77.

Bettarelli, L., Furceri, D., Pizzuto, P. and Shakoor, N. (2023) Environmental Policies and Innovation in Renewable Energy, IMF Working Papers 2023/180, International Monetary Fund.

Bilbiie, F. O., Ghironi, F. and Melitz, M. J. (2012) Endogenous entry, product variety, and business cycles, *Journal of Political Economy*, **120**, 304–345.

Bosch, M. and Maloney, W. (2008) Cyclical movements in unemployment and informality in developing countries, Policy Research Working Paper Series 4648, The World Bank.

Bruhn, M. (2011) License to Sell: The Effect of Business Registration Reform on Entrepreneurial Activity in Mexico, *The Review of Economics and Statistics*, **93**, 382–386.

Busso, M., Fazio, M. V. and Levy Algazi, S. (2012) (In)Formal and (Un)Productive: The Productivity Costs of Excessive Informality in Mexico, IDB Publications (Working Papers) 4047, Inter-American Development Bank.

Cacciatore, M., Duval, R., Fiori, G. and Ghironi, F. (2016) Short-term pain for long-term gain: Market deregulation and monetary policy in small open economies, *Journal of International Money and Finance*, **68**, 358–385.

Cai, Y. and Lontzek, T. S. (2019) The social cost of carbon with economic and climate risks, *Journal of Political Economy*, **127**, 2684 – 2734.

Campos, F., Goldstein, M. and McKenzie, D. (2023) How should the government bring small firms into the formal system? experimental evidence from malawi, *Journal of Development Economics*, **161**, 103045.

Castellanos, K. A. and Heutel, G. (2019) Unemployment, labor mobility, and climate policy, Working Paper 25797, National Bureau of Economic Research.

Cavalcanti, T., Hasna, Z. and Santos, C. (2021) Climate change mitigation policies: Aggregate and distributional effects, Tech. rep., Energy Policy Research Group, University of Cambridge.

Cruz, J.-L. and Rossi-Hansberg, E. (2024) The economic geography of global warming, *The Review of Economic Studies*, **91**, 899â939.

den Haan, W. J., Ramey, G. and Watson, J. (2000) Job destruction and propagation of shocks, *American Economic Review*, **90**, 482â498.

Desmet, K. and Rossi-Hansberg, E. (2015) On the spatial economic impact of global warming, *Journal of Urban Economics*, **88**, 16–37.

Dussaux, D., Dechezlepretre, A. and Glachant, M. (2017) Intellectual property rights protection and the international transfer of low-carbon technologies, GRI Working Papers 323, Grantham Research Institute on Climate Change and the Environment.

Elgin, C., Kose, M. A., Ohnsorge, F. and Yu, S. (2021) Understanding Informality, KoÃ§ University-TUSIAD Economic Research Forum Working Papers 2114, Koc University-TUSIAD Economic Research Forum.

Fernandez Intriago, L. (2020) Carbon taxation, green jobs, and sectoral human capital.

Finkelstein Shapiro, A. (2018) Labor force participation, interest rate shocks, and unemployment dynamics in emerging economies, *Journal of Development Economics*, **133**, 346–374.

Finkelstein Shapiro, A. and Metcalf, G. E. (2023) The macroeconomic effects of a carbon tax to meet the u.s. paris agreement target: The role of firm creation and technology adoption, *Journal of Public Economics*, **218**, 104800.

Fischer, C. and Springborn, M. (2011) Emissions targets and the real business cycle: Intensity targets versus caps or taxes, *Journal of Environmental Economics and Management*, **62**, 352–366.

Fried, S. (2018a) Climate policy and innovation: A quantitative macroeconomic analysis, *American Economic Journal: Macroeconomics*, **10**, 90â118.

Fried, S. (2018b) Stuck In A Corner? Climate Policy In Developing Countries, *Macroeconomic Dynamics*, **22**, 1535–1554.

Ghironi, F. and Melitz, M. J. (2005) International Trade and Macroeconomic Dynamics with Heterogeneous Firms, *The Quarterly Journal of Economics*, **120**, 865–915.

Glachant, M., Dussaux, D., Meniere, Y. and Dechezlepretre, A. (2013) Greening global value chains: innovation and the international diffusion of technologies and knowledge, Policy Research Working Paper Series 6467, The World Bank.

Hafstead, M. A. and Williams, R. C. (2018) Unemployment and environmental regulation in general equilibrium, *Journal of Public Economics*, **160**, 50–65.

Hafstead, M. A. and Williams, R. C. (2021) Distributional effects of environmental policy across workers: A general-equilibrium analysis.

Hambel, C., Kraft, H. and Schwartz, E. (2021) Optimal carbon abatement in a stochastic equilibrium model with climate change, *European Economic Review*, **132**, 103642.

Heutel, G. (2012) How should environmental policy respond to business cycles? optimal policy under persistent productivity shocks, *Review of Economic Dynamics*, **15**, 244–264.

Hopenhayn, H. and Rogerson, R. (1993) Job Turnover and Policy Evaluation: A General Equilibrium Analysis, *Journal of Political Economy*, **101**, 915–938.

Hopenhayn, H. A. (1992) Entry, Exit, and Firm Dynamics in Long Run Equilibrium, *Econometrica*, **60**, 1127–1150.

IFC (2021) A green reboot for emerging markets: Key sectors for post-covid sustainable growth.

Intriago, L. A. F. and MacDonald, D. (2022) Environmental policies and informality: The case of mexico, mimeo.

Jondeau, E., Levieuge, G., Sahuc, J.-G. and Vermandel, G. (2022) Environmental Subsidies to Mitigate Transition risk, EconomiX Working Papers 2022-21, University of Paris Nanterre, EconomiX.

Juillard, M. (1996) Dynare: A Program for the Resolution and Simulation of Dynamic Models with Forward Variables Through the Use of a Relaxation Algorithm, Tech. rep., cEPREMAP Working Papers (Couverture Orange) 9602, CEPREMAP.

Kalkuhl, M. and Wenz, L. (2020) The impact of climate conditions on economic production. evidence from a global panel of regions, *Journal of Environmental Economics and Management*, **103**, 102360.

Känzig, D. R. (2023) The Unequal Economic Consequences of Carbon Pricing, NBER Working Papers 31221, National Bureau of Economic Research, Inc.

Klapper, L., Lewin, A. and Delgado, J. (2011) *The Impact of the Business Environment on the Business Creation Process*, pp. 108–123.

La Porta, R. and Shleifer, A. (2014) Informality and development, *Journal of Economic Perspectives*, **28**, 109–26.

Maloney, W. F. (2004) Informality revisited, *World Development*, **32**, 1159–1178.

Mano, R., Barrett, P., Bergant, K. and Chateau, J. (2021) Modeling the U.S. Climate Agenda: Macro-Climate Trade-offs and Considerations, *IMF Working Papers*, **2021**, 1.

Metcalf, G. E. and Stock, J. H. (2020) Measuring the macroeconomic impact of carbon taxes, *AEA Papers and Proceedings*, **110**, 101â06.

Metcalf, G. E. and Stock, J. H. (2023) The macroeconomic impact of europe's carbon taxes, *American Economic Journal: Macroeconomics*, **15**, 265–86.

Narayan, S. and Doytch, N. (2017) An investigation of renewable and non-renewable energy consumption and economic growth nexus using industrial and residential energy consumption, *Energy Economics*, **68**, 160–176.

Nordhaus, W. (2008) *A Question of Balance: Weighing the Options on Global Warming Policies*, Yale University Press: New Haven and London.

OECD (2022) *Pricing greenhouse gas emissions*, OECD series on carbon pricing and energy taxation, Organization for Economic Co-operation and Development (OECD), Paris Cedex, France.

Ohnsorge, F. and Yu, S. (2021) The Long Shadow of Informality, World Bank Publications - Reports 35782, The World Bank Group.

Pagliari, M. S. and Ferrari Minesso, M. (2021) No country is an island: international cooperation and climate change, Working Paper Series 2568, European Central Bank.

Papageorgiou, C., Saam, M. and Schulte, P. (2017) Substitution between clean and dirty energy inputs: A macroeconomic perspective, *The Review of Economics and Statistics*, **99**, 281–290.

Pigato, M., Black, S. J., Dussaux, D., Mao, Z., McKenna, M., Rafaty, R. and Touboul, S. (2020) *Technology Transfer and Innovation for Low-Carbon Development*, no. 33474 in World Bank Publications - Books, The World Bank Group.

Reidt, N. (2021) Climate Policies and Labor Markets in Developing Countries, CER-ETH Economics working paper series 21/351, CER-ETH - Center of Economic Research (CER-ETH) at ETH Zurich.

Ritchie, H. (2021) Many countries have decoupled economic growth from co2 emissions, even if we take offshored production into account, *Our World in Data*, https://ourworldindata.org/co2-gdp-decoupling.

Roson, R. and Sartori, M. (2016) Estimation of climate change damage functions for 140 regions in the GTAP9 database, Policy Research Working Paper Series 7728, The World Bank.

Steffen, B. (2020) Estimating the cost of capital for renewable energy projects, *Energy Economics*, **88**, 104783.

Timilsina, G. R. (2022) Carbon taxes, *Journal of Economic Literature*, **60**, 1456â1502.

Ulyssea, G. (2018) Firms, informality, and development: Theory and evidence from brazil, *American Economic Review*, **108**, 2015â47.

United Nations (2023) *Technology and Innovation Report 2023: Opening Green Windows, Technological Opportunities for a Low-Carbon World*, United Nations Conference on Trade and Development, New York, NY.

WEO, I. (2022) *Chapter 3 Near-Term Macroeconomic Impact of Decarbonization Policies*, International Monetary Fund, USA, p. CH003.

World Bank (2020) *Situación y tendencias de la fijación del precio al carbono 2020*, World Bank, Washington, DC.

World Bank (2023) *Reality Check: Lessons from 25 Policies Advancing a Low-Carbon Future*, Climate Change and Development Series, World Bank, Washington, DC, license: Creative Commons Attribution CC BY 3.0 IGO.

A Appendix – Not For Publication

A.1 Extended Literature Review

Our work is closest to the macro-climate literature on technology adoption and to the growing literature on the macroeconomic consequences of climate change and climate policy using quantitative macroeconomic models, where this second literature has primarily focused on advanced economies. More recently, these models have been enriched to also assess the effects of climate policies on labor market outcomes.

Macro-Climate Literature in Advanced Economies: Green Technologies Acemoglu *et al.* (2016) analyze the transition of the US to a clean-technology economy in an endogenous growth model and find that subsidies to clean-technology innovation and carbon taxes induce a slow transition, with research subsidies being particularly relevant in limiting the welfare costs associated with the transition. Focusing on the European Union, Annicchiarico *et al.* (2018) use a macro model with environmental externalities and endogenous firm entry to analyze the aggregate effects of a cap on emissions, showing that such policy leads to higher markups and lower aggregate economic activity. Fried (2018a) quantifies the impact of a carbon tax on green-technology innovation in a model with fossil and green energy inputs calibrated to the US, and shows that a carbon tax can generate a large increase in innovation, which in turn reduces the required size of the carbon tax needed to reach a given reduction in emissions. In recent work, Adao *et al.* (2022) build a framework where the adoption of renewable-energy technologies is costly and analyze how the choice over technologies shapes the adoption of renewable energy and therefore the transition to a low-carbon economy. In their model, a carbon tax and a policy that fosters technology adoption are more effective when they are considered jointly.

While revenue from carbon taxation can be rebated back to households, the revenue can also be used to limit the potential adverse effects from carbon taxes or to bolster the development and adoption of green technologies. Mano *et al.* (2021) show that amid endogenous technological change in fuel sources, carbon taxes are more efficient, subsidies on clean energy and carbon taxes are not perfectly substitutable, and the revenue from carbon taxation can be used to limit the fiscal cost of these subsidies. Finally, Jondeau *et al.* (2022) study how using the revenue from carbon taxation to subsidize the creation of emissions-abatement goods induces greater entry into this market and reduces the price of abatement products, thereby lowering the cost of emissions abatement and generating significant savings along the transition towards a net-zero environment.

Macro-Climate Literature in Advanced Economies: Labor Markets Metcalf and Stock (2020, 2023) provide empirical evidence on the employment and macroeconomic consequences of carbon taxes in advanced economies. Hafstead and Williams (2018) characterize the impact of environmental policy on unemployment in the context of the US.[37] Using a two-sector (polluting and green) search model, they show that a policy that reduces emissions generates significant reallocation of employment with limited adverse effects on aggregate unemployment. Fernandez Intriago (2020) documents a similar finding in a model that incorporates sectoral human capital and shows that a carbon tax on energy use induces a change in the skill composition of employment towards low-skilled labor in the polluting sector. Aubert and Chiroleu-Assouline (2019) analyze the impact of environmental policy on income distribution in the presence of heterogeneous workers, while Hafstead and Williams (2021) assess the distributional impact of environmental policy across US workers where search frictions differ for within-industry versus cross-industry matches.

Castellanos and Heutel (2019) use a multi-sector model to characterize how worker mobility across sectors shapes the impact of a carbon tax on aggregate unemployment, and document similar findings to Hafstead and Williams (2018). Finkelstein Shapiro and Metcalf (2023) revisit the labor market and macroeconomic effects of a carbon tax in the US with a focus on the role of green technology adoption and firm entry. They find that when firms can use green technology adoption as a margin of adjustment to policy, a carbon tax

[37] Earlier work analyzes the macroeconomic effects of environmental policy in macro models with frictionless labor markets. For example, Fischer and Springborn (2011), Heutel (2012), and Annicchiarico and Di Dio (2015); Annicchiarico and Dio (2017) are the first to analyze the interaction between environmental policy and business cycle dynamics in one-sector macro models, with Annicchiarico and Di Dio (2015); Annicchiarico and Dio (2017) doing so in a context with nominal rigidities. Annicchiarico and Diluiso (2019) use a two-country model to study the transmission of shocks across countries in the context of carbon taxes and a cap-and-trade scheme, while Pagliari and Ferrari Minesso (2021) use a two-country, two-sector (polluting and green) model with nominal rigidities to study how fiscal and monetary policy and international cooperation shapes emissions and macroeconomic outcomes in a US-Euro Area context.

reduces overall firm creation but has negligible adverse effects on labor market outcomes. Moreover, in contrast to related studies, the tax need not have adverse effects on macroeconomic outcomes and welfare, with green technology adoption playing a key role in explaining these findings.

A.2 Key EME Facts: Additional Details

Table A1: Employment and Firm Structure in Emerging Economies

Country	**Self-Employment (% of Total Employment)**	**Total Informal Employment (% of Total Employment)**	**Informal MSMEs (% of All MSMEs)***	**Formal SML Firms (% of Formal Firms)†**	**Empl. in Formal SML Firms (% of Formal Employment)†**
	(1)	(2)	(3)	(4)	(5)
Argentina	26.5	49.7	81.0	30.5	88.7
Brazil	33.1	40.1	75.0	12.4	77.8
Chile	27.2	29.3	61.2	25.5	93.2
Colombia	49.6	62.1	69.8	7.0	–
Indonesia	51.8	80.1	55.9	1.3	10.8
Malaysia	27.4	–	84.6	24.7	–
Mexico	32.0	57.6	68.2	4.6	60.2
Peru	55.5	68.4	70.8	4.9	28.7
Philippines	36.2	–	84.6	10.4	69.6
South Africa	16.3	40.5	81.8	–	–
Thailand	50.3	–	87.2	–	–
Turkey	31.5	35.2	39.0	3.0	54.8
EME Average	**36.4**	**51.4**	**71.6**	**12.4**	**60.5**

Sources: World Bank World Development Indicators, IFC Enterprise Finance Gap 2010, IFC MSME Economic Indicators 2019. **Note:** MSMEs denotes micro, small, and medium enterprises. SML denotes small, medium, and large enterprises. The definition of micro and small firms differs across economies, but in general micro firms are defined as firms with fewer than 10 workers while firms are defined as firms having between 10 and 50 workers. Formal firms are defined as firms that are registered with their local tax authorities. * The latest available data on informal firms is from the 2010 IFC Enterprise Finance Gap database, which relies on census data (collected every 10 years) for several EMEs. † The latest data for formal SML firms and formal employment in these firms is for either 2016 or 2017 depending on the country. Similar facts hold using data for 2010 from the IFC Enterprise Finance Gap 2010 database. The data on self-employment and informal employment shares is for 2019. The same facts hold if we use data for the same years as the data that is available on firm formality (2010, 2016, or 2017).

Table A2: Energy Sources, Climate-Driven Damages, and Low-Carbon Technologies in Emerging Economies (2019)

Country	**Share of Energy from Fossil Fuels (% of Equivalent Primary Energy)**	**Share of Electricity from Fossil Fuels (% of Total Electricity)**	**Impact of $+3°C$ on GDP (% of GDP)**	**Comparative Advantage in Low-Carbon Tech. Products (Index)**
	(1)	(2)	(3)	(4)
Argentina	85.8	68.6	-0.90	0.05
Brazil	51.5	15.2	-2.13	0.22
Chile	75.9	54.4	-0.26	0.33
Colombia	70.1	24.9	-2.52	0.14
Indonesia	92.1	83.7	-6.24	0.23
Malaysia	93.2	83.9	-10.21	1.17
Mexico	91.6	80.7	-1.15	0.96
Peru	72.1	37.0	-1.91	0.07
Philippines	88.7	73.8	-7.42	0.70
South Africa	95.0	86.9	-1.59	0.58
Thailand	93.0	85.1	-9.13	0.78
Turkey	80.7	56.1	-0.83	0.93
EME Average	**82.5**	**62.5**	**-3.69**	**0.51**

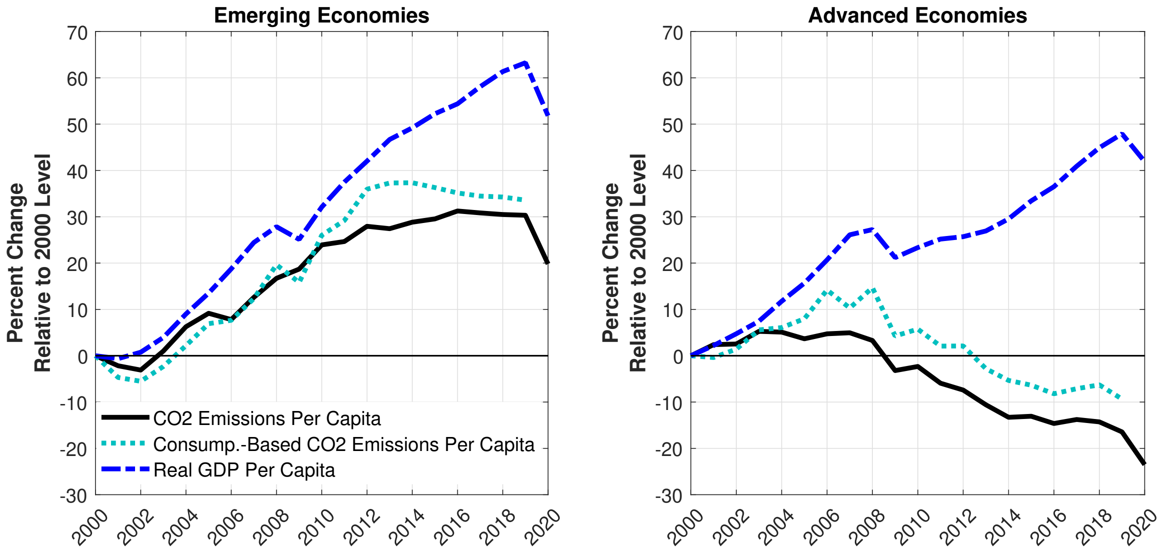
Sources: Our World in Data (https://ourworldindata.org/energy-mix), IMF Climate Change Dashboard (https://climatedata.imf.org/), and Roson and Sartori (2016). **Note:** Equivalent primary energy is obtained by using the substitution method. Non-fossil-fuel energy is comprised of renewables and nuclear power. Non-fossil-fuel electricity is comprised of hydro, solar, wind, nuclear, and other renewables. A value below 1 for the index of comparative advantage in low-carbon technology products can be interpreted as a relative disadvantage in the export potential of these products (see the IMF Climate Change Dashboard for more details). All data are for 2019 unless otherwise noted. Similar facts hold if we use data for 2020 or 2021.

Table A3: Share of Greenhouse Gas Emissions Subject to Positive Price, Average Effective Carbon Prices, Carbon Tax and Net Energy Revenue Estimates in EMEs, and Revenue Potential from Carbon Reforms (2021)

Country	**Share of GHG Emissions Subject to Positive Price**	**Average Effective Carbon Prices (EUR per tCO2e)**	**Carbon Tax Revenue Estimates (% of GDP)**	**Net Energy Tax Revenue Estimates (% of GDP)**	**Revenue Potential from Carbon Reforms (% of GDP)**
	(1)	(2)	(3)	(4)	(5)
Argentina	15.8	0.73	0.08	-0.01	3.5
Brazil	0	0	0	0.17	2.3
Chile	33.2	1.4	0.07	0.72	2.4
Colombia	19.4	0.79	0.06	0.38	1.8
Indonesia	0	0	0	-0.87	4.5
Malaysia	0	0	0	-0.33	5.9
Mexico	42.4	1.2	0.08	1.1	2.5
Peru	0	0	0	0.52	1.8
Philippines	0	0	0	0.83	2.5
South Africa	37.3	1.0	0.20	3.2	10.2
Thailand	–	–	–	–	–
Turkey	0	0	0	1.2	37
EME Average	**13.5**	**0.46**	**0.04**	**0.63**	**3.7**

Source: Figures 2.12, 2.4, 2.8, and 3.1 in OECD (2022). **Note:** Data for Thailand is unavailable. GHG denotes greenhouse gas. Net energy tax revenue estimates are computed using information on fuel excise revenues, carbon tax revenues, ETS revenues, electricity excise revenues, fossil fuel subsidies, and electricity subsidies. Revenue potential from carbon reforms refers specifically to the potential revenue raised from reforms to fossil fuel subsidies and carbon prices.

Figure A1: Growth in Carbon Dioxide Emissions Per Capita and Real GDP Per Capita—Advanced Economies vs. Emerging Economies



Sources: Our World in Data (https://ourworldindata.org/co2-gdp-decoupling), World Bank, and Global Carbon Project. **Note:** Each variable represents the average of that variable in each country group (Emerging or Advanced). Real GDP Per Capita is expressed in PPP Constant 2017 international dollars. Consump.-Based CO2 Emissions Per Capita denotes consumption-based CO2 emissions per capita, which are adjusted for trade (series available until 2019). The group of advanced economies is comprised of: Australia, Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Latvia, Lithuania, Luxembourg, Malta, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Singapore, Slovakia, Slovenia, South Korea, Spain, Sweden, Switzerland, United Kingdom, and the United States.

A.3 Equilibrium Conditions: Benchmark Model

Taking the exogenous processes $\left\{z_{f,t}, z_{i,t}, z_{o,t}, z^r_{e,t}, z^g_{e,t}, em^{row}_t, r^g_{k,t}\right\}$ as given, the allocations and prices $\{Y_t, p_{s,t}, p_{o,t}, Y_{s,t}, Y_{o,t}, k_{f,t}, k_{i,t}, v_{f,t}, v_{i,t}, e_{f,t}, e_{i,t}, N_{f,t}, N_{i,t}, \overline{a}_{s,t}, \widetilde{\pi}_{s,t}, \widetilde{\pi}_{f,t}, \widetilde{\pi}_{i,t}, \pi_{f,t}(\overline{a}_{s,t})\}$,
$\left\{\pi_{i,t}(\overline{a}_{s,t}), \rho^f_{s,t}(\overline{a}_{s,t}), \rho^i_{s,t}(\overline{a}_{s,t}), y_{f,t}(\overline{a}_{s,t}), y_{i,t}(\overline{a}_{s,t}), mc_{f,t}, mc_{i,t}, \widetilde{\rho}^f_{s,t}, \widetilde{\rho}^i_{s,t}, \rho_{e,t}, E_t, \overline{a}_{e,t}, \widetilde{\rho}^r_{e,t}, \widetilde{\rho}^g_{e,t}\right\}$,
$\{\pi^r_{e,t}(\overline{a}_{e,t}), \pi^g_{e,t}(\overline{a}_{e,t}), \rho^r_{e,t}(\overline{a}_{e,t}), \rho^g_{e,t}(\overline{a}_{e,t}), e_{r,t}(\overline{a}_{e,t}), e_{g,t}(\overline{a}_{e,t}), mc^r_{e,t}, mc^g_{e,t}, em_t, x_t, k^r_{e,t}, \mu_t, k^g_{e,t}\}$,
$\left\{k_t, n_{f,t}, n_{i,t}, n_{o,t}, N_{s,t}, e_{h,t}, A_{s,t}, r_{k,t}, s_{f,t}, s_{i,t}, s_{o,t}, w_{f,t}, w_{i,t}, \widetilde{e}_{r,t}, \widetilde{e}_{g,t}, \widetilde{y}_{f,t}, \widetilde{y}_{i,t}, c_t, \widetilde{a}^f_{s,t}, \widetilde{a}^i_{s,t}\right\}$, and
$\{\widetilde{a}^r_{e,t}, \widetilde{a}^g_{e,t}, \Gamma_t, ur_t, lfp_t\}$ satisfy:

$$Y_t = \left[Y_{s,t}^{\frac{\phi_y - 1}{\phi_y}} + Y_{o,t}^{\frac{\phi_y - 1}{\phi_y}}\right]^{\frac{\phi_y}{\phi_y - 1}}, \tag{19}$$

$$p_{s,t} = \left[N_{f,t} \left(\widetilde{\rho}^{f}_{s,t} \right)^{1-\varepsilon} + N_{i,t} \left(\widetilde{\rho}^{i}_{s,t} \right)^{1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}}, \tag{20}$$

$$Y_{s,t} = (p_{s,t})^{-\phi_y} Y_t, \tag{21}$$

$$Y_{o,t} = (p_{o,t})^{-\phi_y} Y_t, \tag{22}$$

$$Y_{o,t} = D(x_t) z_{o,t} n_{o,t}, \tag{23}$$

$$mc_{f,t} D(x_t) z_{f,t} H_{k_f,t} = r_{k,t}, \tag{24}$$

$$mc_{i,t} D(x_t) z_{i,t} F_{k_i,t} = r_{k,t}, \tag{25}$$

$$\frac{\psi_f}{q_{f,t}} = mc_{f,t} D(x_t) z_{f,t} H_{n_f,t} - w_{f,t} + (1-\rho_s) \Xi_{t+1|t} \left(\frac{\psi_f}{q_{f,t+1}} \right), \tag{26}$$

$$\frac{\psi_i}{q_{i,t}} = mc_{i,t} D(x_t) z_{i,t} F_{n_i,t} - w_{i,t} + (1-\rho_s) \Xi_{t+1|t} \left(\frac{\psi_i}{q_{i,t+1}} \right), \tag{27}$$

$$mc_{f,t} D(x_t) z_{f,t} H_{e_f,t} = \rho_{e,t}, \tag{28}$$

$$mc_{i,t} D(x_t) z_{i,t} F_{e_i,t} = \rho_{e,t}, \tag{29}$$

$$N_{f,t} = \left[1 - G(\overline{a}_{s,t}) \right] N_{s,t}, \tag{30}$$

$$N_{i,t} = G(\overline{a}_{s,t}) N_{s,t}, \tag{31}$$

$$\pi_{i,t}(\overline{a}_{s,t}) = \pi_{f,t}(\overline{a}_{s,t}), \tag{32}$$

$$\widetilde{\pi}_{s,t} = \left(\frac{N_{f,t}}{N_{s,t}} \right) \widetilde{\pi}_{f,t} + \left(\frac{N_{i,t}}{N_{s,t}} \right) \widetilde{\pi}_{i,t}, \tag{33}$$

$$\widetilde{\pi}_{f,t} = \left[\widetilde{\rho}^{f}_{s,t} - \frac{mc_{f,t}}{\widetilde{a}^{f}_{s,t}} \right] \widetilde{y}_{f,t} - \psi_f, \tag{34}$$

$$\widetilde{\pi}_{i,t} = \left[\widetilde{\rho}^{i}_{s,t} - \frac{mc_{i,t}}{\widetilde{a}^{i}_{s,t}} \right] \widetilde{y}_{i,t}, \tag{35}$$

$$\pi_{i,t}(\overline{a}_{s,t}) = \left[\rho^{i}_{s,t}(\overline{a}_{s,t}) - \frac{mc_{i,t}}{\overline{a}_{s,t}} \right] y_{i,t}(\overline{a}_{s,t}), \tag{36}$$

$$\pi_{f,t}(\overline{a}_{s,t}) = \left[\rho^{i}_{s,t}(\overline{a}_{s,t}) - \frac{mc_{f,t}}{\overline{a}_{s,t}} \right] y_{f,t}(\overline{a}_{s,t}) - \varphi_f, \tag{37}$$

$$\rho^{f}_{s,t}(\overline{a}_{s,t}) = \frac{\varepsilon}{\varepsilon - 1} \frac{mc_{f,t}}{\overline{a}_{s,t}}, \tag{38}$$

$$\rho^i_{s,t}(\overline{a}_{s,t}) = \frac{\varepsilon}{\varepsilon - 1} \frac{mc_{i,t}}{\overline{a}_{s,t}}, \tag{39}$$

$$y_{f,t}(\overline{a}_{s,t}) = \left(\rho^f_{s,t}(\overline{a}_{s,t})/p_{s,t}\right)^{-\varepsilon} Y_{s,t}, \tag{40}$$

$$y_{i,t}(\overline{a}_{s,t}) = \left(\rho^i_{s,t}(\overline{a}_{s,t})/p_{s,t}\right)^{-\varepsilon} Y_{s,t}, \tag{41}$$

$$\widetilde{y}_{f,t} = \left(\widetilde{\rho}^f_{s,t}/p_{s,t}\right)^{-\varepsilon} Y_{s,t}, \tag{42}$$

$$\widetilde{y}_{i,t} = \left(\widetilde{\rho}^i_{s,t}/p_{s,t}\right)^{-\varepsilon} Y_{s,t}, \tag{43}$$

$$\widetilde{\rho}^f_{s,t} = \frac{\varepsilon}{\varepsilon - 1} \frac{mc_{f,t}}{\widetilde{a}^f_{s,t}}, \tag{44}$$

$$\widetilde{\rho}^i_{s,t} = \frac{\varepsilon}{\varepsilon - 1} \frac{mc_{i,t}}{\widetilde{a}^i_{s,t}}, \tag{45}$$

$$\rho_{e,t} = \left(G(\overline{a}_{e,t}) \left(\widetilde{\rho}^r_{e,t}\right)^{1-\varepsilon_e} + [1 - G(\overline{a}_{e,t})] \left(\widetilde{\rho}^g_{e,t}\right)^{1-\varepsilon_e}\right)^{\frac{1}{1-\varepsilon_e}}, \tag{46}$$

$$E_t = e_{h,t} + e_{f,t} + e_{i,t}, \tag{47}$$

$$\pi^r_{e,t}(\overline{a}_{e,t}) = \pi^g_{e,t}(\overline{a}_{e,t}), \tag{48}$$

$$\widetilde{\rho}^r_{e,t} = \frac{\varepsilon_e}{\varepsilon_e - 1} \frac{mc^r_{e,t}}{\widetilde{a}^r_{e,t}}, \tag{49}$$

$$\widetilde{\rho}^g_{e,t} = \frac{\varepsilon_e}{\varepsilon_e - 1} \frac{mc^g_{e,t}}{\widetilde{a}^g_{e,t}}, \tag{50}$$

$$\pi^r_{e,t}(\overline{a}_{e,t}) = \left[\rho^r_{e,t}(\overline{a}_{e,t}) - \frac{mc^r_{e,t}}{\overline{a}_{e,t}}\right] e_{r,t}(\overline{a}_{e,t}), \tag{51}$$

$$\pi^g_{e,t}(\overline{a}_{e,t}) = \left[\rho^g_{e,t}(\overline{a}_{e,t}) - \frac{mc^g_{e,t}}{\overline{a}_{e,t}}\right] e_{g,t}(\overline{a}_{e,t}) - \varphi_e, \tag{52}$$

$$\rho^r_{e,t}(\overline{a}_{e,t}) = \frac{\varepsilon_e}{\varepsilon_e - 1} \frac{mc^r_{e,t}}{\overline{a}_{e,t}}, \tag{53}$$

$$\rho^g_{e,t}(\overline{a}_{e,t}) = \frac{\varepsilon_e}{\varepsilon_e - 1} \frac{mc^g_{e,t}}{\overline{a}_{e,t}}, \tag{54}$$

$$e_{r,t}(\overline{a}_{e,t}) = \left(\rho^r_{e,t}(\overline{a}_{e,t})/\rho_{e,t}\right)^{-\varepsilon_e} E_t, \tag{55}$$

$$e_{g,t}(\overline{a}_{e,t}) = \left(\rho^g_{e,t}(\overline{a}_{e,t})/\rho_{e,t}\right)^{-\varepsilon_e} E_t, \tag{56}$$

$$\widetilde{e}_{r,t} = \left(\widetilde{\rho}^r_{e,t}/\rho_{e,t}\right)^{-\varepsilon_e} E_t, \tag{57}$$

$$\widetilde{e}_{g,t} = \left(\widetilde{\rho}^{g}_{e,t}/\rho_{e,t}\right)^{-\varepsilon_e} E_t, \tag{58}$$

$$em_t = (1-\mu_{e,t})\left[D(x_t)z^r_{e,t}k^r_{e,t}\right]^{1-\nu_e}, \tag{59}$$

$$x_t = \rho_x x_{t-1} + em_t + em^{row}_t, \tag{60}$$

$$D(x_t)mc^r_{e,t}z^r_{e,t} = r_{k,t} + \left((1-\nu_e)\,\tau_{e,t}(1-\mu_{e,t})\left[D(x_t)z^r_{e,t}k^r_{e,t}\right]^{-\nu_e} + \mu^{\eta}_{e,t}\right)D(x_t)z^r_{e,t}, \tag{61}$$

$$\eta\gamma\mu^{\eta-1}_{e,t} = \tau_{e,t}\left[D(x_t)z^r_{e,t}k^r_{e,t}\right]^{-\nu_e}, \tag{62}$$

$$D(x_t)mc^g_{e,t}z^g_{e,t} = r^g_{k,t}, \tag{63}$$

$$k_t = k_{f,t} + k_{i,t} + k^r_{e,t}, \tag{64}$$

$$n_{f,t} = (1-\rho_s)n_{f,t-1} + s_{f,t}\varrho_{f,t}, \tag{65}$$

$$n_{i,t} = (1-\rho_s)n_{i,t-1} + s_{i,t}\varrho_{i,t}, \tag{66}$$

$$n_{o,t} = (1-\rho_o)n_{o,t-1} + s_{o,t}\phi_o, \tag{67}$$

$$N_{s,t+1} = (1-\delta_s)\left(N_{s,t} + A_{s,t}\right), \tag{68}$$

$$\mathbf{u}_{e_h,t} = \rho_{e,t}\mathbf{u}_{c,t}, \tag{69}$$

$$\varphi_s = (1-\delta_s)\Xi_{t+1|t}\left[\widetilde{\pi}_{s,t+1} + \varphi_s\right], \tag{70}$$

$$1 = \Xi_{t+1|t}\left[r_{k,t+1} + (1-\delta)\right], \tag{71}$$

$$\frac{\mathbf{h}_{lfp_{f,t}}}{\mathbf{u}_{c,t}} = \varrho_{f,t}\left[w_{f,t} + (1-\rho_s)\Xi_{t+1|t}\left(\frac{1-\varrho_{f,t+1}}{\varrho_{f,t+1}}\right)\left(\frac{\mathbf{h}_{lfp_{f,t+1}}}{\mathbf{u}_{c,t+1}}\right)\right], \tag{72}$$

$$\frac{\mathbf{h}_{lfp_{i,t}}}{\mathbf{u}_{c,t}} = \varrho_{i,t}\left[w_{i,t} + (1-\rho_s)\Xi_{t+1|t}\left(\frac{1-\varrho_{i,t+1}}{\varrho_{i,t+1}}\right)\left(\frac{\mathbf{h}_{lfp_{i,t+1}}}{\mathbf{u}_{c,t+1}}\right)\right], \tag{73}$$

$$\frac{\mathbf{h}_{lfp_{o,t}}}{\mathbf{u}_{c,t}} = \phi_o\left[p_{o,t}D(x_t)z_{o,t} + (1-\rho_o)\Xi_{t+1|t}\left(\frac{1-\phi_o}{\phi_o}\right)\left(\frac{\mathbf{h}_{lfp_{o,t+1}}}{\mathbf{u}_{c,t+1}}\right)\right], \tag{74}$$

$$w_{f,t} = \nu_n\left(mc_{f,t}D(x_t)z_{f,t}H_{n_f,t} + (1-\rho_s)\,\Xi_{t+1|t}\psi_f\theta_{f,t+1}\right), \tag{75}$$

$$w_{i,t} = \nu_n\left(mc_{i,t}D(x_t)z_{i,t}F_{n_i,t} + (1-\rho_s)\,\Xi_{t+1|t}\psi_i\theta_{i,t+1}\right), \tag{76}$$

$$D(x_t)z^r_{e,t}k^r_{e,t} = G(\overline{a}_{e,t})\left(\frac{\widetilde{e}_{r,t}}{\widetilde{a}^r_{e,t}}\right), \tag{77}$$

$$D(x_t) z_{e,t}^g k_{e,t}^g = [1 - G(\overline{a}_{e,t})] \left(\frac{\widetilde{e}_{g,t}}{\widetilde{a}_{e,t}^g} \right), \tag{78}$$

$$D(x_t) z_{f,t} H(n_{f,t}, k_{f,t}, e_{f,t}) = N_{f,t} \left(\frac{\widetilde{y}_{f,t}}{\widetilde{a}_{s,t}^f} \right), \tag{79}$$

$$D(x_t) z_{i,t} F(n_{i,t}, k_{i,t}, e_{i,t}) = N_{i,t} \left(\frac{\widetilde{y}_{i,t}}{\widetilde{a}_{s,t}^i} \right), \tag{80}$$

$$Y_t = c_t + (k_{t+1} - (1-\delta) k_t) + \psi_f v_{f,t} + \psi_i v_{i,t} + \varphi_s A_{s,t} + \varphi_f N_{f,t} + \varphi_e [1 - G(\overline{a}_{e,t})] + \Gamma_t + r_{k,t}^g k_{e,t}^g, \tag{81}$$

$$\widetilde{a}_{s,t}^i = \widetilde{a}_{s,t}^f \left(\frac{\overline{a}_{s,t}^{k_p - (\varepsilon - 1)} - a_{s,min}^{k_p - (\varepsilon - 1)}}{\overline{a}_{s,t}^{k_p} - a_{s,min}^{k_p}} \right)^{\frac{1}{\varepsilon - 1}} a_{s,min}, \tag{82}$$

$$\widetilde{a}_t^f = \left(\frac{k_p}{k_p - (\varepsilon - 1)} \right)^{\frac{1}{\varepsilon - 1}} \overline{a}_{s,t}, \tag{83}$$

$$\widetilde{a}_{e,t}^r = \widetilde{a}_{e,t}^g \left(\frac{\overline{a}_{e,t}^{k_p^e - (\varepsilon_e - 1)} - a_{e,min}^{k_p^e - (\varepsilon_e - 1)}}{\overline{a}_{e,t}^{k_p^e} - a_{e,min}^{k_p^e}} \right)^{\frac{1}{\varepsilon_e - 1}} a_{e,min}, \tag{84}$$

$$\widetilde{a}_{e,t}^g = \left(\frac{k_p^e}{k_p^e - (\varepsilon_e - 1)} \right)^{\frac{1}{\varepsilon_e - 1}} \overline{a}_{e,t}, \tag{85}$$

$$\Gamma_t = \gamma \mu_{e,t}^\eta D(x_t) z_{e,t}^r k_{e,t}^r, \tag{86}$$

$$ur_t = \frac{(1 - \varrho_{f,t}) s_{f,t} + (1 - \varrho_{i,t}) s_{i,t} + (1 - \phi_o) s_{o,t}}{lfp_t}, \tag{87}$$

$$lfp_t = n_{f,t} + n_{i,t} + n_{o,t} + (1 - \varrho_{f,t}) s_{f,t} + (1 - \varrho_{i,t}) s_{i,t} + (1 - \phi_o) s_{o,t}. \tag{88}$$

A.4 Data-Consistent Model Variables

Recall that aggregate price index in the economy, P_t, is given by

$$P_t = \left[P_{s,t}^{1-\phi_y} + P_{o,t}^{1-\phi_y} \right]^{\frac{1}{1-\phi_y}}.$$

In a symmetric equilibrium, the nominal price of total salaried output, $P_{s,t}$, is given by

$$P_{s,t} = \left[N_{f,t} \left(\widetilde{p}_{f,t} \right)^{1-\varepsilon} + N_{i,t} \left(\widetilde{p}_{i,t} \right)^{1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}},$$

where $\widetilde{p}_{f,t} \equiv p_{f,t}(\widetilde{a}^f_{s,t})$ and $\widetilde{p}_{i,t} \equiv p_{i,t}(\widetilde{a}^i_{s,t})$ are average nominal prices. Recalling that $N_{f,t} = [1 - G(\overline{a}_{s,t})]\, N_{s,t}$ and $N_{i,t} = G(\overline{a}_{s,t})N_{s,t}$, we can write the expression for $P_{s,t}$ as

$$P_{s,t} = N_{s,t}^{\frac{1}{1-\varepsilon}} \left[(1 - G(\overline{a}_{s,t}))\left(\widetilde{p}_{f,t}\right)^{1-\varepsilon} + (G(a_{i,t}))\left(\widetilde{p}_{i,t}\right)^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}}.$$

Then, the aggregate price index can be written as

Thus, we can write this last expression as

$$P_t = \left[N_{s,t}^{\frac{1-\phi_y}{1-\varepsilon}} \left[(1 - G(\overline{a}_{s,t}))\left(\widetilde{p}_{f,t}\right)^{1-\varepsilon} + (G(a_{i,t}))\left(\widetilde{p}_{i,t}\right)^{1-\varepsilon}\right]^{\frac{1-\phi_y}{1-\varepsilon}} + P_{o,t}^{1-\phi_y}\right]^{\frac{1}{1-\phi_y}},$$

where the love-for-variety component stems solely from having an endogenous measure of salaried firms and is therefore embodied in $N_{s,t}$. Thus, the adjustment needed to convert a given model-based quantity variable λ^m_t into a data-consistent model variable λ^d_t is $\lambda^d_t = \lambda^m_t \Theta_t$ where $\Theta_t = \left(N_{s,t}^{\frac{1-\phi_y}{1-\varepsilon}} + 1\right)^{\frac{1}{1-\phi_y}}$ see (see Cacciatore *et al.*, 2016, for a similar expression).

A.5 Baseline Calibration: Parameter Values

Table A4: 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, production 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 producers	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. idiosyncratic prod.	Normalization
a_{min}^e	1	Min. idiosyncratic 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 abatement cost function	Hafstead and Williams III (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	0.0139	Utility parameter, HH energy	$e_h/E = 0.26$
D_0	0.0000034434	Damages function parameter	Pollution damages/GDP $= 0.0125$
$\psi_f\ (= \psi_i)$	0.1487	Salaried vacancy posting cost	$(\psi_f v_f + \psi_i v_i)/Y = 0.03$
φ_f	0.3586	Fixed cost of firm formality	$\varphi_f/Y = 0.08$
φ_e	0.0363	Fixed cost of g tech. adoption	Share of r energy prod. $= 0.84$
e^{row}	22.5967	Emissions rest of world	$em^{row}/(em + em^{row}) = 0.90$
κ_f	1.2450	LFP disutility param. for f	$lfp = 0.63$
κ_i	0.9902	LFP disutility param. for i	$(n_f)/(n_f + n_i + n_o) = 0.542$
κ_o	1.0543	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	0.4697	i-firm exog. prod.	$w_f/w_i = 1.25$
z_o	2.5252	Self-employed exog. prod.	Total f-firm output share $= 0.70$
r_k^g	0.0377	Cost of green capital k_e^g	$(r_k^g + \varphi_e/k_e^g) - r_k = 0.06$
$\bar{x}$	8348.3	Pre-industrial pollution stock	$\bar{x} = D_1 x$

A.6 Empirical Validation of Model: Growth in Emissions and Change in Self-Employment Shares in the Data

Table A5: Relationship Between Growth in Emissions and Change in the Self-Employment Share—Model Validation in the Data

	Baseline Emerging Economy Calibration		**Advanced Economy Calibration (Lower Baseline SE Share and Higher Baseline f-Output Share)**	
	Carbon Tax Reduces Emissions	Lower r Energy, Exog. Productivity Reduces Emissions	Carbon Tax Reduces Emissions	Lower r Energy, Exog. Productivity Reduces Emissions
	(1)	(2)	(3)	(4)
Perc. Change in Emissions	-10	-10	-10	-10
Perc.-Pt. Change in SE Share	0.522	0.615	0.202	0.236
Perc.-Pt. Change in SE Share Holding Output Growth Constant	0.185	0.241	0.078	0.105

Note: The self-employment share in the model is defined as $(n_o) / (n_f + n_i + n_o)$. Output growth is held constant by adjusting exogenous aggregate productivity in response to the change in emissions. Using alternative parameters to keep output growth constant delivers similar findings. The advanced economy calibration consists of setting a self-employment share of 14 percent (vs. 36 percent in EMEs) and a share of f-firm output in total output of 90 percent (vs. 70 percent in EMEs), both of which are consistent with advanced-economy averages.

Table A6: Empirical Relationship Between Growth in Emissions and Change in the Self-Employment Share—Emerging Economies and Advanced Economies

a. Emerging Economies

Change in SE Share$_{t,t-1}$	(1)	(2)	(3)	(4)
Percent Change in CO2 Emissions$_{t,t-1}$	**-0.029*** **	**-0.016**	**-0.023** **	**-0.014**
	(-2.98)	(-1.58)	(-2.29)	(-1.36)
Percent Change in Real GDP Per Capita$_{t,t-1}$	—	-0.084***	—	-0.084***
		(-3.85)		(-2.88)
Country Fixed Effects	Yes	Yes	Yes	Yes
Time Fixed Effects	No	No	Yes	Yes
Overall R^2	0.04	0.11	0.12	0.17
Observations	240	240	240	240
No. of Countries	12	12	12	12
Time Span	2000-2019	2000-2019	2000-2019	2000-2019

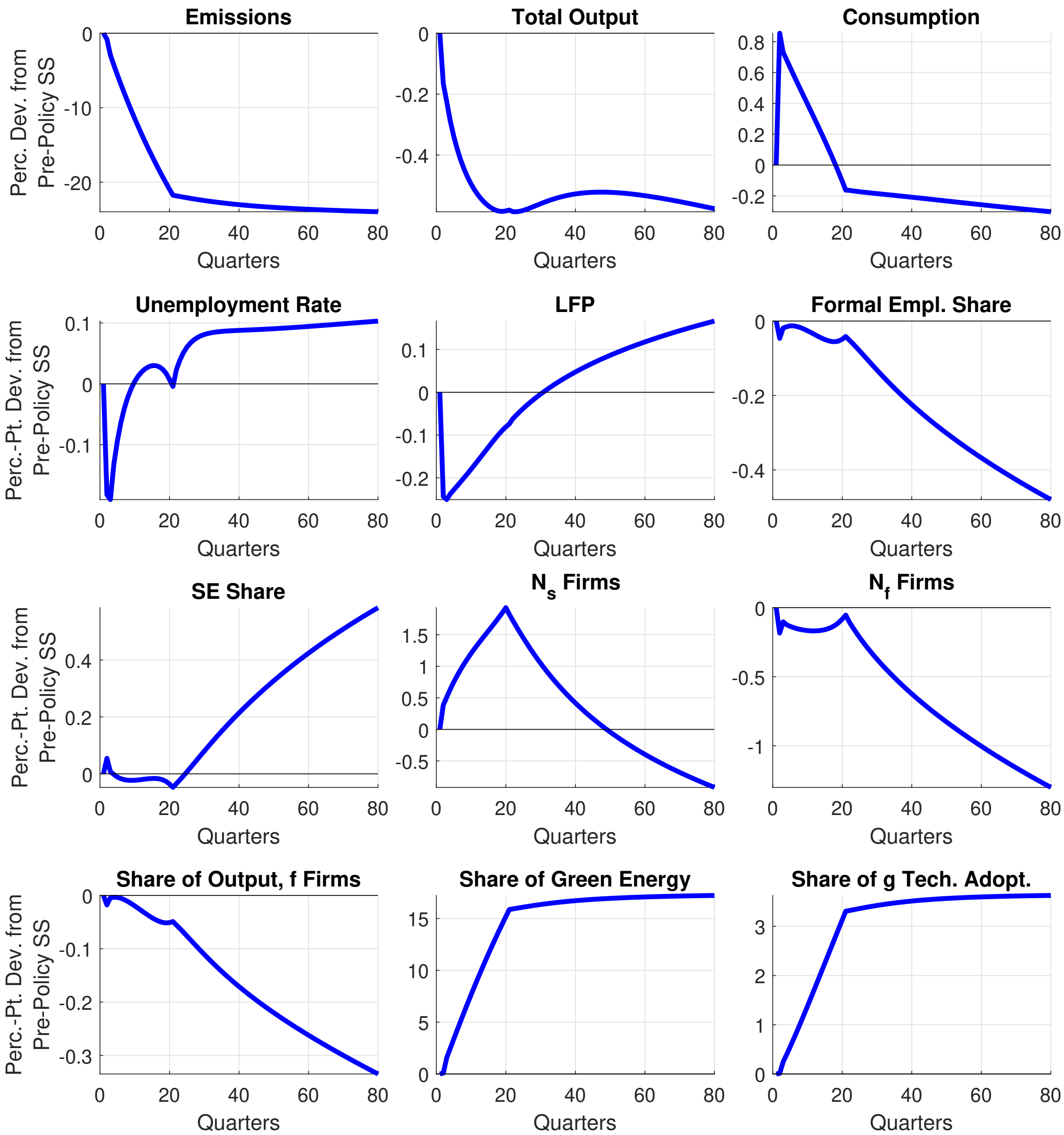
b. Advanced Economies

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

Sources: World Bank Development Indicators and Carbon Project via Our World in Data. **Note:** The self-employment (SE) share in the data is the share of self-employment in total employment. Real GDP per capita is expressed in PPP terms using 2017 international dollars. t statistics in parentheses. *** and ** denote significance at the 1 and 5 percent levels, respectively. The group of advanced economies is comprised of: Australia, Austria, Belgium, Bulgaria, Canada, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Latvia, Lithuania, Luxembourg, Malta, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Singapore, Slovakia, Slovenia, South Korea, Spain, Sweden, Switzerland, United Kingdom, and the United States.

A.7 Robustness Analysis: Benchmark Model

Figure A2: Gradual Increase in Carbon Tax and Transitional Dynamics—Benchmark Model with i- and f-Firm Capital Adjustment Costs



Note: 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. We assume that i and f firms face a capital adjustment cost given by $(\varphi_k/2) (k_{j,t} - k_{j,t-1})^2$ for $j \in \{i, f\}$ and set $\varphi_k = 5$ as a baseline.

Table A7: Summary of Robustness Experiments

Robustness Experiment	New Baseline Targets/Parameters	Original Baseline Targets/Parameters	Qualitative Diff. vs. Benchmark Results? (Yes/No)	Quantitative Diff. vs. Benchmark Results?
Higher baseline green-energy share	26 percent	16 percent	No	Smaller quant. changes
Formal-vacancy costs > informal costs	$\psi_f = 2\psi_i$	$\psi_f = \psi_i$	No	No meaningful diff.
Higher energy share + lower capital share	$\alpha_e = 0.10, \alpha_f = 0.27, \alpha_i = 0.17$	$\alpha_e = 0.05, \alpha_f = 0.33, \alpha_i = 0.22$	No	Larger quant. changes
Greater damages/GDP ratio	2 percent	1.25 percent	No	Smaller quant. changes
Higher elasticity of emissions	0.896 ($\nu_e = 0.104$)	0.696 ($\nu_e = 0.304$)	No	Smaller quant. changes
Greater energy-producer concentration	$\varepsilon_e = 3.5$, $k_p^e = 3.7$	$\varepsilon_e = 4$, $k_p^e = 4.2$	No	Larger quant. changes
Higher energy share among f firms	$\alpha_e^f = 0.10$, $\alpha_e^i = 0.05$	$\alpha_e^f = \alpha_e^i = 0.05$	No	No meaningful diff.
Lower cost of green capital	$(r_k^g - r_k) = 0.03$	$(r_k^g - r_k) = 0.06$	No	No meaningful diff.
Lower and Higher Values for φ_s	$\varphi_s = 0.5$ and $\varphi_s = 2$	$\varphi_s = 1$	No	No meaningful diff.
Constant damages function $D(x)$	$D(x)$ held at baseline x	Endogenous $D(x)$	No	Larger quant. changes
Firm-formality cost a function of mc_f	$\varphi_f mc_{f,t}$	φ_f	No	No meaningful diff.
Self-employed use energy in production	Use SE labor, energy	Only SE labor	No	Smaller quant. changes
Combination of regular and green capital in green energy production	$D(x) z_e^g \left(k_e^g\right)^{\alpha_e^g} \left(k_e^{gr}\right)^{1-\alpha_e^g}$ with $\alpha_e^g = 0.5$	Only green capital k_e^g	No	Larger quant. changes
Lower damages cost parameter γ	$\gamma = 0.05$	$\gamma = 1$	No	Smaller quant. changes

Table A8: Long Run Effects of Carbon Tax (25-Percent Reduction in Emissions)—Benchmark Results vs. Alternative Parameterizations and Assumptions 1

Variable	**Benchmark Model**	**Benchmark Model Higher Baseline Green Energy Share**	**Benchmark Model Lower Baseline Cost of Green Capital**
	(1)	(2)	(3)
	Percent Δ Rel. to Base.	**Percent Δ** Rel. to Base.	**Percent Δ** Rel. to Base.
Total Output	-0.857	-0.627	-0.778
Consumption	-0.491	-0.345	-0.495
Capital Investment	-9.467	-8.473	-9.539
Total Employment (Level)	0.417	0.304	0.406
Real Wage f	-0.402	-0.283	-0.375
Real Wage i	-0.398	-0.280	-0.372
Salaried Firms (N_s)	-2.888	-2.134	-2.654
f Firms (N_f)	-2.751	-2.031	-2.529
i Firms (N_i)	-5.859	-2.138	-2.658
f Ave. Idiosync. Prod. $\left(\widetilde{a}_s^f\right)$	-0.034	-0.025	-0.030
i Ave. Idiosync. Prod. $\left(\widetilde{a}_s^i\right)$	-0.007	-0.005	-0.006
Ave. Salaried Firm Prod.	0.008	-0.001	0.007
Welfare Gain (% of Consumption)	-1.848	-1.352	-1.762
	PP Δ Rel. to Base.	**PP Δ** Rel. to Base.	**PP Δ** Rel. to Base.
Share of f Firms (N_f/N_s)	0.005	0.004	0.004
Share of f Output in Total Output	-0.732	-0.542	-0.679
f Employment Share	-1.047	-0.778	-0.972
i Salaried Employment Share	-0.250	-0.186	-0.231
Self-Employment Share	1.297	0.964	1.202
Unemployment Rate	0.153	0.114	0.142
LFP Rate	0.368	0.270	0.353
Emissions Abate. Rate (μ_e)	3.461	3.615	2.965
Share of e Producers Using g Tech.	3.666	2.367	6.381
Share of Green Energy	17.515	15.217	19.712
Tax Revenue-Output Ratio	0.144	0.155	0.110

Note: 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. Percent Δ denotes Percent Change. PP Δ Change denotes Percentage-Point Change. Rel. to Base. denotes Relative to Baseline.

Table A9: Long Run Effects of Carbon Tax (25-Percent Reduction in Emissions)—Benchmark Results vs. Alternative Parameterizations and Assumptions 2

Variable	**Benchmark Model**	**Benchmark Model Firm Formality Cost $\varphi_f mc_f$**	**Benchmark Model Diff. Vacancy Costs $\psi_i = 2\psi_f$**
	(1)	(2)	(3)
	Percent Δ Rel. to Base.	**Percent Δ** Rel. to Base.	**Percent Δ** Rel. to Base.
Total Output	-0.857	-0.800	-0.860
Consumption	-0.491	-0.450	-0.491
Capital Investment	-9.467	-9.442	-9.474
Total Employment (Level)	0.417	0.386	0.409
Real Wage f	-0.402	-0.372	-0.399
Real Wage i	-0.398	-0.368	-0.406
Salaried Firms (N_s)	-2.888	-2.717	-2.902
f Firms (N_f)	-2.751	-2.030	-2.780
i Firms (N_i)	-5.859	-2.742	-2.906
f Ave. Idiosync. Prod. $\left(\widetilde{a}_s^f\right)$	-0.034	-0.168	-0.030
i Ave. Idiosync. Prod. $\left(\widetilde{a}_s^i\right)$	-0.007	-0.033	-0.006
Ave. Salaried Firm Prod.	0.008	0.039	0.007
Welfare Gain (% of Consumption)	-1.848	-1.734	-1.853
	PP Δ Rel. to Base.	**PP Δ** Rel. to Base.	**PP Δ** Rel. to Base.
Share of f Firms (N_f/N_s)	0.005	0.024	0.004
Share of f Output in Total Output	-0.732	-0.665	-0.745
f Employment Share	-1.047	-0.964	-1.056
i Salaried Employment Share	-0.250	-0.256	-0.244
Self-Employment Share	1.297	1.220	1.301
Unemployment Rate	0.153	0.144	0.154
LFP Rate	0.368	0.342	0.364
Emissions Abate. Rate (μ_e)	3.461	3.467	3.460
Share of e Producers Using g Tech.	3.666	3.691	3.663
Share of Green Energy	17.515	17.594	17.508
Tax Revenue-Output Ratio	0.144	0.144	0.144

Note: 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. Percent Δ denotes Percent Change. PP Δ Change denotes Percentage-Point Change. Rel. to Base. denotes Relative to Baseline.

Table A10: Long Run Effects of Carbon Tax (25-Percent Reduction in Emissions)—Benchmark Results vs. Alternative Parameterizations and Assumptions 3

Variable	**Benchmark Model**	**Benchmark Model Higher Energy Share in Production,** $\alpha_e = 0.10$	**Benchmark Model Higher Baseline Pollution Damages (2 Percent of GDP)**
	(1)	(2)	(3)
	Percent Δ Rel. to Base.	**Percent Δ** Rel. to Base.	**Percent Δ** Rel. to Base.
Total Output	-0.857	-1.977	-0.749
Consumption	-0.491	-1.165	-0.408
Capital Investment	-9.467	-15.778	-9.366
Total Employment (Level)	0.417	1.137	0.372
Real Wage f	-0.402	-1.016	-0.322
Real Wage i	-0.398	-1.007	-0.318
Salaried Firms (N_s)	-2.888	-6.229	-2.597
f Firms (N_f)	-2.751	-5.746	-2.470
i Firms (N_i)	-5.859	-6.246	-2.601
f Ave. Idiosync. Prod. $\left(\widetilde{a}_s^f\right)$	-0.034	-0.122	-0.031
i Ave. Idiosync. Prod. $\left(\widetilde{a}_s^i\right)$	-0.007	-0.024	-0.006
Ave. Salaried Firm Prod.	0.008	0.018	0.007
Welfare Gain (% of Consumption)	-1.848	-4.117	-1.640
	PP Δ Rel. to Base.	**PP Δ** Rel. to Base.	**PP Δ** Rel. to Base.
Share of f Firms (N_f/N_s)	0.005	0.017	0.005
Share of f Output in Total Output	-0.732	-1.428	-0.671
f Employment Share	-1.047	-2.243	-0.960
i Salaried Employment Share	-0.250	-0.613	-0.229
Self-Employment Share	1.297	2.856	1.189
Unemployment Rate	0.153	0.337	0.140
LFP Rate	0.368	0.951	0.331
Emissions Abate. Rate (μ_e)	3.461	3.344	3.486
Share of e Producers Using g Tech.	3.666	3.208	3.712
Share of Green Energy	17.515	16.024	17.665
Tax Revenue-Output Ratio	0.144	0.140	0.148

Note: 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. Percent Δ denotes Percent Change. PP Δ Change denotes Percentage-Point Change. Rel. to Base. denotes Relative to Baseline.

Table A11: Long Run Effects of Carbon Tax (25-Percent Reduction in Emissions)—Benchmark Results vs. Alternative Parameterizations and Assumptions 4

Variable	**Benchmark Model**	**Benchmark Model Constant Damages Function $D(x)$**	**Benchmark Model Lower Energy Intensity in i Firms**
	(1)	(2)	(3)
	Percent Δ Rel. to Base.	**Percent Δ** Rel. to Base.	**Percent Δ** Rel. to Base.
Total Output	-0.857	-1.039	-0.830
Consumption	-0.491	-0.631	-0.466
Capital Investment	-9.467	-9.599	-9.119
Total Employment (Level)	0.417	0.493	0.359
Real Wage f	-0.402	-0.539	-0.373
Real Wage i	-0.398	-0.534	-0.369
Salaried Firms (N_s)	-2.888	-3.375	-2.758
f Firms (N_f)	-2.751	-3.221	-2.929
i Firms (N_i)	-5.859	-3.380	-2.751
f Ave. Idiosync. Prod. $\left(\widetilde{a}_s^f\right)$	-0.034	-0.038	0.042
i Ave. Idiosync. Prod. $\left(\widetilde{a}_s^i\right)$	-0.007	-0.008	0.008
Ave. Salaried Firm Prod.	0.008	0.009	-0.011
Price of Energy	11.628	11.808	11.587
Welfare Gain (% of Consumption)	-1.848	-2.196	-1.760
	PP Δ Rel. to Base.	**PP Δ** Rel. to Base.	**PP Δ** Rel. to Base.
Share of f Firms (N_f/N_s)	0.005	0.005	-0.006
Share of f Output in Total Output	-0.732	-0.835	-0.840
f Employment Share	-1.047	-1.194	-1.100
i Salaried Employment Share	-0.250	-0.284	-0.134
Self-Employment Share	1.297	1.478	1.234
Unemployment Rate	0.153	0.176	0.146
LFP Rate	0.368	0.432	0.327
Emissions Abate. Rate (μ_e)	3.461	3.440	3.462
Share of e Producers Using g Tech.	3.666	3.583	3.671
Share of Green Energy	17.515	17.246	17.532
Tax Revenue-Output Ratio	0.144	0.143	0.145

Note: 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. Percent Δ denotes Percent Change. PP Δ Change denotes Percentage-Point Change. Rel. to Base. denotes Relative to Baseline.

Table A12: Long Run Effects of Carbon Tax (25-Percent Reduction in Emissions)—Benchmark Results vs. Alternative Parameterizations and Assumptions 5

Variable	**Benchmark Model**	**Benchmark Model** $\nu_e = 0.103$	**Benchmark Model** $\varepsilon_e = 3.5$ **and** $k_p^e = 3.7$
	(1)	(2)	(3)
	Percent Δ Rel. to Base.	**Percent Δ** Rel. to Base.	**Percent Δ** Rel. to Base.
Total Output	-0.857	-0.698	-0.960
Consumption	-0.491	-0.383	-0.514
Capital Investment	-9.467	-7.838	-9.521
Total Employment (Level)	0.417	0.335	0.447
Real Wage f	-0.402	-0.319	-0.445
Real Wage i	-0.398	-0.315	-0.440
Salaried Firms (N_s)	-2.888	-2.365	-3.208
f Firms (N_f)	-2.751	-2.251	-3.055
i Firms (N_i)	-5.859	-2.369	-3.213
f Ave. Idiosync. Prod. $\left(\widetilde{a}_s^f\right)$	-0.034	-0.028	-0.038
i Ave. Idiosync. Prod. $\left(\widetilde{a}_s^i\right)$	-0.007	-0.005	-0.007
Ave. Salaried Firm Prod.	0.008	0.006	0.009
Price of Energy	11.628	9.685	12.679
Welfare Gain (% of Consumption)	-1.848	-1.495	-2.006
	PP Δ Rel. to Base.	**PP Δ** Rel. to Base.	**PP Δ** Rel. to Base.
Share of f Firms (N_f/N_s)	0.005	0.004	0.005
Share of f Output in Total Output	-0.732	-0.599	-0.808
f Employment Share	-1.047	-0.859	-1.156
i Salaried Employment Share	-0.250	-0.205	-0.277
Self-Employment Share	1.297	1.064	1.432
Unemployment Rate	0.153	0.126	0.169
LFP Rate	0.368	0.298	0.398
Emissions Abate. Rate (μ_e)	3.461	2.669	3.623
Share of e Producers Using g Tech.	3.666	3.848	4.421
Share of Green Energy	17.515	14.256	16.607
Tax Revenue-Output Ratio	0.144	0.091	0.156

Note: 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. Percent Δ denotes Percent Change. PP Δ Change denotes Percentage-Point Change. Rel. to Base. denotes Relative to Baseline.

Table A13: Long Run Effects of Carbon Tax (25-Percent Reduction in Emissions)—Benchmark Results vs. Alternative Parameterizations and Assumptions 6

Variable	**Benchmark Model**	**No Salaried Firm Entry**	**Regular Capital Used in Green Energy Prod.**
	(1)	(2)	(3)
	Percent Δ Rel. to Base.	**Percent Δ** Rel. to Base.	**Percent Δ** Rel. to Base.
Total Output	-0.857	-0.781	- 1.026
Consumption	-0.491	-0.591	-0.424
Capital Investment	-9.467	-6.499	-7.536
Total Employment (Level)	0.417	0.243	0.412
Real Wage f	-0.402	-0.561	-0.445
Real Wage i	-0.398	-0.560	-0.441
Salaried Firms (N_s)	-2.888	–	-3.365
f Firms (N_f)	-2.751	-1.927	-3.199
i Firms (N_i)	-5.859	1.079	-3.371
f Ave. Idiosync. Prod. $\left(\widetilde{a}_s^f\right)$	-0.034	0.464	-0.041
i Ave. Idiosync. Prod. $\left(\widetilde{a}_s^i\right)$	-0.007	0.182	-0.008
Ave. Salaried Firm Prod.	0.008	-0.142	0.009
Price of Energy	11.628	10.871	12.826
Welfare Gain (% of Consumption)	-1.848	-0.853	-1.945
	PP Δ Rel. to Base.	**PP Δ** Rel. to Base.	**PP Δ** Rel. to Base.
Share of f Firms (N_f/N_s)	0.005	-0.692	0.006
Share of f Output in Total Output	-0.732	-0.589	-0.833
f Employment Share	-1.047	-0.711	-1.192
i Salaried Employment Share	-0.250	0.134	-0.289
Self-Employment Share	1.297	0.577	1.480
Unemployment Rate	0.153	0.069	0.175
LFP Rate	0.368	0.201	0.380
Emissions Abate. Rate (μ_e)	3.461	3.513	4.049
Share of e Producers Using g Tech.	3.666	3.889	1.087
Share of Green Energy	17.515	18.209	14.511
Tax Revenue-Output Ratio	0.144	0.317	0.190

Note: 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. Percent Δ denotes Percent Change. PP Δ Change denotes Percentage-Point Change. Rel. to Base. denotes Relative to Baseline. For the model version in Column (3), we assume a Cobb-Douglas production function that combines green capital with regular capital under equal shares to produce green energy.

Table A14: Long Run Effects of Carbon Tax (25-Percent Reduction in Emissions)—Benchmark Results vs. Alternative Parameterizations and Assumptions 7

Variable	**Benchmark Model**	**Benchmark Model Lower Baseline** $\varphi_s = 0.5$	**Benchmark Model Higher Baseline** $\varphi_s = 2$
	(1)	(2)	(3)
	Percent Δ Rel. to Base.	**Percent Δ** Rel. to Base.	**Percent Δ** Rel. to Base.
Total Output	-0.857	-0.823	- 0.931
Consumption	-0.491	-0.465	-0.555
Capital Investment	-9.467	-10.511	-8.493
Total Employment (Level)	0.417	0.419	0.414
Real Wage f	-0.402	-0.371	-0.473
Real Wage i	-0.398	-0.367	-0.469
Salaried Firms (N_s)	-2.888	-2.877	-2.903
f Firms (N_f)	-2.751	-2.761	-2.725
i Firms (N_i)	-5.859	-2.879	-2.918
f Ave. Idiosync. Prod. $\left(\widetilde{a}_s^f\right)$	-0.034	-0.028	-0.044
i Ave. Idiosync. Prod. $\left(\widetilde{a}_s^i\right)$	-0.007	-0.004	-0.011
Ave. Salaried Firm Prod.	0.008	0.004	0.015
Price of Energy	11.628	11.662	11.551
Welfare Gain (% of Consumption)	-1.848	-1.848	-1.848
	PP Δ Rel. to Base.	**PP Δ** Rel. to Base.	**PP Δ** Rel. to Base.
Share of f Firms (N_f/N_s)	0.005	0.002	0.015
Share of f Output in Total Output	-0.732	-0.733	-0.730
f Employment Share	-1.047	-1.047	-1.046
i Salaried Employment Share	-0.250	-0.248	-0.254
Self-Employment Share	1.297	1.295	1.300
Unemployment Rate	0.153	0.153	0.153
LFP Rate	0.368	0.370	0.367
Emissions Abate. Rate (μ_e)	3.461	3.461	3.461
Share of e Producers Using g Tech.	3.666	3.666	3.665
Share of Green Energy	17.515	17.517	17.512
Tax Revenue-Output Ratio	0.144	0.113	0.184

Note: 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. Percent Δ denotes Percent Change. PP Δ Change denotes Percentage-Point Change. Rel. to Base. denotes Relative to Baseline.

Table A15: Long Run Effects of Carbon Tax (25-Percent Reduction in Emissions)—Benchmark Results vs. Alternative Parameterizations and Assumptions 8

Variable	**Benchmark Model**	**Benchmark Model Baseline** $\gamma = 0.05$	**Benchmark Model Fixed LFP**
	(1)	(2)	(3)
	Percent Δ Rel. to Base.	**Percent Δ** Rel. to Base.	**Percent Δ** Rel. to Base.
Total Output	-0.857	-0.609	- 1.598
Consumption	-0.491	-0.313	-1.110
Capital Investment	-9.467	-7.054	-10.007
Total Employment (Level)	0.417	0.238	-0.225
Real Wage f	-0.402	-0.251	-0.293
Real Wage i	-0.398	-0.248	-0.288
Salaried Firms (N_s)	-2.888	-2.156	-4.644
f Firms (N_f)	-2.751	-2.114	-4.511
i Firms (N_i)	-5.859	-2.158	-4.649
f Ave. Idiosync. Prod. $\left(\widetilde{a}_s^f\right)$	-0.034	-0.010	-0.033
i Ave. Idiosync. Prod. $\left(\widetilde{a}_s^i\right)$	-0.007	-0.002	-0.007
Ave. Salaried Firm Prod.	0.008	0.003	0.011
Price of Energy	11.628	8.704	11.935
Welfare Gain (% of Consumption)	-1.848	-1.318	-2.662
	PP Δ Rel. to Base.	**PP Δ** Rel. to Base.	**PP Δ** Rel. to Base.
Share of f Firms (N_f/N_s)	0.005	0.002	0.005
Share of f Output in Total Output	-0.732	-0.596	-1.082
f Employment Share	-1.047	-0.791	-1.436
i Salaried Employment Share	-0.250	-0.161	-0.315
Self-Employment Share	1.297	0.952	1.751
Unemployment Rate	0.153	0.112	0.206
LFP Rate	0.368	0.227	–
Emissions Abate. Rate (μ_e)	3.461	10.337	3.397
Share of e Producers Using g Tech.	3.666	2.462	3.408
Share of Green Energy	17.515	12.639	16.689
Tax Revenue-Output Ratio	0.144	0.136	0.362

Note: 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. Percent Δ denotes Percent Change. PP Δ Change denotes Percentage-Point Change. Rel. to Base. denotes Relative to Baseline.

Table A16: Long Run Effects of Carbon Tax (25-Percent Reduction in Emissions)—Model with Energy Use in Self-Employment

Variable	**Benchmark Model, Energy Use in SE**	**No Green Tech. Adoption Choice, Energy Use in SE**	**No Green Energy, Energy Use in SE**
	(1)	(2)	(3)
	Percent Δ Rel. to Base.	**Percent Δ** Rel. to Base.	**Percent Δ** Rel. to Base.
Total Output	-0.666	-1.240	-2.427
Consumption	-0.483	-0.551	-0.987
Capital Investment	-10.844	-10.627	-11.799
Total Employment (Level)	0.311	0.412	0.768
Real Wage f	-0.575	-0.933	-1.771
Real Wage i	-0.571	-0.927	-1.760
Salaried Firms (N_s)	-1.725	-3.157	-6.161
f Firms (N_f)	-1.672	-3.042	-5.932
i Firms (N_i)	-1.727	-3.161	-6.169
f Ave. Idiosync. Prod. $\left(\widetilde{a}_s^f\right)$	-0.013	-0.028	-0.058
i Ave. Idiosync. Prod. $\left(\widetilde{a}_s^i\right)$	-0.003	-0.006	-0.011
Ave. Salaried Firm Prod.	0.003	0.007	0.014
Price of Energy	11.487	18.116	35.181
Welfare Gain (% of Consumption)	-1.434	-2.118	-3.960
	PP Δ Rel. to Base.	**PP Δ** Rel. to Base.	**PP Δ** Rel. to Base.
Share of f Firms (N_f/N_s)	0.002	0.004	0.008
Share of f Output in Total Output	-0.341	-0.606	-1.207
f Employment Share	-0.492	-0.876	-1.733
i Salaried Employment Share	-0.113	-0.210	-0.416
Self-Employment Share	0.605	1.086	2.149
Unemployment Rate	0.077	0.137	0.270
LFP Rate	0.249	0.354	0.671
Emissions Abate. Rate (μ_e)	3.515	5.085	6.368
Share of e Producers Using g Tech.	3.895	–	–
Share of Green Energy	18.228	9.660	–
Tax Revenue-Output Ratio	0.147	0.285	0.435

Note: 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. Percent Δ denotes Percent Change. PP Δ Change denotes Percentage-Point Change. Rel. to Base. denotes Relative to Baseline.

Table A17: Calibration Differences Between Brazil and Mexico (2019 Data)

Calibration Target	**Brazil**	**Mexico**
Cost of firm registration (% of per capita GNI)	4.2	15.2
Labor force participation rate	64.3	61.2
Employment outside of formal sector	59.9	55.8
Unemployment rate	12.05	5.05
Transition probability of entering SE from unemployment	0.11	0.15
Self-Employment Share	33.1	31.9
GDP loss from pollution damages (% of GDP)	0.71	0.38
Household energy share	23.0	22.0
Informal sector size (% of GDP)	40.0	29.9
Polluting energy share	51.5	91.6
Share of domestic emissions in global emissions	1.3	1.4

Sources: World Bank World Development Indicators, Our World in Data, Bosch and Maloney (2008).

Table A18: Long Run Effects of a 25-Percent Reduction in Emissions From a Carbon Tax in Energy Sector—Brazil vs. Mexico

Variable	**Brazil**	**Mexico**
	Percent Δ Rel. to Base.	**Percent Δ** Rel. to Base.
Total Output	-0.383	-0.730
Consumption	-0.308	-0.749
Capital Investment	-5.811	-8.399
Total Employment (Level)	0.425	1.526
Real Wage Formal Workers	-0.319	-0.981
Real Wage Informal Workers	-0.315	-0.980
Salaried Firms	-0.875	-1.059
Formal Salaried Firms	-0.753	-1.133
Informal Salaried Firms	-0.879	-1.058
Price of Energy	4.608	13.154
Welfare Gain (% of Consumption)	-0.755	-1.447
	PP Δ Rel. to Base.	**PP Δ** Rel. to Base.
Share of Formal Firms	0.004	-0.001
Share of Formal Output in Total Output	-0.086	-0.034
Formal Employment Share	-0.262	-0.575
Informal Salaried Employment Share	-0.226	-0.284
Self-Employment Share	0.488	0.859
Unemployment Rate	0.035	0.132
LFP Rate	0.299	1.020
Share of Energy Producers Using Green Technology	0.781	5.355
Share of Green Energy	11.185	22.047
Tax Revenue-Output Ratio	0.150	0.144

Note: All real variables are expressed in data-consistent terms. Values are rounded to three decimal places. Percent Δ denotes Percent Change. PP Δ Change denotes Percentage-Point Change. Rel. to Base. denotes Relative to Baseline.

A.8 Additional Model Results

Table A19: Long Run Effects of Carbon Tax (25-Percent Reduction in Emissions)—Benchmark Model vs. Model without Green Technology Choice vs. Model without Green Energy

Variable	**Benchmark Model**	**No Green Tech. Adoption Choice**	**No Green Energy**
	(1)	(2)	(3)
	Percent Δ Rel. to Base.	**Percent Δ** Rel. to Base.	**Percent Δ** Rel. to Base.
Total Output	-0.857	-1.452	-2.634
Consumption	-0.491	-0.613	-1.055
Capital Investment	-9.467	-9.602	-11.245
Total Employment (Level)	0.417	0.585	1.041
Real Wage f	-0.402	-0.641	-1.141
Real Wage i	-0.398	-0.635	-1.129
Salaried Firms (N_s)	-2.888	-4.729	-8.503
f Firms (N_f)	-2.751	-4.499	-8.095
i Firms (N_i)	-5.859	-4.737	-8.517
f Ave. Idiosync. Prod. $\left(\widetilde{a}_s^f\right)$	-0.034	-0.057	-0.106
i Ave. Idiosync. Prod. $\left(\widetilde{a}_s^i\right)$	-0.007	-0.011	-0.021
Ave. Salaried Firm Prod.	0.008	0.0133	0.025
Price of Energy	11.628	17.760	19.260
Welfare Gain (% of Consumption)	-1.848	-2.744	-4.847
	PP Δ Rel. to Base.	**PP Δ** Rel. to Base.	**PP Δ** Rel. to Base.
Share of f Firms (N_f/N_s)	0.005	0.008	0.015
Share of f Output in Total Output	-0.732	-1.175	-2.153
f Employment Share	-1.047	-1.675	-3.034
i Salaried Employment Share	-0.250	-0.405	-0.731
Self-Employment Share	1.297	2.080	3.764
Unemployment Rate	0.153	0.245	0.442
LFP Rate	0.368	0.538	0.964
Emissions Abate. Rate (μ_e)	3.461	4.910	5.153
Share of e Producers Using g Tech.	3.666	–	–
Share of Green Energy	17.515	9.040	–
Tax Revenue-Output Ratio	0.144	0.270	0.387

Note: 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. Percent Δ denotes Percent Change. PP Δ Change denotes Percentage-Point Change. Rel. to Base. denotes Relative to Baseline.

Table A20: Long Run Effects of Carbon Tax (25-Percent Reduction in Emissions)—Self-Employment Exacerbates the Adverse Effects of the Carbon Tax

Variable	No Self-Employment		Benchmark Model	
	No Green Tech. Adopt.	With Green Tech. Adopt.	No Green Tech. Adopt.	With Green Tech. Adopt.
	(1)	(2)	(3)	(4)
	Percent Δ Rel. to Base.	Percent Δ Rel. to Base.	Percent Δ Rel. to Base.	Percent Δ Rel. to Base.
Total Output	-1.023	-0.538	-1.452	-0.857
Consumption	-0.582	-0.502	-0.613	-0.491
Capital Investment	-8.232	-8.475	-9.602	-9.467
Total Employment (Level)	0.095	0.144	0.585	0.417
Real Wage f	-1.202	-0.718	-0.641	-0.402
Real Wage i	-1.178	-0.704	-0.635	-0.398
Salaried Firms (N_s)	-1.516	-0.791	-4.729	-2.888
f Firms (N_f)	-1.452	-0.788	-4.499	-2.751
i Firms (N_i)	-1.518	-0.791	-4.737	-5.859
Ave. Salaried Firm Prod.	0.002	0.001	0.0133	0.008
Price of Energy	17.723	11.215	17.760	11.628
Welfare Gain (% of Consumption)	-1.498	-1.079	-2.744	-1.848
	PP Δ Rel. to Base.	PP Δ Rel. to Base.	PP Δ Rel. to Base.	PP Δ Rel. to Base.
Share of f Firms (N_f/N_s)	0.001	0.000	0.008	0.005
Share of f Output in Total Output	0.023	0.001	-1.175	-0.732
f Employment Share	0.037	0.006	-1.675	-1.047
i Salaried Employment Share	-0.037	-0.006	-0.405	-0.250
Self-Employment Share	–	–	2.080	1.297
Unemployment Rate	0.058	0.033	0.245	0.153
LFP Rate	0.100	0.114	0.538	0.368
Emissions Abate. Rate (μ_e)	5.125	3.525	4.910	3.461
Share of e Producers Using g Tech.	–	3.942	–	3.666
Share of Green Energy	9.803	18.371	9.040	17.515
Tax Revenue-Output Ratio	0.263	0.135	0.270	0.144

Note: 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. Percent Δ denotes Percent Change. PP Δ Change denotes Percentage-Point Change. Rel. to Base. denotes Relative to Baseline.

Table A21: Long Run Effects of Carbon Tax (25-Percent Reduction in Emissions)—Benchmark Model vs. Model with Self-Employment Held at Baseline vs. Model without Self-Employment

Variable	Model Without Self-Employment	Benchmark Model	
		SE Share Held Held at Baseline†	Main Results (Table 2)
	(1)	(2)	(3)
	Percent Δ Rel. to Base.	**Percent Δ** Rel. to Base.	**Percent Δ** Rel. to Base.
Total Output	-0.538	-0.534	-0.857
Consumption	-0.502	-0.455	-0.491
Capital Investment	-8.475	-8.826	-9.467
Total Employment (Level)	0.144	-0.062	0.417
Real Wage f	-0.718	-0.661	-0.402
Real Wage i	-0.704	-0.658	-0.398
Salaried Firms (N_s)	-0.791	-1.022	-2.888
f Firms (N_f)	-0.788	-1.021	-2.751
i Firms (N_i)	-0.791	-1.022	-5.859
Ave. Salaried Firm Prod.	0.001	0.000	0.008
Price of Energy	11.215	11.258	11.628
Welfare Gain (% of Consumption)	-1.079	-1.033	-1.848
	PP Δ Rel. to Base.	**PP Δ** Rel. to Base.	**PP Δ** Rel. to Base.
Share of f Firms (N_f/N_s)	0.000	0.000	0.005
Share of f Output in Total Output	0.001	-0.117	-0.732
f Employment Share	0.006	0.001	-1.047
i Salaried Employment Share	-0.006	-0.001	-0.250
Self-Employment Share	–	0.000*	1.297
Unemployment Rate	0.033	0.239	0.153
LFP Rate	0.114	0.126	0.368
Emissions Abate. Rate (μ_e)	3.525	3.519	3.461
Share of e Producers Using g Tech.	3.942	3.913	3.666
Share of Green Energy	18.371	18.283	17.515
Tax Revenue-Output Ratio	0.135	0.147	0.144

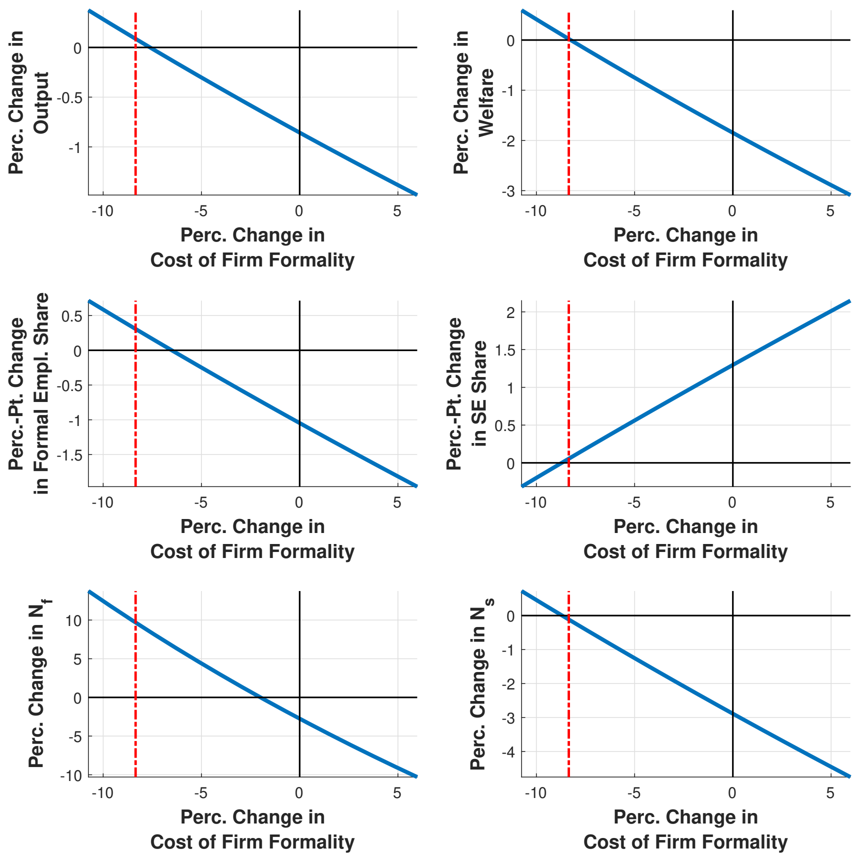
Note: Average salaried firm productivity (Ave. Salaried Firm Prod.) is defined as $(N_f/N_s)\, z_f \widetilde{a}_s^f + (N_i/N_s)\, z_i \widetilde{a}_s^i$. In the absence of self-employment, the formal employment share is $(n_f)\,/\,(n_f + n_i)$. In the benchmark model, the formal employment share is $(n_f)\,/\,(n_f + n_i + n_o)$ 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. Percent Δ denotes Percent Change. PP Δ Change denotes Percentage-Point Change. Rel. to Base. denotes Relative to Baseline. † When we increase the carbon tax to generate a 25-percent reduction in emissions, we increase the value of parameter ϕ_o so that the share of self-employment n_o (and therefore the level s_o) remains fixed at its baseline (no-carbon-tax) level. Changing other parameters associated with self-employment ($z_o$or κ_o) delivers the same conclusions. * denotes a target.

Table A22: Long Run Effects of Joint Carbon Tax (25-Percent Reduction in Emissions) and Exogenous Reduction in φ_f—Benchmark Model vs. Models without Technology Adoption and Without Green Energy

Variable	**Benchmark Model Carbon Tax and Exogenous Reduction in φ_f**	**No Green Tech. Adopt., Carbon Tax and Exogenous Reduction in φ_f**	**No Green Energy, Carbon Tax and Exogenous Reduction in φ_f**
	(1)	(2)	(3)
	Percent Δ Rel. to Base.	**Percent Δ** Rel. to Base.	**Percent Δ** Rel. to Base.
Total Output	0.086	-0.565	-1.850
Consumption	0.190	0.046	-0.448
Capital Investment	-9.076	-9.215	-10.924
Total Employment (Level)	-0.094	0.085	0.566
Real Wage f	0.110	-0.167	-0.739
Real Wage i	0.110	-0.164	-0.731
Salaried Firms (N_s)	-0.116	-2.113	-6.176
f Firms (N_f)	9.680	7.598	3.348
i Firms (N_i)	-0.460	-2.453	-6.513
Ave. Salaried Firm Prod.	0.542	0.548	0.565
Price of Energy	11.130	17.844	33.597
Welfare Gain (% of Consumption)	0.022	-0.962	-3.251
	PP Δ Rel. to Base.	**PP Δ** Rel. to Base.	**PP Δ** Rel. to Base.
Share of f Firms (N_f/N_s)	0.332	0.336	0.347
Share of f Output in Total Output	0.345	-0.118	-1.136
f Employment Share	0.307	-0.362	-1.802
i Salaried Employment Share	-0.362	-0.520	-0.854
Self-Employment Share	0.055	0.882	2.656
Unemployment Rate	0.004	0.102	0.311
LFP Rate	-0.057	0.124	0.572
Emissions Abate. Rate (μ_e)	3.556	5.108	6.194
Share of e Producers Using g Tech.	4.081	–	–
Share of Green Energy	18.790	9.742	–
Tax Revenue-Output Ratio	0.148	0.284	0.412

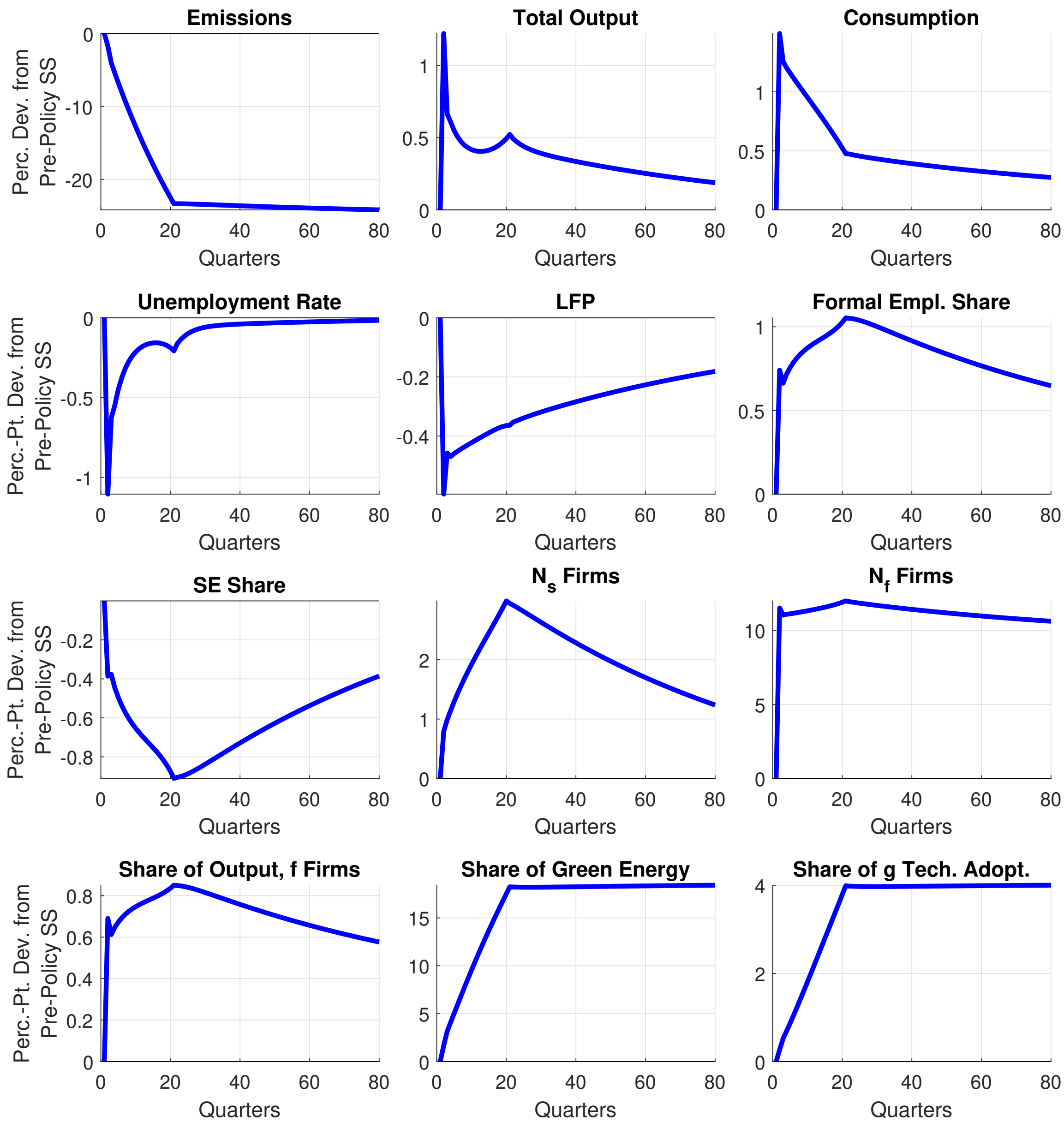
Note: Average salaried firm productivity (Ave. Salaried Firm Prod.) is defined as $(N_f/N_s)\, z_f \widetilde{a}_s^f + (N_i/N_s)\, z_i \widetilde{a}_s^i$. The formal employment share, $(n_f)\,/\,(n_f + n_i + n_o)$, is the mirror image of the informal employment share. The self-employment share is defined 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. Percent Δ denotes Percent Change. PP Δ Change denotes Percentage-Point Change. Rel. to Base. denotes Relative to Baseline.

Figure A3: Long Run Effects of Carbon Tax (25-Percent Reduction in Emissions) Under Different Simultaneous Changes in the Baseline Cost of Firm Formality φ_f (Benchmark Model)



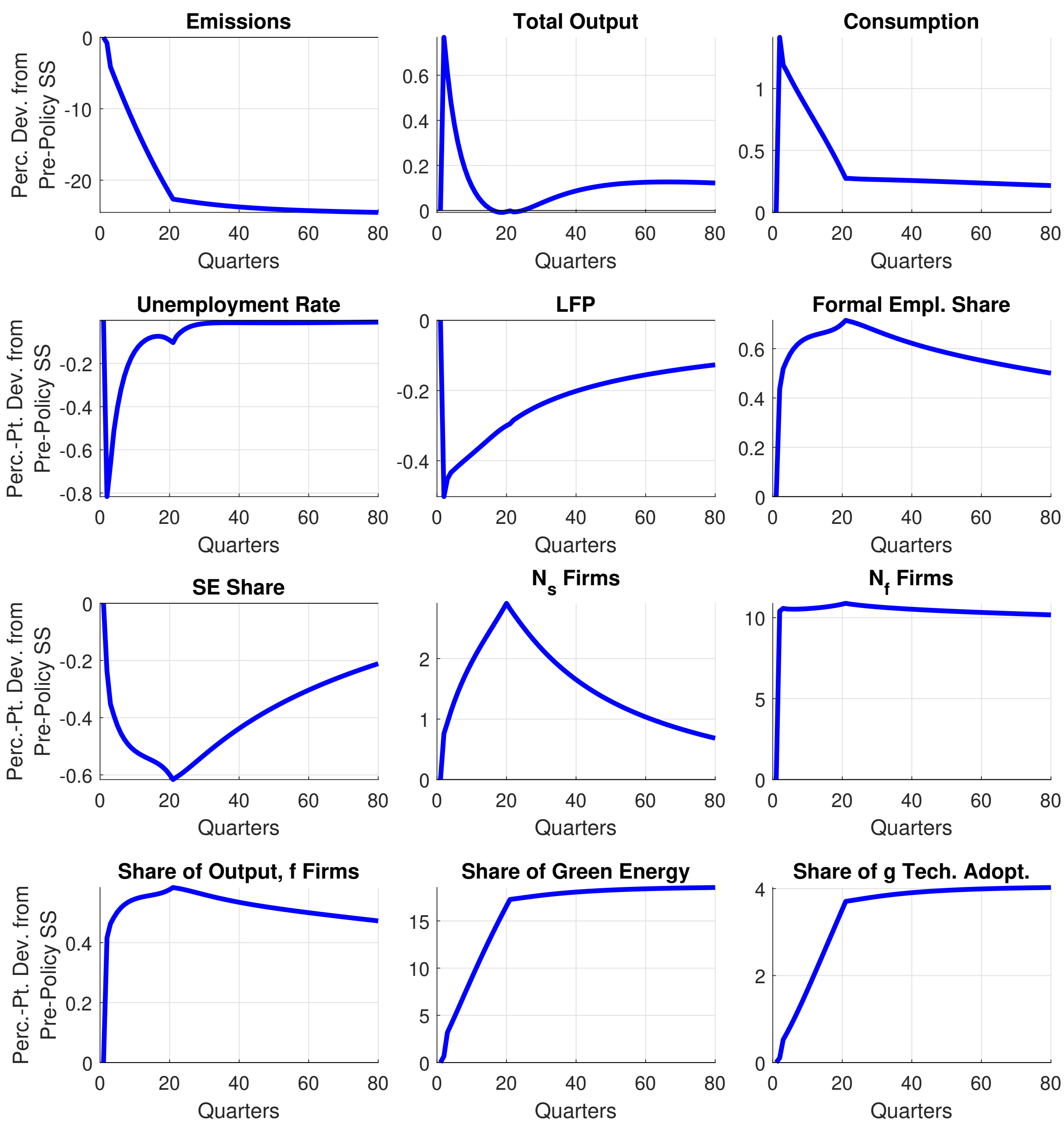
Note: The formal employment share, $(n_f)\,/\,(n_f + n_i + n_o)$, is the mirror image of the informal employment share. The self-employment share is defined as $(n_o)\,/\,(n_f + n_i + n_o)$. The vertical dash-dotted red line marks the 8.35-reduction in the cost of firm formality considered in the experiment in column (3) of Table 4. The vertical black line at zero marks the benchmark carbon-tax scenario with no change in the cost of firm formality (the experiment shown in column (2) of Table 4).

Figure A4: Transitional Dynamics with Exogenous Reduction in Cost of Firm Formality φ_f and Gradual Increase in Carbon Tax (25 Percent Reduction in Emissions)—Benchmark Model



Note: 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.

Figure A5: Transitional Dynamics with Exogenous Reduction in Cost of Firm Formality φ_f and Gradual Increase in Carbon Tax (25 Percent Reduction in Emissions)—Benchmark Model with i- and f-Firm Capital Adjustment Costs



Note: 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. We assume that i and f firms face a capital adjustment cost given by $(\varphi_k/2)(k_{j,t}-k_{j,t-1})^2$ for $j \in \{i, f\}$ and set $\varphi_k = 5$ as a baseline.

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