IDB WORKING PAPER SERIES Nº IDB-WP-1429

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April 2023

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Cataloging-in-Publication data provided by the
Inter-American Development Bank
Felipe Herrera Library

Finkelstein Shapiro, Alan.
Climate policies, labor markets, and macroeconomic outcomes in emerging economies / Alan Finkelstein Shapiro, Victoria Nuguer.
p. cm. — (IDB Working Paper Series; 1429)
Includes bibliographic references.
1. Labor market-Latin America-Econometric models. 2. Fiscal policy-Latin America-Econometric models. 3. Carbon taxes-Latin America-Econometric models. 4. Environmental policy-Latin America-Econometric models. 5. Developing countries-Environmental aspects-Econometric models. 6. Green technology-Latin America-Econometric models. I. Nuguer, Victoria. II. Inter-American Development Bank. Department of Research and Chief Economist. III. Title. IV. Series.
IDB-WP-1429

http://www.iadb.org

Abstract[*]

We study the labor market and macroeconomic effects of introducing a carbon tax in the energy sector in emerging economies (EMEs) by building a framework with equilibrium unemployment and firm entry that incorporates key elements of the distinct employment and firm structure of EMEs. Our model endogenizes the adoption of green energy-production technologies—a core element of policy discussions regarding the transition to a low-carbon economy. Calibrating the model to EME data, we show that a carbon tax fosters greater green technology adoption and increases the share of green energy produced. However, the tax leads to higher energy prices, which reduce salaried firm creation and formal employment and increase self-employment, labor participation, and unemployment. As a result, the tax generates output and welfare losses. Green technology adoption plays a key role in limiting the quantitative magnitude of these losses, while the response of self-employment is crucial to explaining the adverse labor market and macroeconomic effects of the policy. Given this finding, we show that a carbon tax coupled with a plausible reduction in the cost of becoming a formal firm can offset the adverse effects of the tax and generate a transition to a lower-carbon economy with minimal economic costs. Finally, we show that lowering green-technology adoption costs or the cost of green-energy production inputs—two alternative climate policies—reduces emissions while limiting the output and welfarecosts compared to a carbon tax.

JEL classifications: E20, E24, E61, H23, J46, J64, O44, Q52, Q55
Keywords: Environmental and fiscal policy, Carbon taxes, Endogenous firm creation, Green technology adoption, Search frictions, Unemployment, Labor force par ticipation, Informality and self-employment, Emerging economies

[*] We thank Diana MacDonald, Luis A. Fernández Intriago, Amartya Lahiri, Yu-chin Chen, Henry Siu, Jesse Perla, Gorkem Bostanci, Giovanni Gallipoli, Patrick Baylis, and Katherine Wagner for helpful conversations, and seminar participants at the Vancouver School of Economics, the IMF Department Research Series on Climate Change, ITAM, and the ITESM for useful comments and feedback. This project received funding support from the Inter-American Development Bank. The views in this paper are solely the responsibility of the authors and should not be interpreted as representing the views of the Inter-American Development Bank, its Executive Board, or its Management. Any errors are our own.
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1 Introduction

We study the labor market and macroeconomic effects of introducing a carbon tax in emerging economies (EMEs).[1] A focus on these economies is important for at least two main reasons. First, the latest data suggest that the combined annual carbon dioxide emissions of EMEs represent almost 10 percent of global emissions, which makes the group of EMEs the largest carbon dioxide emitter after China, the United States, and the group of EU-28 countries. Second, compared to advanced economies, EMEs continue to rely more heavily on energy from polluting sources like coal, gas, and oil. While their contribution to global GDP has remained roughly unchanged in the last 20 years—with advanced economies seeing a reduction in their share and other developing economies seeing an increase in their share—the contribution of EMEs to global emissions has continued to rise. In fact, while advanced economies have exhibited a decoupling of economic growth from the growth in carbon emissions, economic growth in EMEs is still associated with growing emissions (see Figure 1 in Section 2). According to IMF WEO (2020), given the standing of EMEs in the world, reductions in emissions by EMEs will be needed to limit the costs and damages from climate change since emissions reductions by advanced economies alone are insufficient to limit these costs. Amid the global impetus to limit emissions, several EMEs are therefore considering the introduction of carbon taxation (or its expansion if a carbon-tax scheme is already in place); see Figure ES.1 in World Bank (2020).

Policy discussions of carbon taxation and other climate policies in EMEs are all the more relevant given these economies' distinct firm and employment structure, characterized by higher barriers to firm formality, the prevalence of small, informal, and less productive salaried firms, and much larger shares of self-employment (the majority of which is informal or unregistered) compared to advanced economies. The dominance of informal firms and

[1] We focus on the group of EMEs that has been extensively studied in the international macro literature, and that shares many employment, firm, and production characteristics. This group is comprised of: Argentina, Brazil, Chile, Colombia, Indonesia, Malaysia, Mexico, Peru, the Philippines, South Africa, Thailand, and Turkey. We exclude China and India given their size and their distinct employment and production structure compared to EMEs (for example, India has a much larger share of agricultural employment and production relative to EMEs). See Adrian, Bolton, and Kleinnijenhuis (2022) for the impetus to introduce carbon pricing in order to reduce global emissions, and for a quantification of the economic costs and gains of phasing out coal, an important contributor to these emissions.

employment in EMEs is reflected in a limited ability to collect tax revenue, weak formal safety nets for workers who must go through job transitions, large productivity differentials between formal and informal firms, and lower aggregate productivity, all of which limit EMEs' growth potential (La Porta and Shleifer, 2014). These growth barriers may be further exacerbated by a carbon tax, thereby raising the economic costs and risks associated with the transition to a low-carbon economy. More broadly, a key unanswered question is whether the policy lessons from existing quantitative frameworks that analyze the labor market and aggregate effects of carbon taxation—models that are primarily rooted in the structure of advanced economies—carry through to EMEs.

Against this backdrop, we build a general equilibrium search and matching framework with self-employment, negative pollution externalities stemming from the production of energy, and endogenous salaried firm entry and selection into formality that captures key elements of the employment and firm structure of EMEs. Self-employment, the number of formal and informal salaried firms and their employment, firm productivity, and the economy's production structure are endogenous and therefore respond to policy. In the model, households and firms use energy. The production of energy generates harmful carbon emissions as a by-product, which contribute to pollution and reduce aggregate productivity. While energy producers can be subject to a carbon tax on their emissions, they can undertake costly abatement to limit the burden of the tax.

The adoption of existing green (emissions-free) technologies in key sectors such as energy can play a crucial role alongside carbon pricing in meeting emissions reduction targets. The cost of these technologies is steadily falling, which facilitates their adoption and therefore the transition to a low-carbon economy (Pigato et al., 2020; IFC, 2021). While the majority of these technologies are developed and produced in advanced economies, green technologies are increasingly being adopted by EMEs as part of their ongoing efforts to limit their emissions, and a carbon tax and other climate policies can further incentivize the adoption of these technologies. To account for this important extensive margin of adjustment, in our framework, energy producers can choose between a regular (polluting) or green (emissions-free) production technology. This makes the share of energy producers that use green technologies—the polluting-green technological composition of energy production—endogenous and therefore responsive to changes in structural, market, and policy factors.

We calibrate the model to a representative EME using data on the average composition of employment, firms, economic activity, and the polluting-green energy mix for the group of EMEs listed in footnote 1. We then analyze the labor market and macroeconomic effects of introducing a carbon tax in the energy sector that reduces emissions by 25 percent—a reduction that is in line with policy scenarios in IMF WEO (2022).

Our model analysis delivers four main findings. First, in the long run, the carbon tax leads to an increase in both the share of green energy and the share of energy producers using green technologies. However, this endogenous shift in the production of energy leads to higher energy prices, lower new salaried-firm creation, a reduction in the number of formal firms and in the share of formal employment, and to an increase in self-employment that is strong enough to bolster overall labor force participation. By reshaping the composition of employment and production towards (informal) self-employment, the carbon tax ultimately reduces consumption, GDP, and welfare, and raises unemployment and labor informality. Despite these long-term output and welfare costs, the transition path is characterized by a short-term increase in consumption, formal salaried employment, and salaried formal firms, and by a temporary decline in the unemployment rate. These short-term positive effects are explained by the fact that the carbon tax drastically reduces the demand for capital among polluting energy producers, thereby freeing up capital for salaried firms.

Second, energy producers' ability to adopt green technologies plays a key role in significantly limiting the long-term adverse effects of the carbon tax on labor markets, firms, and aggregate economic activity in EMEs. Abstracting from this margin—that is, having representative polluting and green energy producers but no choice to change energy production technologies—implies that the output and welfare costs are almost twice as large. Abstracting from green energy altogether leads to an almost threefold increase in the output and welfare costs of the carbon tax. Thus, green technology adoption is a fundamental margin that significantly limits the economic and welfare costs of the tax.

Third, the carbon-tax-induced increase in self-employment—a core employment category in EMEs—is an important contributor to the reduction of output and welfare as resources are reallocated away from more productive salaried firms and towards less productive self-employment, and the increase in search for self-employment opportunities amid lower salaried job creation bolsters overall labor force participation. A simple counterfactual model experiment shows that the increase in self-employment stemming from the carbon tax is responsible for roughly 30 percent of the output cost and 45 percent of the welfare cost of the carbon tax in the long run.

Finally, given this last finding, we analyze the impact of a joint policy that reduces the (regulatory) cost of becoming a formal firm while achieving the original 25-percent reduction in emissions using a carbon tax. Using EME data to discipline the quantitative reduction in the cost of becoming a formal firm in the model, we show that 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. Critically, this important finding holds as long as energy producers have the choice to adopt green technologies. The reason behind this result is simple: the reduction in the cost of firm formality is strong enough to offset the otherwise adverse effects of the carbon tax on firms' decisions to enter the market, become formal, and hire salaried workers. In fact, the quantitative (and data-disciplined) reduction in the cost of firm formality amid a carbon tax leads to an equilibrium increase in both the number of formal firms and in the overall number of salaried (formal and informal) firms. In turn, the job creation decisions of these firms bolster formal employment and limit the extent to which individuals search for self-employment opportunities. This prevents the reallocation of resources away from formal salaried firms and into self-employment that would take place under the carbon tax alone, resulting in a positive (albeit quantitatively small) increase in output and welfare. More broadly, this experiment points to a low-cost, plausible policy that EMEs can implement alongside carbon taxation in order to foster the transition to a low-carbon economy with minimal short- and long-term economic costs.

Our main analysis focuses on the introduction of a carbon tax in the energy sector. To put the effects of the carbon tax in perspective, we exploit the presence of the green technology adoption margin in our framework and consider the effects of two alternative climate policies that directly promote the adoption of these technologies or the production of green energy. In particular, reducing the cost of green-technology adoption to achieve the original 25-percent reduction in emissions delivers the same qualitative labor-market and aggregate effects as a carbon tax, but smaller quantitative output and welfare costs. In contrast, reducing the cost of green-energy production inputs—in the model, the cost of green capital—to achieve the original 25-percent reduction in emissions results in a *reduction* in equilibrium energy prices. The lower price of energy bolsters salaried firm creation, the number and share of formal firms, and formal employment and output, and delivers output and welfare *gains*. These results further highlight the central role of policy-induced changes in energy prices in shaping the labor market and macroeconomic effects of climate policies in EMEs.

The rest of the paper is structured as follows. Section 2 summarizes related literature and places our work in the context of existing work on the macroeconomic and labor market effects of carbon taxes. It also presents key facts on the employment and firm structure in EMEs, select characteristics of the energy sources and energy mix, estimated damages from climate change, and the relative advantage in low-carbon (or green) technologies in these economies. Section 3 describes the model. Section 4 presents our quantitative analysis and findings and discusses the key economic mechanisms behind our main results. Section 5 concludes.

2 Related Literature and Key Facts

2.1 Related Literature and Contributions

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.[2]

Macro-Climate Literature in Advanced Economies: Green Technologies Acemoglu et al. (2016) analyze the transition of the United States to a clean-technology economy in an endogenous growth model and find that subsidies to clean-technology innovation and

[2]For empirical evidence on the employment and macroeconomic consequences of carbon taxes in advanced economies, see Metcalf and Stock (2020, 2022).

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, Correani, and Di Dio (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.[3] 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 United States 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.[4] Fried, Novan, and Peterman (2021b) study how climate policy uncertainty in the United States shapes emissions reductions and show that policy uncertainty has a small effect on emissions (via reduced investment and the greater use of cleaner technologies) compared to the implementation of a carbon tax. In recent work, Adao, Narajabad, and Temzelides (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. For example, Fried, Novan, and Peterman (2021a) show that a U.S. carbon tax policy whose revenue is used to reduce capital income taxes and to make labor income taxes more progressive is welfare maximizing. In turn, Barrett et al. (2021) show that amid endogenous technological change in fuel sources, carbon taxes are

[3] Fischer and Springborn (2011), Heutel (2012), and Annicchiarico and Di Dio (2015, 2017) analyze the interaction between environmental policy and business cycle dynamics in one-sector environments, with Annicchiarico and Di Dio (2015, 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 Ferrari and Pagliari (2022) 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 U.S.-Euro Area context. For recent studies on the international transmission of environmental policy via trade, see Egger et al. (2021).

[4] In earlier work, Goulder and Mathai (2000) study how the response of technological change to policy affects the design of carbon taxes. Popp (2002) shows empirically how energy prices have a strong positive impact on innovation in energy-efficient technologies in the United States

play an important role in shaping the welfare effects of climate policies. In turn, having an endogenous production structure with firm selection into formality and an endogenous polluting-green energy structure allows us to jointly assess how climate policies affect the endogenous productivity profile of the economy, the composition of employment, firms, and energy, and the energy transition towards a lower-carbon environment. A key finding that emerges only as a result of our endogenous polluting-green energy structure is that energy producers' ability to adopt green technologies can significantly limit the adverse labor market and aggregate effects of a carbon tax. Moreover, if combined with other plausible and implementable policies that facilitate firm formality, a carbon tax can deliver lower emissions alongside positive labor market, macroeconomic, and welfare outcomes, in both the short and long term.

Turning to Cavalcanti, Hasna, and Santos (2022), we complement their work in five main ways. First, our framework focuses on the distinct structure of labor markets and firms in EMEs as opposed to skill heterogeneity, with the composition of employment between salaried and self-employment and the endogenous firm structure being at the core of our model and main findings. Second, by modeling the labor market via search frictions, our analysis directly speaks to the impact of a carbon tax on unemployment and labor force participation in these economies. Third, as emphasized above, instead of adopting a representative energy-producer structure where both polluting and green energy must be used in the production of total energy, our model endogenizes the technological composition of total energy production by allowing green technology *adoption* to be an explicit margin of adjustment for energy producers. That is, our model features not just an intensive margin of energy usage but also an extensive margin. As noted in Section 1, this implies that with an ambitious-enough climate policy, our framework can generate an outcome where the economy can in principle cease to rely on polluting technologies—a full transition to a zero-carbon economy. Fourth, by incorporating salaried firm formality and informality in a context where formality is a firm's choice, we are able to assess the productivity and formality consequences of climate policies in EMEs. Finally, the tractability of our model allows us to quantitatively characterize both the steady-state effects of climate policies as well as the policy-induced transition path towards a lower-carbon economy. Reidt (2021), Fern ¨ndezIntriago and MacDonald (2022), and Cavalcanti, Hasna, and Santos (2022) all abstract from characterizing this transition.

2.2 Firms and Labor Markets, Energy and Climate Risk, and Green Technologies in EMEs

We focus on a well-known group of EMEs comprised of Argentina, Brazil, Chile, Colombia, Indonesia, Malaysia, Mexico, Peru, the Philippines, South Africa, Thailand, and Turkey.[5] These economies share several labor market and firm characteristics that make them distinct from advanced economies, but are also different from low-income economies by having much lower shares of agricultural employment in total employment—an employment category that we abstract from analyzing explicitly. In addition, once we move beyond advanced economies and China, the EMEs we consider are responsible for the bulk of carbon emissions in their respective regions, thereby making them a natural group to study in the context of carbon taxation and climate policy.[6]

Employment and Firm Structure in EMEs Table 1 provides a visual summary of the following three main facts about the employment and firm structure of EMEs:[7]

1. Self-employment—most of which is categorized as informal—accounts for almost 40 percent of total employment, while total (self-employed and salaried) informal employment represents more than 50 percent of total employment;

2. More than 95 percent of firms are micro, small, and medium enterprises (MSMEs), and more than 70 percent of those firms are informal;

[5] Even though Indonesia is not always included in the standard group of EMEs studied in the literature, Indonesia is a key contributor to carbon emissions in South East Asia alongside Malaysia and Thailand, and has a very similar employment and firm structure to the other EMEs we consider.

[6] 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 United States and Canada (Global Carbon Project).

[7] Per 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.

3. Formal small, medium, and large (SML) firms account for less than 15 percent of the total number of SML firms but employ more than 60 percent of formal workers.

For future reference in Section 3, we note that employment in the energy sector in EMEs—a key source of carbon dioxide emissions—represents, on average, only between 0.6 and 1.2 percent of total employment—a minuscule fraction of total employment in these economies.

Table 1: 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, and 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 are 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).

The prevalence of informal firms in EMEs is particularly important given the well-known presence of large productivity differentials between formal and informal firms (La Porta and Shleifer, 2014; Amin et al. 2019). To put these four facts in perspective, advanced economies have an average share of self-employment in total employment of 14 percent, a firm informality share of roughly 30 percent, and almost 70 percent of formal employment in formal SML firms (IFC Enterprise Finance Gap 2010).[8]

Energy Sources, Climate-Driven Damages, and Low-Carbon Technologies in EMEs Table 2 summarizes the following facts about EMEs' total energy composition, climate-driven damages, and their relative advantage in the development of low-carbon (or green) technologies:

1. Fossil fuels (coal, gas, and oil) represent more than 80 percent of these economies' current energy sources, and almost 65 percent of their electricity sources (similar facts hold if we consider energy and electricity consumption);

2. An increase in temperature of $3°C$ is estimated to reduce GDP in EMEs by an average of 3.7 percent, and EMEs face greater climate-driven risk compared to advanced economies (IMF Climate Dashboard);

3. EMEs have lower export potential of low-carbon technology products (a comparative disadvantage in these products) compared to advanced economies.

[8] The group of advanced economies is comprised of: 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.

Table 2: 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.

To put the facts above in perspective, in advanced economies, energy and electricity from fossil fuels represent 73 percent of total energy and 40 percent of total electricity, respectively. Also, in those same economies, an increase in temperature of $3°C$ would be associated with an average increase in GDP of 0.69 percent (driven primarily by increased tourism; see Roson and Sartori, 2016). Finally, advanced economies are considerably more prone to exporting low-carbon technology products (with an average index of comparative advantage in these goods of 0.95, including at least seven advanced economies with an index above 1, vs. an average index of 0.51 in EMEs). Indeed, 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, EMEs' progress in shifting the total energy composition towards renewables and other green energy sources relies on imported low-carbon technologies from advanced economies and less so on the domestic creation and production of these technologies.

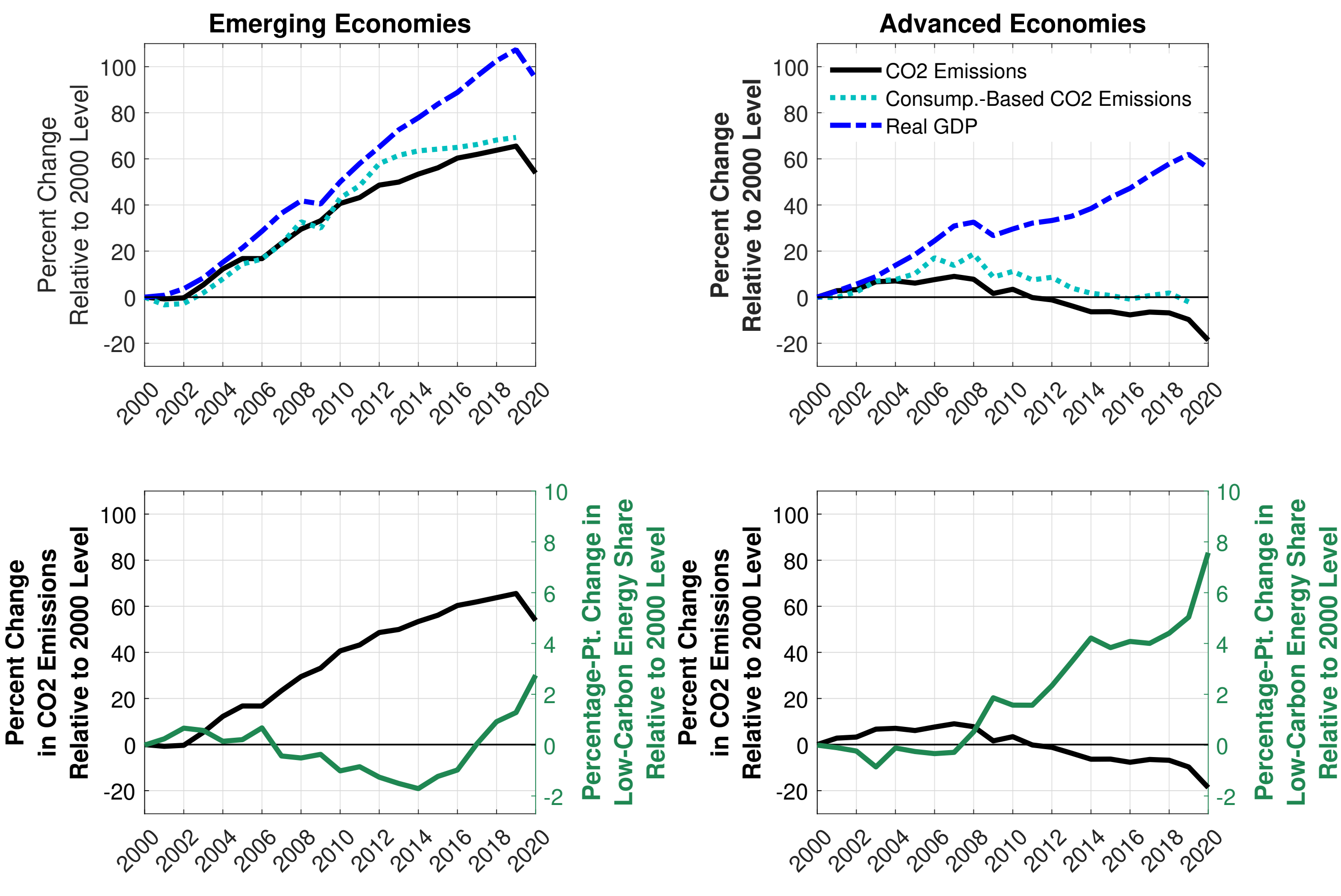
Carbon Dioxide Emissions and Economic Activity in EMEs In the last 20 years, advanced economies have been able to continue to grow while limiting, and eventually reducing, the growth in carbon emissions.[10] This fact holds even if we consider consumption-based measures of carbon emissions, which adjust for the potential offshoring of pollution-generating production in these economies. In contrast, in the same time span, economic growth in EMEs has been accompanied by a steady increase in carbon emissions. These facts are summarized in the two top panels of Figure 1 and hold even if we consider emissions and real GDP in per capita terms (see Figure A1 in Appendix A.1). In turn, the bottom panels of the same figure show the growth in carbon emissions and the change in the share of low-carbon energy in each country group relative to year 2000. The decoupling between the growth in carbon emissions and economic growth in advanced economies around 2010 coincides with a steady and rapid increase in the share of low-carbon energy, which is partly rooted in the development and adoption of green technologies. In contrast, in the same time frame, the share of low-carbon energy in EMEs remained unchanged or exhibited

[9] See Glachant et al. (2013) for related evidence on climate innovation across countries, low-carbon patent inflows, and capital-goods imports in EMEs. Also, see Dussaux et al. (2017) on the importance of intellectual property rights for the transfer of low-carbon technologies from advanced economies to EMEs.

[10] For a summary of the link between economic growth and carbon emissions, see Ritchie (2021).

a slight decrease, though this pattern started to reverse starting in 2017, with the share of low-carbon energy exhibiting a steady increase.

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

Based on the facts in Tables 1 and 2, Section 3 presents a search and matching model with firm entry, endogenous salaried-firm and salaried-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 (meant to reflect its imported, non-generic nature compared to more standard physical capital).

3 The Model

We consider a closed economy comprised of production firms, households, energy producers, and a passive government represented by exogenous fiscal (carbon-tax) policy. Households consume energy as part of their consumption bundle while production firms use energy as one of their inputs. The labor market is characterized by search and matching frictions that give rise to equilibrium unemployment, and the production structure features endogenous firm entry in the spirit of Bilbiie, Ghironi, and Melitz (2012).[11]

There are two categories of production firms: salaried and self-employed firms. Total output is a composite of output produced by monopolistically competitive salaried firms whose entry is endogenous and subject to sunk costs, and output produced by self-employed (or owner-only) firms whose entry is also endogenous. The creation of self-employed firms stems from households' labor force participation decisions. While self-employed firms rely on owner-supplied labor as their sole input, salaried firms use salaried labor, physical capital, and energy as inputs.[12] Moreover, once salaried firms enter the market, they must choose to adopt one of available two production technologies based on their realized idiosyncratic productivity. Salaried firms with a high-enough realized idiosyncratic productivity level adopt a more productive and capital-intensive technology compared to salaried firms with low idiosyncratic productivity, but only after incurring a fixed cost.[13] Salaried firms that

[11]See Patra (2020) for a version of the workhorse Bilbiie, Ghironi, and Melitz (2012) framework with energy as an additional input.

[12]As noted in Section 4.2.4 and shown in Table A4 of Appendix A.5, our main results and conclusions remain unchanged if we assume that the self-employed also use energy as an input.

[13]The decision of a salaried firm to remain informal or become formal follows broadly the way in which firms decide whether to export their output or sell domestically in Ghironi and Melitz (2005); whether to offshore production or produce domestically in Zlate (2016); whether to adopt digital technologies or

adopt the more productive and capital-intensive technology are labeled as formal, and the fixed cost of adopting this technology can be interpreted as the cost of becoming a formal firm.

This endogenous salaried-firm structure has two related advantages. First, it allows us to tractably capture the formal-informal salaried firm structure that characterizes most EMEs, where informal salaried firms tend to use a less productive and capital-intensive technology, while formal salaried firms incur additional operating costs (including those associated with being registered with local government and tax authorities) and, in return, have access to a more productive and capital-intensive technology.[14] By letting firms decide which technology they adopt, we endogenize the degree of firm formality. Second, our structure allows us to consider how climate policies shape the endogenous productivity and formal-informal profiles of salaried firms, where the prevalence of firm formality can have aggregate implications.

A representative household has a unit mass of household members. The household owns all production firms and energy producers and makes labor force participation decisions by choosing their members' search behavior across the three categories of employment: salaried employment in informal firms, salaried employment in formal firms, and self-employment. The household derives utility from a consumption bundle of goods and energy, which are assumed to be complements, and disutility from its members' participation in the labor market.

There is a fixed measure of monopolistically competitive energy producers normalized to one. Each energy producer uses physical capital to produce.[15] A novel feature of our frame-

use a standard production technology in Finkelstein Shapiro and Mandelman (2021); and whether to use a polluting production technology or to adopt green production technologies in Finkelstein Shapiro and Metcalf (2023).

[14]See, for example, Amin, Ohnsorge, and Okou (2019). Two concrete examples of the benefits of being formal include better access to formal finance (which facilitates greater investment in capital or more cutting-edge technologies) and basic legal/institutional protections, both of which tend to be associated with greater firm productivity. In turn, the fixed cost associated with the more productive technology embodies the cost of being formal (for example, the regulatory costs of registering the firm with local tax authorities and maintaining the required permits necessary to operate, or the resource costs that firms have to incur to access formal credit markets). We abstract from explicitly modeling improved access to formal finance—an important benefit of being formal and a factor that is associated with greater productivity—to keep our framework tractable. Instead, we assume that having access to a more productive technology partly reflects better access to formal finance.

[15]As noted in Section 2, ILO data show that a minuscule fraction of the employed labor force in EMEs is in the energy sector (on average, between 0.6 and 1.2 percent of total employment depending on the economic activities that are included in the sector). Given this very small share of employment in the sector and the

work is that energy producers can choose the production technology they use based on their idiosyncratic productivity. Energy producers with idiosyncratic productivity below an endogenously determined threshold use a regular production 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 economic damages via reduced aggregate productivity, where these damages are taken as given by energy producers—a negative environmental externality. Energy producers using the regular, polluting technology face a carbon tax on their emissions, and they can reduce their carbon-tax burden by incurring emissions-abatement expenditures.

Energy producers with idiosyncratic productivity above the threshold incur a fixed cost and adopt a green (emissions-free) production technology. Since this technology does not generate emissions, it is not subject to the carbon tax. This technology requires a different type of physical capital relative to the capital used with the regular technology—this alternative capital represents the technology-specific capital associated with green technologies, which is often imported by EMEs. As such, we assume that the price of this type of capital is exogenous.[16] The energy produced by each endogenous energy-producer category is aggregated and supplied as an energy bundle to households and production firms. Importantly, this energy production structure makes the polluting-green technological composition of energy in the economy—and therefore the possibility of a transition to a low-carbon economy from a technological point of view—endogenous.[17] As a baseline, we assume that the carbon-tax revenue is transferred lump-sum to households.

The production and labor market structure in our framework is an adaptation of Finkelstein Shapiro and Mandelman (2021), who analyze the link between firm digital adoption and labor market outcomes in developing countries using a search-and-matching model where

fact that we use search frictions to model the labor market, we abstract from introducing labor as an input in the energy sector.

[16] Given the complexity of our baseline framework, we abstract from explicitly modeling an open economy with an import margin for green technologies and inputs and make the simplifying assumption that for EMEs, the price of green capital is not influenced by their demand and is exogenously determined. See Barrett (2021) for recent work on the international diffusion of technologies and their role in addressing climate change.

[17] See Finkelstein Shapiro and Metcalf (2023) for a U.S.-focused framework where the endogenous polluting-green technological composition is present at the goods-production level—that is, production firms decide whether to use a polluting or green technology to produce—as opposed to the energy-production level.

households make salaried and self-employment labor force participation decisions, salaried-firm entry is endogenous, and heterogeneous salaried firms make decisions on the adoption of information and communication technologies (ICT). While the supply side of the labor market in our model is the same as in their model, we modify their framework in three ways. First, instead of focusing on salaried firms' decisions over the adoption of ICT, we consider salaried firms' decisions to become formal, where doing so entails a fixed cost but is associated with a more productive and capital-intensive technology. Second, we assume that households face energy expenditures and that salaried firms use salaried labor, physical capital, and energy to produce. Third, we introduce energy producers who choose whether to use a regular production technology that, as a byproduct, generates harmful emissions and damages reflected in lower aggregate productivity (a negative environmental externality), or to adopt a green technology (subject to a fixed cost), thereby making the dirty-green technological composition of energy production endogenous.

3.1 Production Structure

3.1.1 Total Output

Total output in the economy 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 the substitutability between salaried and self-employment output. A perfectly-competitive final goods firm chooses $Y_{s,t}$ and $Y_{o,t}$ to maximize profits $\Pi_{y,t} = [P_t Y_t - p_{s,t} Y_{s,t} - p_{o,t} Y_{o,t}]$ subject to the output aggregator Y_t, where P_t is the aggregate price index, and $P_{s,t}$ and $P_{o,t}$ are the nominal prices of total salaried output and total self-employment output, respectively. It is straightforward to show that $Y_{s,t} = (p_{s,t})^{-\phi_y} Y_t$ and $Y_{o,t} = (p_{o,t})^{-\phi_y} Y_t$, where $p_{s,t} = P_{s,t}/P_t$ and $p_{o,t} = P_{o,t}/P_t$. It follows that 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

There is an endogenous measure of monopolistically competitive salaried production firms whose entry is subject to sunk costs. For expositional clarity in the description of labor market frictions and salaried firms' choices of technology, we assume that each salaried firm uses intermediate goods to produce, where the production of intermediate goods is carried out by a representative intermediate-goods firm that relies on labor (subject to search and matching frictions), physical capital, and energy.[18] Depending on salaried firms' idiosyncratic productivity upon entry, salaried firms decide whether to use intermediate goods that are produced with a more productive and capital-intensive technology, which requires incurring a fixed cost, or to use intermediate goods that are produced with a less productive and capital-intensive technology that is readily available upon entering the market at no additional cost. Of note, within the context of our model, using intermediate goods that are produced with a given production technology is equivalent to adopting that production technology.

With this in mind and recalling the description of salaried firms and the mapping between technology adoption and formality status at the beginning of Section 3, we refer to firms that adopt the more productive technology with subscript f for formal and to firms that adopt the less productive technology with subscript i for informal.[19]

Intermediate Goods Production A representative producer uses labor subject to search and matching frictions, physical capital, and energy to produce intermediate goods that are used by salaried firms. For simplicity and without loss of generality, this intermediate-goods producer is in charge of producing the intermediate goods that each category of salaried firms f and i uses, and we differentiate between the variables associated with each intermediate-goods category by using the same subscripts assigned to the salaried-firm categories, f and i.

Formally, the intermediate goods producer chooses vacancies $v_{j,t}$, desired salaried employment $n_{j,t}$, physical capital demand $k_{j,t}$, and energy demand $e_{j,t}$ for each intermediate-goods

[18] For a similar separation of firm entry, technology selection, and the production and hiring process, see Finkestein Shapiro and Mandelman (2021).

[19] Other factors that characterize formal firms include the presence of payroll and other taxes associated with hiring and maintaining formal workers at the firm. We abstract from these factors and note that incorporating these taxes does not change our main conclusions.

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 type of salaried employment j

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

where $\Xi_{t|0}$ is the household's stochastic discount factor (defined in the household's problem further below), $0 < \rho_s < 1$ is the exogenous separation probability and $0 < q_{j,t} < 1$ denotes the endogenous job-filling probability in employment category j (a function of category-specific market tightness). In the intermediate-goods producer profit function, for each intermediate-goods category $j \in \{f, i\}$, $mc_{j,t}$ is the real price of intermediate goods, $z_{j,t}$ denotes exogenous productivity, $w_{j,t}$ is the real wage, $r_{k,t}$ is the real price of capital, ψ_j is the vacancy posting cost, and $\rho_{e,t}$ is the real price of energy. Physical capital is perfectly mobile, and the price of energy is the same across the two categories. $H(n_{f,t}, k_{f,t}, e_{f,t})$ and $F(n_{i,t}, k_{i,t}, e_{i,t})$ are constant-returns-to-scale functions associated with the f and i production technologies, respectively, where 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 salaried firms (see Nordhaus, 2008). That is, for a given set of inputs, an increase in the pollution stock reduces intermediate-goods producers' output via lower productivity levels.[20]

The intermediate-goods producer's optimal choices are characterized by standard capital demand conditions

$$mc_{f,t} D(x_t) z_{f,t} H_{k_f,t} = r_{k,t}, \tag{2}$$

and

[20] 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.

$$mc_{i,t}D(x_t)z_{i,t}F_{k_i,t} = r_{k,t}, \tag{3}$$

standard job creation conditions

$$\frac{\psi_f}{q_{f,t}} = mc_{f,t}D(x_t)z_{f,t}H_{n_f,t} - w_{f,t} + (1-\rho_s)\Xi_{t+1|t}\left(\frac{\psi_f}{q_{f,t+1}}\right), \tag{4}$$

and

$$\frac{\psi_i}{q_{i,t}} = mc_{i,t}D(x_t)z_{i,t}F_{n_i,t} - w_{i,t} + (1-\rho_s)\Xi_{t+1|t}\left(\frac{\psi_i}{q_{i,t+1}}\right), \tag{5}$$

and energy demand conditions that equate the marginal benefit of a unit of energy to its marginal cost:

$$mc_{f,t}D(x_t)z_{f,t}H_{e_f,t} = \rho_{e,t}, \tag{6}$$

and

$$mc_{i,t}D(x_t)z_{i,t}F_{e_i,t} = \rho_{e,t}. \tag{7}$$

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 $\varphi_s > 0$ and enters 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 firms' individual 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, 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

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

where $\rho_{i,t}(a_s)$ is the real output price of firm a_s using the i technology and $mc_{i,t}$ the 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

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

where $\rho_{f,t}(a_s)$ is the real output price of firm a_s using the f technology and $mc_{f,t}$ is the real marginal cost.

Noting that the demand function for firm a_s's output operating in category $j \in \{f, i\}$ is given by $y_{j,t}(a_s) = (\rho_{j,t}(a_s)/p_{s,t})^{-\varepsilon} Y_{s,t}$, it is straightforward to show that optimal pricing for each category j is given by

$$\rho_{j,t}(a_s) = \frac{\varepsilon}{\varepsilon - 1} \frac{mc_{j,t}}{a_s}. \tag{8}$$

In turn, the threshold productivity level $\overline{a}_{s,t}$ is implicitly given by the condition

$$\pi_{i,t}(\overline{a}_{s,t}) = \pi_{f,t}(\overline{a}_{s,t}). \tag{9}$$

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

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

where, given the threshold productivity level $\overline{a}_{s,t}$, the number of informal and formal salaried firms are given by $N_{i,t} = G(\overline{a}_{s,t})N_{s,t}$ and $N_{f,t} = \left[1 - G(\overline{a}_{s,t})\right] N_{s,t}$, respectively.

The average idiosyncratic productivity levels of salaried firms in the i and f categories 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 $\widetilde{a}^f_{s,t} = \left[\left(\frac{1}{1-G(\overline{a}_{s,t})}\right) \int_{\overline{a}_{s,t}}^{\infty} a_s^{\varepsilon-1} dG(a_s)\right]^{\frac{1}{\varepsilon-1}}$, respectively.[21] Then, we define the following average prices and quantities: $\widetilde{\rho}^{i}_{s,t} = \rho^{i}_{s,t}(\widetilde{a}^{i}_{s,t}) = \frac{\varepsilon}{\varepsilon-1}\frac{mc_{i,t}}{\widetilde{a}^{i}_{s,t}}$, $\widetilde{\rho}^{f}_{s,t} = \rho^{f}_{s,t}(\widetilde{a}^{f}_{s,t}) = \frac{\varepsilon}{\varepsilon-1}\frac{mc_{f,t}}{\widetilde{a}^{f}_{s,t}}$, $\widetilde{y}_{i,t} = y_{i,t}(\widetilde{a}^{i}_{s,t})$, and $\widetilde{y}_{f,t} = y_{f,t}(\widetilde{a}^{f}_{s,t})$. Finally, we can define average real salaried-firm profits as $\widetilde{\pi}_{s,t} = \left(\frac{N_{i,t}}{N_{s,t}}\right)\pi_{i,t}(\widetilde{a}^{i}_{s,t}) + \left(\frac{N_{f,t}}{N_{s,t}}\right)\pi_{f,t}(\widetilde{a}^{f}_{s,t})$.

3.1.3 Energy Producers

There is a continuum of monopolistically competitive energy producers indexed by a_e with a fixed measure normalized to one, where a_e denotes the energy producers' idiosyncratic productivity and is drawn 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.[22] Energy producers choose to adopt one of two available 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. However, energy producers using the r technology can abate these emissions by incurring 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 idiosyncratic productivity 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 domestic physical capital as an input, the g technology relies on a different type of physical capital that is specific to the g technology.[23]

Total Energy Production The total amount of energy produced is given by $E_t = \left(\int_0^1 e_t(a_e)^{\frac{\varepsilon_e-1}{\varepsilon_e}} da_e\right)^{\frac{\varepsilon_e}{\varepsilon_e-1}}$ 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

[21] For similar expressions for average idiosyncratic productivity, see, among others, Zlate (2016) in the context of offshoring, Finkelstein Shapiro and Mandelman (2021) in the context of firm digital adoption, and Finkelstein Shapiro and Metcalf (2023) in the context of green technology adoption by production firms.

[22] Recall from Section 2 that a minuscule share of employment in EMEs is in energy-related sectors.

[23] As noted at the beginning of Section 3, this assumption captures in a reduced-form way the fact that EMEs tend to obtain green technologies and their inputs from distinct sources—mainly via imports from advanced economies—compared to more generic physical capital that can be accumulated domestically.

write $E_t = \left(\int_0^{\overline{a}_{e,t}} e_{r,t}(a_e)^{\frac{\varepsilon_e - 1}{\varepsilon_e}} da_e + \int_{\overline{a}_{e,t}}^1 e_{g,t}(a_e)^{\frac{\varepsilon_e - 1}{\varepsilon_e}} da_e\right)^{\frac{\varepsilon_e}{\varepsilon_e - 1}}$, 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 $P_{e,t} = \left(\int_0^1 p_{e,t}(a_e)^{1-\varepsilon_e} da_e\right)^{\frac{1}{1-\varepsilon_e}}$, 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 energy as $P_{e,t} = \left(\int_0^{\overline{a}_{e,t}} p^r_{e,t}(a_e)^{1-\varepsilon_e} da_e + \int_{\overline{a}_{e,t}}^1 p^g_{e,t}(a_e)^{1-\varepsilon_e} da_e\right)^{\frac{1}{1-\varepsilon_e}}$, 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 simplicity *only*, we follow a similar approach to the description of salaried firms in Section 3.1.2 and 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.[24]

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 inputs associated with the r technology, $z^r_{e,t}$ and $k^r_{e,t}$ are the exogenous productivity and the physical capital, respectively, associated with the production of these inputs, em_t denotes net emissions from the production of these inputs, and Γ_t is an abatement cost function. Note that the price of $k^r_{e,t}$ is the same as the price of capital used by salaried firms. Analogously, $mc^g_{e,t}$ is the real price of the inputs associated with the g technology, $z^g_{e,t}$ and $k^g_{e,t}$ are the exogenous productivity and the physical capital, respectively, associated with the production of these inputs, and $r^g_{k,t}$ is the real price of

[24]Jointly describing the production of energy inputs and the pricing and technology choices of energy producers delivers the same equilibrium conditions as the setting we describe below.

capital $k^g_{e,t}$. $r^g_{k,t}$ is assumed to be exogenous and potentially different from $r_{k,t}$ to reflect the fact that in EMEs, inputs associated with the g technology tend to be imported (recall that we abstract from explicitly modeling an open economy). Note that the production of these inputs is also affected by pollution damages $D(x_t)$.

Following the literature (Heutel, 2012; Annicchiarico and di Dio, 2015), the total cost of abatement Γ_t 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 $\eta > 1$. In turn, emissions net of abatement are given by $em_t = (1-\mu_{e,t})\left[D(x_t)z_tk^r_{e,t}\right]^{1-\nu_e}$, where $0 < \nu_e \leq 1$. Finally, emissions add to the pollution stock $x_t = \rho_x x_{t-1} + em_t + em^{row}_t$, where $0 < \rho_x < 1$ determines the persistence of past pollution and em^{row}_t denotes exogenous emissions from the rest of the world.

The optimal choices of the intermediate energy input producer are given by a demand condition for capital associated with the r technology:

$$D(x_t)mc^r_{e,t}z^r_{e,t} = r_{k,t} + \Big((1-\nu_e)\,\tau_{e,t}(1-\mu_{e,t})\left[D(x_t)z^r_{e,t}k^r_{e,t}\right]^{-\nu_e} + \mu^{\eta}_{e,t}\Big)\,D(x_t)z^r_{e,t}, \qquad (11)$$

an optimal emissions abatement decision:

$$\eta\gamma\mu^{\eta-1}_{e,t} = \tau_{e,t}\left[D(x_t)z^r_{e,t}k^r_{e,t}\right]^{-\nu_e}, \qquad (12)$$

and a standard demand condition for capital associated with the g technology:

$$D(x_t)mc^g_{e,t}z^g_{e,t} = r^g_{k,t}. \qquad (13)$$

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

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

Instead, if producer a_e uses the g technology, its individual real profits are

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

where $\rho^r_{e,t}(a_e)$ and $\rho^g_{e,t}(a_e)$ denote producer a_e's relative price of energy produced with the r technology and with the g technology, respectively, and $mc^r_{e,t}$ and $mc^g_{e,t}$ are the respective real marginal costs. It follows that an energy producer a_e is indifferent between the two technologies if $\pi^r_{e,t}(\overline{a}_{e,t}) = \pi^g_{e,t}(\overline{a}_{e,t})$, 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 $e_{r,t}(a_e) = \left(\rho^r_{e,t}(a_e)/\rho_{e,t}\right)^{-\varepsilon_e} E_t$ and $e_{g,t}(a_e) = \left(\rho^g_{e,t}(a_e)/\rho_{e,t}\right)^{-\varepsilon_e} E_t$, it follows that the optimal relative prices of energy for each category are $\rho^r_{e,t}(a_e) = \frac{\varepsilon_e}{\varepsilon_e - 1}\frac{mc^r_{e,t}}{a_e}$ and $\rho^g_{e,t}(a_e) = \frac{\varepsilon_e}{\varepsilon_e - 1}\frac{mc^g_{e,t}}{a_e}$.

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

$$E_t = \left(\left(G(\overline{a}_{e,t})\right) \widetilde{e}_{r,t}^{\frac{\varepsilon_e - 1}{\varepsilon_e}} + \left(1 - G(\overline{a}_{e,t})\right) \widetilde{e}_{g,t}^{\frac{\varepsilon_e - 1}{\varepsilon_e}} \right)^{\frac{\varepsilon_e}{\varepsilon_e - 1}}, \tag{14}$$

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

$$\rho_{e,t} = \left(G(\overline{a}_{e,t}) \left(\widetilde{\rho}^r_{e,t}\right)^{1 - \varepsilon_e} + \left[1 - G(\overline{a}_{e,t})\right] \left(\widetilde{\rho}^g_{e,t}\right)^{1 - \varepsilon_e} \right)^{\frac{1}{1 - \varepsilon_e}}. \tag{15}$$

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 total energy producers' profits by $\widetilde{\pi}_{e,t} \equiv G(\overline{a}_{e,t})\widetilde{\pi}^r_{e,t} + \left(1 - G(\overline{a}_{e,t})\right)\widetilde{\pi}^g_{e,t}$.

3.2 Households and Self-Employment

A representative household with a large number of members owns all producers and firms. The household derives utility from consuming a composite final good c_t and energy $e_{h,t}$, where c_t and $e_{h,t}$ are assumed to be complements, 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

$$\begin{aligned} c_t + \varphi_s A_{s,t} + \rho_{e,t} e_{h,t} + k_{t+1} - (1-\delta)\, k_t \\ = w_{f,t} n_{f,t} + w_{i,t} n_{i,t} + p_{o,t} D(x_t) z_{o,t} n_{o,t} + r_{k,t} k_t + \widetilde{\pi}_{s,t} N_{s,t} + \Pi_{a,t} + T_t, \end{aligned}$$

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

$$n_{j,t} = (1-\rho_s) n_{j,t-1} + s_{j,t} \varrho_{j,t}, \tag{16}$$

the evolution of self-employment

$$n_{o,t} = (1-\rho_o) n_{o,t-1} + s_{o,t} \phi_o, \tag{17}$$

and the evolution of salaried firms

$$N_{s,t+1} = (1-\delta_s)\left(N_{s,t} + A_{s,t}\right), \tag{18}$$

where $0 < \varrho_{j,t} < 1$ is the endogenous job-finding probability in salaried category j (a function of category-specific market tightness). In the evolution of self-employment, $0 < \rho_o < 1$ is the exogenous probability that a self-employed individual exits self-employment and $0 < \phi_o < 1$ is the exogenous probability that household members searching for self-employment opportunities successfully transition to self-employment.

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 final-goods firm profits $\Pi_{y,t}$. T_t denotes lump-sum transfers from the government. As a baseline, we assume that these transfers are financed with the revenue from taxing emissions. $p_{o,t}D(x_t)z_{o,t}n_{o,t}$ 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 of a self-employed individual. Similar to salaried-firm production and energy production, self-employment production is also adversely affected by pollution damages via $D(x_t)$.

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 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

$$\mathbf{u}_{e_h,t} = \rho_{e,t}\mathbf{u}_{c,t}, \tag{19}$$

which equates the marginal benefit of a unit of energy to its marginal cost; standard optimal salaried firm creation and physical capital accumulation conditions

$$\varphi_s = (1-\delta_s)\Xi_{t+1|t}\left[\widetilde{\pi}_{s,t+1} + \varphi_s\right], \tag{20}$$

and

$$1 = \Xi_{t+1|t}\left[r_{k,t+1} + (1-\delta)\right], \tag{21}$$

optimal labor force participation decisions for f and i salaried workers

$$\frac{\mathbf{h}_{lfp_{f,t}}}{\mathbf{u}_{c,t}} = \varrho_{f,t}\left[w_{f,t} + (1-\rho_s)\Xi_{t+1|t}\left(\frac{1-\varrho_{f,t+1}}{\varrho_{f,t+1}}\right)\left(\frac{\mathbf{h}_{lfp_{f,t+1}}}{\mathbf{u}_{c,t+1}}\right)\right], \tag{22}$$

and

$$\frac{\mathbf{h}_{lfp_{i,t}}}{\mathbf{u}_{c,t}} = \varrho_{i,t}\left[w_{i,t} + (1-\rho_s)\Xi_{t+1|t}\left(\frac{1-\varrho_{i,t+1}}{\varrho_{i,t+1}}\right)\left(\frac{\mathbf{h}_{lfp_{i,t+1}}}{\mathbf{u}_{c,t+1}}\right)\right], \tag{23}$$

and an optimal labor force participation decision for self-employment

$$\frac{\mathbf{h}_{lfp_{o,t}}}{\mathbf{u}_{c,t}} = \phi_o \left[p_{o,t} D(x_t) z_{o,t} + (1-\rho_o) \Xi_{t+1|t} \left(\frac{1-\phi_o}{\phi_o} \right) \left(\frac{\mathbf{h}_{lfp_{o,t+1}}}{\mathbf{u}_{c,t+1}} \right) \right], \tag{24}$$

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 for each employment category equate the marginal cost of participating in that category to the expected marginal benefit of doing so. The expected marginal benefit for each category is comprised of two elements: the individual's contemporaneous real earnings and the continuation value associated with remaining employed in the same category in the next period.

3.3 Matching Processes and 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 therefore 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 firms and salaried workers. It is straightforward to show that the real wages for formal and informal salaried workers, respectively, are given by

$$w_{f,t} = \nu_n \left(mc_{f,t} D(x_t) z_{f,t} H_{n_f,t} + (1-\rho_s) \mathbb{E}_t \Xi_{t+1|t} \psi_f \theta_{f,t+1} \right), \tag{25}$$

and

$$w_{i,t} = \nu_n \left(mc_{i,t} D(x_t) z_{i,t} F_{n_i,t} + (1-\rho_s) \mathbb{E}_t \Xi_{t+1|t} \psi_i \theta_{i,t+1} \right), \tag{26}$$

where $0 < \nu_n < 1$ is workers' bargaining power.

3.4 Market Clearing

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

$$D(x_t)z_{f,t}H(n_{f,t},k_{f,t},e_{f,t}) = N_{f,t}\left(\frac{\widetilde{y}_{f,t}}{\widetilde{a}^{f}_{s,t}}\right), \tag{27}$$

and

$$D(x_t)z_{i,t}F(n_{i,t},k_{i,t},e_{i,t}) = N_{i,t}\left(\frac{\widetilde{y}_{i,t}}{\widetilde{a}^{i}_{s,t}}\right). \tag{28}$$

Similarly, market clearing in the energy sector is given by

$$D(x_t)z^{r}_{e,t}k^{r}_{e,t} = G(\overline{a}_{e,t})\left(\frac{\widetilde{e}_{r,t}}{\widetilde{a}^{r}_{e,t}}\right), \tag{29}$$

$$D(x_t)z^{g}_{e,t}k^{g}_{e,t} = [1-G(\overline{a}_{e,t})]\left(\frac{\widetilde{e}_{g,t}}{\widetilde{a}^{g}_{e,t}}\right), \tag{30}$$

and

$$E_t = e_{h,t} + e_{f,t} + e_{i,t}. \tag{31}$$

while market clearing in the physical capital market is characterized by

$$k_t = k_{f,t} + k_{i,t} + k^{r}_{e,t}, \tag{32}$$

where $inv_t \equiv k_{t+1} - (1-\delta)\,k_t$ denotes total physical capital investment (recall that $k^{g}_{e,t}$ differs from the physical capital used by production firms and r energy producers). Finally, the resource constraint of the economy is

$$Y_t = c_t + (k_{t+1} - (1-\delta)k_t) + \psi_f v_{f,t} + \psi_i v_{i,t} + \varphi_s A_{s,t} + \varphi_f N_{f,t} + \varphi_e\left[1-G(\overline{a}_{e,t})\right] + \Gamma_t + r^{g}_{k,t}k^{g}_{e,t}, \tag{33}$$

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

As noted in Ghironi and Melitz (2005) and Bilbiie, Ghironi, and Melitz (2012), 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. As such, 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—in other words, 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 model's variety effect from the model's aggregate price index (see Appendix A.3 for more details). Unless otherwise noted, all quantity variables we discuss below are expressed in data-consistent terms.

4.1 Baseline Calibration

Functional Forms Household utility is $\mathbf{u}(c_t, e_{h,t}) = \frac{\left((c_t)^{1-\sigma_e}\left(e_{h,t}\right)^{\sigma_e}\right)^{1-\sigma_c}}{1-\sigma_c}$ while 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 (see Finkelstein Shapiro and Mandelman, 2021, for a similar functional form for the disutility of labor force participation). The matching functions associated with salaried employment are constant-returns-to-scale and given by $m(s_{j,t}, v_{j,t}) = (s_{j,t}v_{j,t}) / \left(s_{j,t}^{\xi} + v_{j,t}^{\xi}\right)^{1/\xi}$ for $j \in \{f, i\}$, where $\xi > 0$ (den Haan, Ramey, and Watson, 2000). Intermediate-goods producers use Cobb-Douglas production functions where energy is a complement to labor and capital: $H(n_{f,t}, k_{f,t}, e_{f,t}) = (n_{f,t})^{1-\alpha_f-\alpha_e}(k_{f,t})^{\alpha_f}(e_{f,t})^{\alpha_e}$ 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 $\widetilde{a}^f_{s,t} = \left(\frac{k^s_p}{k^s_p-(\varepsilon-1)}\right)^{\frac{1}{\varepsilon-1}} \overline{a}_{s,t}$ while the average idiosyncratic productivities of energy producers are $\widetilde{a}^r_{e,t} = \widetilde{a}^g_{e,t}\left(\frac{\overline{a}^{k^e_p-(\varepsilon_e-1)}_{e,t}-\left(a^e_{min}\right)^{k^e_p-(\varepsilon_e-1)}}{\overline{a}^{k^e_p}_{e,t}-\left(a^e_{min}\right)^{k^e_p}}\right)^{\frac{1}{\varepsilon_e-1}} a^e_{min}$ and $\widetilde{a}^g_{e,t} = \left(\frac{k^e_p}{k^e_p-(\varepsilon_e-1)}\right)^{\frac{1}{\varepsilon_e-1}} \overline{a}_{e,t}$.

Following the modeling approach of pollution damages in Annicchiarico, Correani, and Di Dio (2018) and Annicchiarico and Diluiso (2019), the pollution 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 represents steady-state pollution. 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: $\Gamma_t = \gamma\mu^\eta_t D(x_t) z^r_{e,t} k^r_{e,t}$, where $\gamma > 0$ and $\eta > 1$.[25]

Parameters from Literature A period is a quarter. We normalize the exogenous productivity of formal salaried firms so that $z_f = 1$. Similarly, we set the exogenous productivities in the energy sector to $z^r_e = z^g_e = 1$.[26] We set the capital shares of salaried production firms to $\alpha_f = 0.32$ and $\alpha_i = 0.22$, which captures the fact that f firms are more capital intensive than i firms. This choice also generates an outcome where, consistent with available data, the majority of the capital stock is held by f firms (see, for example, Busso, Fazio, and Levy, 2012). As a baseline, the energy share in salaried-firm production is $\alpha_e = 0.05$ (see, for example, Adao et al., 2022). We choose 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 these values are standard 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

[25] For a similar functional form assumption in a more standard context without energy production where production firms' output generates emissions and these emissions can be abated by incurring abatement expenditures, see Heutel (2012).

[26] 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^r_e and z^g_e to match other relevant data targets associated with the energy sector.

the bargaining power of salaried workers to $\nu_n = 0.50$.

As a baseline, we set the elasticity of substitution between energy producers $\varepsilon_e = 4$, the elasticity of labor force participation $\phi_n = 0.26$, the elasticity of substitution between salaried and self-employment output $\phi_y = 4$, 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 $k_p^e > \varepsilon_e - 1$.[27] Our main findings remain unchanged if we consider alternative values to this baseline parameterization. Following the macro literature on endogenous firm entry, we normalize the sunk entry cost of salaried firms, $\varphi_s = 1$, and set the minimum levels of idiosyncratic productivity for salaried production firms and energy producers to $a_{min}^s = 1$ and $a_{min}^e = 1$.

Turning to the parameters associated with the environmental side of the model, 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 findings are not dependent on these values. First, we set the carbon tax $\tau_e = 0$ as a baseline since most EMEs do not have a nationwide carbon tax. In turn, 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 III, 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) and the persistence of the pollution stock to $\rho_x = 0.9979$ (Heutel, 2012).

[27] Existing evidence suggests that the elasticity of substitution between polluting and green energy inputs is greater than 1 (see, for example, Papageorgiou, Saam, and Schulte, 2017).

Table 3: Parameter Description and Baseline Values in Benchmark Model

Parameters from Literature and Baseline Parameter Values			
Parameter	Value	Parameter Description	Source
α_f	0.32	Capital share, formal firms	EME literature
α_i	0.22	Capital share, informal firms	Baseline assumption
α_e	0.05	Energy share, 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	$\bar{x} = D_1 x$

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 $\psi_f = \psi_i$ (this assumption does not change our main conclusions). With this in mind, 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).

These targets 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);[28] a ratio of total vacancy-posting costs to output of 3 percent (in line with the search and matching literature); an average cost of becoming a formal firm (the cost of business-startup procedures, which includes the cost of registering a firm with local government and tax authorities) of 8 percent of gross national income per capita (World Bank Enterprise Surveys); a spread between the effective cost of using the g technology per unit of capital k_e^g and the per-unit cost of using capital k_e^r of 6 percent (Steffen, 2020);[29]; a ratio of carbon dioxide emissions from the rest of the world to total world emissions of 0.90 (Global Carbon Project); an average 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); a wage differential between formal and informal salaried employment of 1.25 (ILO); a share of polluting (regular) energy production

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

[29] 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 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 $\bar{x} = D_1 x$.

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 $\bar{x} = 8348.3$. Of note, given the endogenous productivity components of f and i firms (embodied in average firm productivities $\widetilde{a}_s^f$ and $\widetilde{a}_s^i$), in our baseline calibration the overall (endogenous) 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- and Short-Run Effects of a Carbon Tax

Using this baseline calibration, we analyze the impact of a carbon tax that reduces emissions by 25 percent relative to their baseline level. This quantitative reduction in emissions is in line with the climate policy experiments in IMF WEO (2022). In what follows, we characterize the long-run (steady-state) effects and the transition path of the economy to a lower-carbon equilibrium. Then, we dissect the main forces and mechanisms behind our findings in Section 4.3. In doing so, we highlight the quantitative role of green technology adoption and green energy; the relevance of self-employment, salaried firm creation, and the composition of salaried firms; and the potential benefits of policy complementarities with carbon taxes and alternative climate policies.

4.2.1 Long-Run Effects

Summary of Main Results Table 4 shows the long run (steady state) 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.[30] Recall from Section 2 that informal employment is defined as the sum of self-employment n_o and informal salaried employment n_i. As such, the share of (salaried) formal employment $n_f/\left(n_f+n_i+n_o\right)$ is the mirror image of the informal employment share.

The carbon tax leads to a reduction in total output and consumption of roughly 0.85 and 0.50 percent, respectively. By generating an equilibrium increase in the price of energy, the carbon tax pushes salaried firms to reduce their energy, labor, and capital demand. The reduction 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; as we describe further below, this increase is driven by the expansion in self-employment. The tax also reduces the incentive to create new salaried firms. This is reflected in a contraction of almost 3 percent in the measure of salaried firms and, in turn, in a reduction in the measures of both f and i firms. Surprisingly, both the 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 level both remain virtually unaffected by the 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.

[30] Following Fried (2018) and Finkelstein Shapiro and Metcalf (2023), 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.

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

Variable	Model Values (Levels)		**Percent Change**
	Baseline (No Tax)	**After Tax**	Relative to Baseline
Total Output	1.716	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. Perc.-Pt. Change denotes Percentage-Point Change.

In particular, the share of formal-sector output falls by roughly 0.70 percentage points while the share of f salaried employment in total employment falls by more than 1 percentage point. The share of i salaried employment also falls, though by much less. Importantly, the reduction in salaried labor demand pushes households to move more of their members to search for self-employment opportunities, ultimately resulting in an increase of 1.3 percentage points in the share of self-employment. The significant increase in self-employment is responsible for the 1 percentage-point increase in the share of informal employment (not shown) as well as the increase in the level of total employment.[31] As salaried firms cut back on hiring and household members search more for self-employment opportunities, the unemployment rate increases by roughly 0.15 percentage points. Finally, the increase in search activity—primarily for self-employment—puts upward pressure on labor force participation, leading to 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 welfare by 1.85 percent.

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. More importantly, the tax shifts the endogenous energy-production structure towards green energy: the share of energy producers generating green energy 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.

To summarize our main findings, the carbon tax reduces emissions, increases the share of energy producers that use of green technologies and, in doing so, generates a non-trivial

[31] 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 on 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 (24)). As summarized in Section 4.2.4, assuming that the self-employed also use energy in production—implying that policy-induced changes in energy prices directly affect the decision to become self-employed by increasing the costs of producing in self-employment—does not change the main model mechanisms and delivers the same conclusions as our benchmark model.

increase in the economy's share of green energy. At the same time, by raising the price of energy, the tax has adverse effects on salaried firm creation and formal employment, and leads to a reallocation of employment away from salaried employment and towards self-employment. The resulting reallocation of employment and search behavior leads to an increase in labor force participation and to a slight uptick in the unemployment rate. The adverse effects of the tax on formal employment and on salaried firms are ultimately reflected in a reduction in consumption, total output, and welfare, and in a lower share of formal employment.

4.2.2 Model Validation: Growth in Carbon Emissions and Changes in Self-Employment in the Data

The results in Table 4 suggest that a reduction in carbon emissions is associated with an increase in the share of self-employment in EMEs—that is, the model suggests that there is a negative relationship between these two variables. As we discuss in Section 4.3, this relationship plays an important role in shaping the labor market and macroeconomic effects of a carbon tax. While the reduction in emissions in the model is induced by the introduction of a carbon tax in the energy sector—that is, by a change in policy—the same negative relationship arises when we consider a change in emissions that stems from changes in non-policy parameters.

To see this more explicitly, Table A1 in Appendix A.4 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 (column (1) of Table A1) and, for illustrative purposes only, when the reduction in emissions stems a reduction in the exogenous productivity of r energy producers (column (2) of Table A1).[32] In both cases, the share of self-employment increases. Moreover, Table A1 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

[32]The 10-percent reduction in emissions is merely illustrative, and similar results hold for alternative reductions. Changing the exogenous productivity of r energy producers is a natural exercise to consider given that this productivity directly affects the generation of emissions. Similar qualitative findings hold if we consider a reduction in emissions due to lower green-technology-adoption costs.

Table A2 in Appendix A.4 shows results from a simple panel regression with country and time fixed effects using annual data from 2000 to 2019 for the EMEs listed 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.

For completeness and further model validation, Table A1 shows the same model experiments for an "advanced economy" baseline calibration—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 vs. the original 70 percent) relative to our original baseline EME calibration. As shown in Table A1 (columns (3) and (4)), 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, and the relationship effectively vanishes when output growth is held constant. Using data for advanced economies in a panel setting, Section b. of Table A2 in Appendix A.4 confirms that the model outcomes under the advanced-economy calibration are also consistent with the data.

4.2.3 Transition Path to Lower Carbon Economy

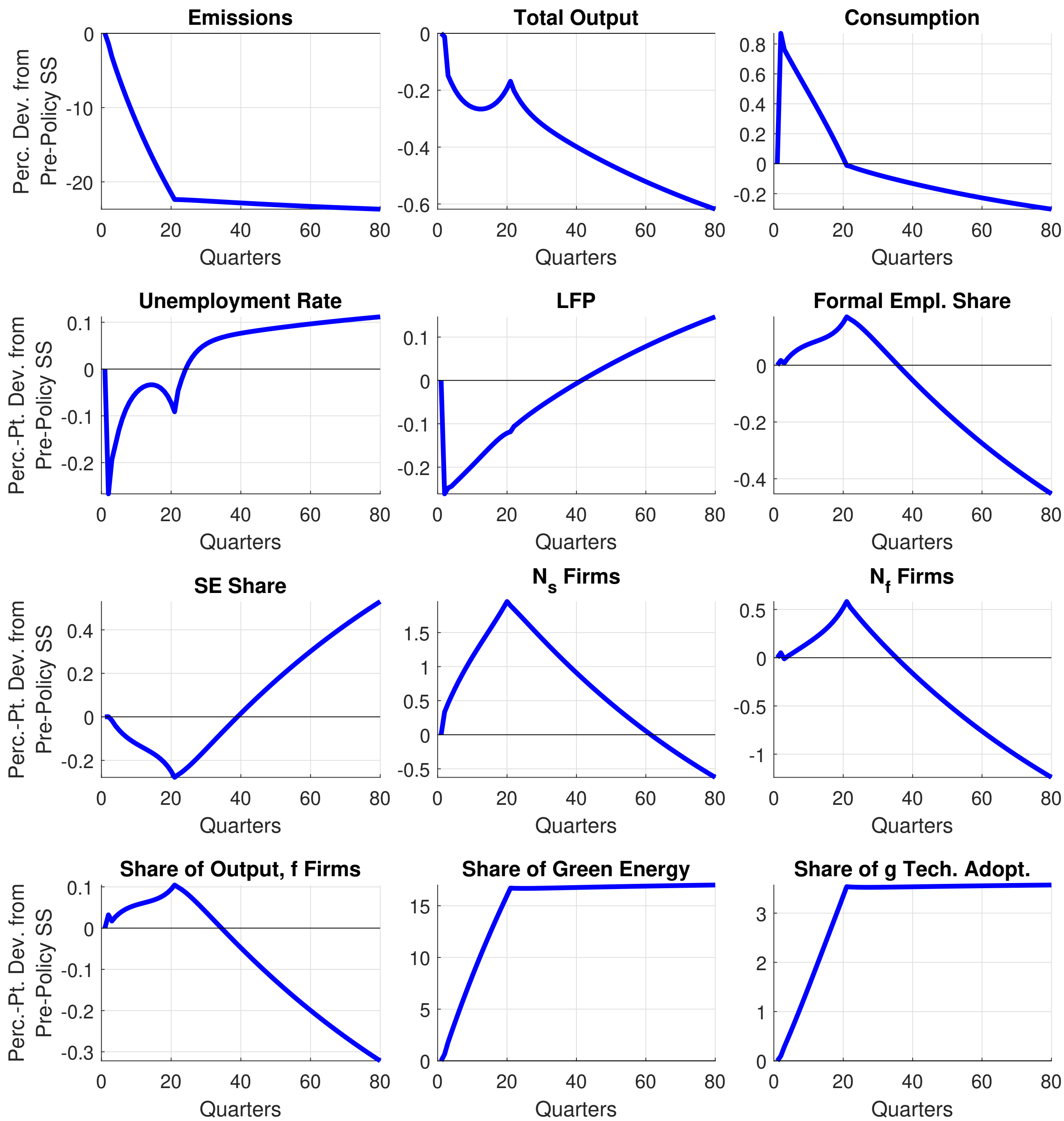
Summary of Main Results Figure 2 plots the transition path in a scenario where we increase the carbon tax gradually and uniformly over the course of 8 years (or 32 quarters) to ultimately achieve the 25-percent reduction in emissions in the long run. This time horizon is broadly consistent with a 2030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

As we raise the carbon tax gradually, 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 decline in physical capital demand by r energy producers, which is strong enough to drastically 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 the share of energy producers using these technologies and to an increase in the share of green energy.

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.[33] 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. 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.

[33]This result continues 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.

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.

Critically, the decline in self-employment search explains the decline in the share of self-employment as fewer individuals become self-employed. It 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. Of note, even though both salaried firm categories initially expand, their output is not strong enough to offset the decline in self-employment output. Hence the decline in total output as the carbon tax is put in place.

Once emissions stabilize at their lower long-run level, given the long-run carbon tax, r energy producers also stabilize their capital demand. Coupled with the 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-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 their respective long-run levels as shown in Table 4. Convergence to the new steady state is slow due to the presence of frictional labor markets and the costly nature of salaried firm creation.

The Role of Capital Adjustment Costs Figure 2 considers the transition path to a lower-emissions equilibrium in an environment where physical capital can be reallocated without frictions or additional costs. 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.5 shows the transition path in a version of the model where we assume that 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 reduction in output.

4.2.4 Robustness Analysis

We consider the following independent alternatives in our baseline calibration: a higher baseline share of green energy in total energy; higher vacancy posting costs for f firms compared to i firms; a lower physical capital share and a higher energy share in the production function of salaried firms; greater pollution damages as a share of GDP; a higher elasticity of emissions with respect to r energy production; greater producer concentration in the energy sector; a higher energy share among f firms; and a lower cost of green capital. In turn, we consider a version of the model where 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 fixed); a version of the model where the cost of becoming an f firm depends on the firm's marginal cost and can therefore change with policy; and a version of the model where the self-employed also use energy as an input in production.[34] Table A3 in Appendix A.5 presents the details and summarizes the main conclusions of these robustness checks (these checks are explicitly documented in Tables A4, A5, A6, A7, and A8 in the same Appendix).

Two findings from these experiments are worth highlighting. First, as shown in Table A9 in Appendix A.5, 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 total output, and in welfare. Thus, the simplifying assumption that the self-employed do not use energy to produce does not change any of 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.

[34] 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.

4.3 Economic Mechanisms

To understand the economic mechanisms behind the results in Sections 4.2.1 and 4.2.3, we consider three separate experiments that allow us to identify the main channels via which the carbon tax shapes labor market and macroeconomic outcomes. Once we have identified these channels, we compare how a carbon tax compares to alternative climate policies that reduce the barriers to the adoption of green technologies and the use of green energy.

4.3.1 The Relevance of Green Technology Adoption Choices and Green Energy

A central feature of our framework is the joint inclusion of an intensive and an extensive margin of green energy production. The intensive margin is embodied in the existence of both polluting and green energy production. The extensive margin is embodied in energy producers' choice on which production technology (polluting or green) they use to generate energy—a choice that is rooted in their idiosyncratic productivity and the presence of technology adoption costs. As we emphasized in Section 3, this second margin implies that the structure of energy production is endogenous. These two margins play a key role in shaping the quantitative effects of a carbon tax.

Table 5 compares the long-run impact of the carbon tax in the benchmark model (originally shown in the last column of Table 4 and reproduced in column (1) of Table 5) to two variants of the benchmark model. For comparability, we consider the same carbon-tax-induced 25-percent reduction in emissions for each of the models. The first model variant (column (2) of Table 5) features polluting and green energy production but shuts down the extensive margin of energy production: the two categories of energy producers have a fixed measure and energy producers can adjust their production inputs, but they cannot choose or change their technologies. The second model variant (column (3) of Table 5) eliminates green energy (and therefore green technology adoption) altogether. Each column of Table 5 shows the changes relative to the no-carbon tax (baseline) scenario for the corresponding model specified at the top of the column.

Table 5: 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 Change Relative to Baseline	**Percent Change** Relative to Baseline	**Percent Change** Relative to Baseline
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
	Perc.-Pt. Change Relative to Baseline	**Perc.-Pt. Change** Relative to Baseline	**Perc.-Pt. Change** Relative to Baseline
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. Perc.-Pt. Change denotes Percentage-Point Change.

The results in Table 5 make clear that green technology adoption is a powerful mechanism that (1) plays an important role in increasing the contribution of green energy to total energy production, and (2) quantitatively limits the adverse effects of the carbon tax on formal employment, output, and welfare. Specifically, the absence of a choice on green technology adoption implies that a carbon tax-induced reduction in emissions leads to reductions in output and welfare that are, respectively, 70 and 50 percent greater than the corresponding reductions in the benchmark model. The larger negative effects on output and welfare stem from the larger reduction in the contribution of f firms—firms that tend to be more productive—to total output and the associated reallocation of resources towards self-employment. The larger increase in self-employment contributes to a larger reduction in the share of formal employment and to a larger increase in the unemployment rate. Without green technology adoption, the overall amount of revenue raised with the carbon tax is greater, resulting in a greater tax revenue-output ratio compared to the benchmark model.

When we abstract from green energy altogether, the quantitative adverse effects of the carbon tax on labor market and macroeconomic outcomes are magnified relative to the first variant. Focusing on labor informality, both the shares of self-employment and informal employment (the mirror image of the formal employment share) increase by more than 3 percentage points without green energy—this is twice as much as in a model with green energy but no green technology adoption choices and three times as much as in the benchmark model. Moreover, the unemployment rate increases by almost 0.45 percentage points—almost three times as much as in the benchmark model. Given these results, output and welfare fall by almost 3 and 5 percent, respectively—also almost three times as much compared to the benchmark model. Of note, the increase in labor informality does not generate meaningful changes in average salaried firm productivity, but is instead reflected in a sharp reduction in both the overall number of salaried firms and in the number of salaried firms in each of the two categories. The reduction in the number of salaried firms in turn contributes to the reduction in total output. We revisit the importance of the change in salaried firm creation as well as the composition of salaried firms further below.

All told, the results in Table 5 stress the importance of green technology adoption as a key margin of adjustment that can limit the adverse effects of a carbon tax on formal employment and salaried employment more broadly, output, consumption, and welfare.

4.3.2 The Relevance of Self-Employment

One of the main takeaways that emerges from Table 5 is that self-employment—a key source of employment in EMEs—is an important labor-market adjustment mechanism in response to the carbon tax. To better understand the relevance of self-employment in shaping labor market outcomes amid carbon taxation, Table 6 compares the results of the benchmark model (column (1) of Table 6) to those of an experiment where, using the same model and considering the same 25-percent reduction in emissions, we hold the share of self-employment at its (no-tax) baseline when we increase the carbon tax (column (2) of Table 6).[35]

As shown in the table, when the share of self-employment remains fixed at its baseline, the carbon tax not only has smaller adverse effects on output and welfare, but also a smaller adverse impact on the total number of salaried firms and on the number of salaried firms in each category. This, in turn, leads to a substantially smaller decline in the contribution of f firms to total output and to virtually no change in the share of formal employment.

To understand why holding the share of self-employment at its baseline has smaller adverse aggregate effects, first consider our benchmark model, where the self-employment share is allowed to respond to the carbon tax. Recall that the carbon tax pushes households to reallocate their members away from searching for salaried jobs and towards searching for self-employment opportunities. As a result, the pool of salaried searchers falls, and the pool of potential workers from which salaried formal and informal firms can hire becomes smaller. This increases the expected marginal cost of filling a vacancy, which pushes salaried firms to reduce salaried vacancy postings.

[35]Specifically, 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.

Table 6: Long-Run Effects of Carbon Tax (25-Percent Reduction in Emissions)—Benchmark Model vs. Model with Self-Employment Held at (No-Tax) Baseline Level and Model with Carbon Tax Alongside Exogenous Reduction in Cost of Firm Formality φ_f

Variable	**Benchmark Model Carbon Tax**	**Benchmark Model SE Share Held at Baseline**	**Benchmark Model Carbon Tax with Exogenous Reduction in φ_f**
	(1)	(2)	(3)
	Percent Change Relative to Baseline	**Percent Change** Relative to Baseline	**Percent Change** Relative to Baseline
Total Output	-0.857	-0.534	0.086
Consumption	-0.491	-0.455	0.190
Capital Investment	-9.467	-8.826	-9.076
Total Employment (Level)	0.417	-0.062	-0.094
Real Wage f	-0.402	-0.661	0.110
Real Wage i	-0.398	-0.658	0.110
Salaried Firms (N_s)	-2.888	-1.022	-0.116
f Firms (N_f)	-2.751	-1.021	9.680
i Firms (N_i)	-5.859	-1.022	-0.460
Ave. Salaried Firm Prod.	0.008	0.000	0.542
Price of Energy	11.628	11.258	11.130
Welfare Gain (% of Consumption)	-1.848	-1.033	0.022
	Perc.-Pt. Change Relative to Baseline	**Perc.-Pt. Change** Relative to Baseline	**Perc.-Pt. Change** Relative to Baseline
Share of f Firms (N_f/N_s)	0.005	0.000	0.332
Share of f Output in Total Output	-0.732	-0.117	0.345
f Employment Share	-1.047	0.001	0.307
i Salaried Employment Share	-0.250	-0.001	-0.362
Self-Employment Share	1.297	0.000*	0.055
Unemployment Rate	0.153	0.239	0.004
LFP Rate	0.368	0.126	-0.057
Emissions Abate. Rate (μ_e)	3.461	3.519	3.556
Share of e Producers Using g Tech.	3.666	3.913	4.081
Share of Green Energy	17.515	18.283	18.790
Tax Revenue-Output Ratio	0.144	0.147	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. Perc.-Pt. Change denotes Percentage-Point Change. A * denotes a target.

The resulting reduction in salaried employment ends up reducing the demand for capital and energy, ultimately leading to a reduction in salaried output and total output. When the share of self-employment is held fixed at its baseline, the reduction in the pool of searchers for salaried jobs is quantitatively smaller, which limits the extent to which the expected marginal cost of filling a vacancy increases compared to the benchmark model. As such, the reduction in salaried (formal and informal) vacancies and employment is smaller, in turn leading to a smaller reduction in salaried and total output compared to our benchmark environment where the share of self-employment increases in response to the carbon tax.

It should be noted that the carbon tax has slightly larger positive effects on both the share of energy producers adopting green technologies and on the share of green energy in total energy. In other words, when self-employment is able to respond to the tax, the resulting increase in self-employment limits the extent to which the tax, in addition to reducing the incentive to use polluting energy technologies, encourages a transition to green technologies and to green energy.

4.3.3 Lower Barriers to Firm Formality with a Carbon Tax

The results in Table 5 show that green technology adoption plays a fundamental role in limiting the adverse effects of the carbon tax on output. At the same time, the carbon tax ends up reducing the share of formal employment, mainly by reducing salaried job creation and encouraging greater self-employment. Given the pervasiveness of labor informality in EMEs and the challenges it represents for growth (Ohnsorge and Yu, 2021), this finding has significant policy relevance.

Column (3) of Table 6 presents results from a policy experiment that highlights how EMEs can limit the adverse effects of a carbon tax on formality and economic activity while at the same time achieving their emissions-reduction objective. Specifically, we consider a *joint policy* that reduces the cost to salaried firms of being formal, φ_f, by 8.35 percent relative to its baseline value while at the same time using a carbon tax to achieve a reduction in emissions of 25 percent. Changes to φ_f are a natural policy to consider since they can be implemented at a relatively low cost via plausible government reforms. Moreover, the quantitative reduction in φ_f we consider is not only reasonable but also disciplined by the most recent observed change in the average cost that firms face to become formal in our EME group.[36] 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.[37]

Recall that the carbon tax leads to an increase in the equilibrium price of energy, which raises salaried firms' input costs, lowers average salaried-firm profits, reduces the incentive to create salaried jobs and new salaried firms, and pushes households to reallocate their members towards self-employment. Reducing the cost of firm formality as the carbon tax is introduced limits the extent to which the tax adversely affects f firms' 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. Indeed, as shown in Table 6, the joint policy leads to a 0.33 percentage-point *increase* in the share of f firms, 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 (recall that 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. The resulting shifts in the composition of employment, firms, and economic activity away from

[36] 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). 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). We reduce φ_f by 8.35 percent relative to its baseline average value, which is consistent with the reduction in the *average* EME cost between 2018 and 2019 and brings down the cost to roughly 7.3 percent of income per capita in the new equilibrium (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, Goldstein, and McKenzie, 2023).

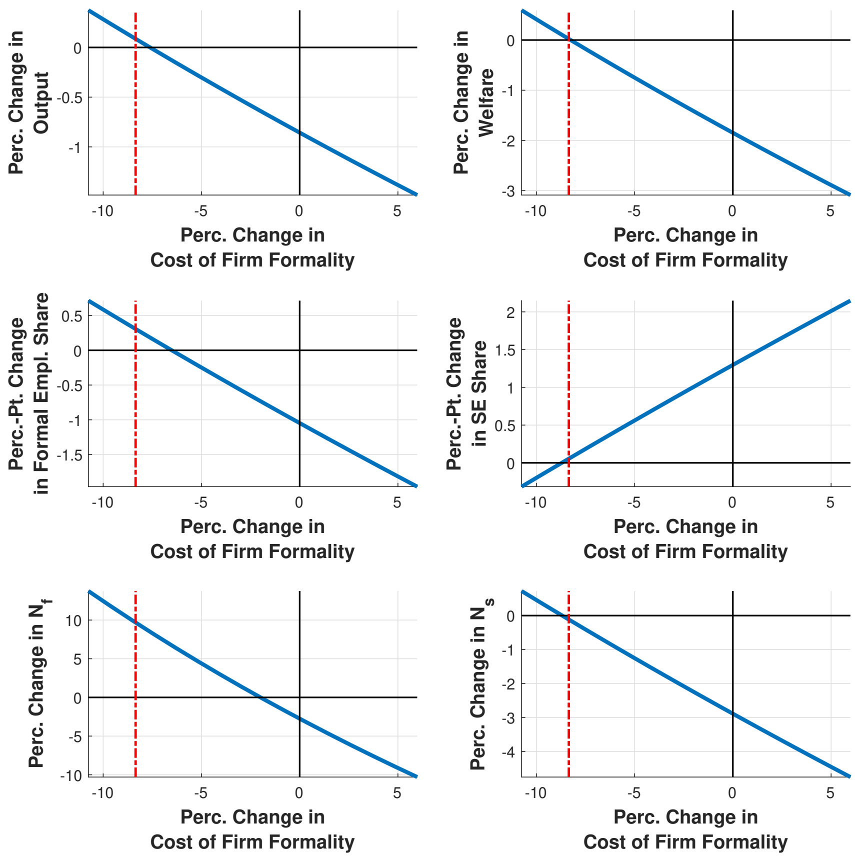
[37] For completeness, Table A10 of Appendix A.6 shows that the same policy experiment in contexts where we abstract from green technology adoption or green energy altogether still generates output and welfare costs. These results confirm the importance of green technology adoption for limiting the adverse impact of the carbon tax, as well as the interaction between this margin of adjustment and other policies.

self-employment and towards formal firms ultimately offset the output, consumption, and welfare losses that the carbon tax otherwise generates, and keep unemployment from rising.

To further highlight how the joint policy can limit the adverse effects of a carbon tax on formality, economic activity, and welfare, Figure 3 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.* For reference, the vertical dash-dotted red line marks the scenario in column (3) of Table 6 (that is, the scenario with a 8.35-percent reduction in φ_f) while the vertical line at zero marks the benchmark, no-change-in-firm-formality-cost scenario (column (1) of Table 6).

As the figure illustrates, 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. More broadly, the largest reduction in the cost of firm formality we consider in Figure 3 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.

Figure 3: 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 6. 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 (1) of Table 6).

For completeness, Figure A3 in Appendix A.6 shows the transition path for this joint policy while Figure A4 in the same Appendix shows a version with capital adjustment costs. A key takeaway from looking at 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 costs associated with the transition to a lower-carbon economy, even if the transition takes place amid capital adjustment costs.

4.3.4 Alternative Climate Policies

In addition to using a carbon tax, EMEs can also implement alternative climate policies to reduce emissions and foster a transition to a lower-carbon economy. Two such policies are: (1) a reduction in the cost of green technology adoption (φ_e in our model), and (2) a reduction in the cost of green capital, which is used by energy producers that rely on the g technology (r_k^g in the model). Both policies can be implemented with the use of targeted subsidies or, for example, with the removal of trade barriers if green technologies and green capital are imported, as tends to be the case in EMEs (Pigato et al., 2020).

Table 7 compares the outcomes of the carbon-tax analysis in the benchmark model (shown originally in Table 4 and reproduced in column (1) of Table 7) to the outcomes of these two alternative climate policies in the same model. For comparability with our carbon-tax analysis, the two alternative climate policies each reduce emissions by 25 percent relative to their baseline level. Moreover, for transparency, we assume that these policies are financed with non-distortionary taxes. Reducing emissions by 25 percent via a reduction in the fixed cost of green technology adoption φ_g entails a reduction of almost 85 percent in φ_g relative to its baseline (a non-trivial reduction). In turn, reducing emissions by 25 percent via a reduction in the price of green capital r_k^g requires a much more modest and plausible 16-percent reduction in r_k^g from its baseline level.

Table 7: Long-Run Effects of Climate Policies in Benchmark Model (25-Percent Reduction in Emissions)—Carbon Tax vs. Reduction in Cost of Green Technology Adoption φ_e vs. Reduction in Cost of Green Capital r_k^g

Variable	**Benchmark Model Carbon Tax**	**Benchmark Model Reduction in Cost of Green Tech. Adopt. φ_e**	**Benchmark Model Reduction in Price r_k^g of k_e^g**
	(1)	(2)	(3)
	Percent Change Relative to Baseline	**Percent Change** Relative to Baseline	**Percent Change** Relative to Baseline
Total Output	-0.857	-0.415	0.526
Consumption	-0.491	-0.441	0.115
Capital Investment	-9.467	-10.024	-9.083
Total Employment (Level)	0.417	0.317	-0.112
Real Wage f	-0.402	-0.231	0.263
Real Wage i	-0.398	-0.229	0.261
Salaried Firms (N_s)	-2.888	-1.545	1.491
f Firms (N_f)	-2.751	-1.478	1.416
i Firms (N_i)	-5.859	-1.547	1.494
Ave. Salaried Firm Prod.	0.008	-0.001	0.001
Price of Energy	**11.628**	**7.491**	**-2.750**
Welfare Gain (% of Consumption)	-1.848	-1.252	0.705
	Perc.-Pt. Change Relative to Baseline	**Perc.-Pt. Change** Relative to Baseline	**Perc.-Pt. Change** Relative to Baseline
Share of f Firms (N_f/N_s)	0.005	0.002	-0.003
Share of f Output in Total Output	-0.732	-0.422	0.308
f Employment Share	-1.047	-0.604	0.450
i Salaried Employment Share	-0.250	-0.139	0.113
Self-Employment Share	1.297	0.743	-0.563
Unemployment Rate	0.153	0.087	-0.069
LFP Rate	0.368	0.260	-0.117
Emissions Abate. Rate (μ_e)	3.461	0.000	0.000
Share of e Producers Using g Tech.	3.666	15.884	7.268
Share of Green Energy	17.515	27.724	29.177
Tax Revenue-Output Ratio	0.144	0.000	0.000

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. Perc.-Pt. Change denotes Percentage-Point Change.

Column (2) of Table 7 shows that, compared to the effects of a carbon tax, a reduction in emissions stemming from lower green-technology adoption costs generates half the output losses, two-thirds of the welfare losses, and slightly more than half of the decline in the formal employment share and in the measure of formal salaried firms. At the same time, the policy leads to an increase in the share of energy producers using the g technology and in the share of green energy that are, respectively, almost 5 times and 2 times greater compared to the corresponding changes using a carbon tax.

The fact that this policy has adverse effects on formal employment, salaried firms, and macroeconomic outcomes in the absence of distortionary taxes is initially surprising, even if these adverse effects are quantitatively smaller than those of a carbon tax. The main reason for this finding is that, by shifting energy producers' technological and input choices, the reduction in the cost of green technology adoption results in an equilibrium increase in the price of energy. The increase in energy prices not only pushes salaried firms to reduce job creation but also reduces the incentive to create firms in the first place, leading to a reduction in the equilibrium measure of salaried firms across categories and to an increase in the share of self-employment. These effects are qualitatively similar to those of a carbon tax, but quantitatively smaller given the absence of tax distortions.

Column (3) of Table 7 shows that compared to the effects of a carbon tax, a reduction in the cost of green capital can have net *positive* effects on output, consumption, the measures of salaried firms, the share of formal employment, and welfare (recall that the 25-percent reduction in emissions is achieved with only a 16-percent reduction in the cost of green capital). Moreover, the increase in the share of green energy is quantitatively similar to the one in the first alternative climate policy. Critically, by directly reducing the cost of inputs used in green energy production and shifting energy producers towards the g technology, this second alternative climate policy ends up putting *downward* pressure on the price of energy and leads to an equilibrium reduction in energy prices. As a result, salaried firms bolster job creation, new salaried firm creation becomes more appealing, and household members' incentive to search for self-employment opportunities falls.

The end result is an increase in the measure of salaried firms across the board, a reduction the share of self-employment, and an increase in the share of formal employment. The shift of the employment and production structure towards formality ultimately results in greater household income, greater consumption, and greater output. Moreover, as shown in Figure A5 in Appendix A.6, the positive effects of a reduction in the cost of green capital are also present in the transition path towards the lower-emissions equilibrium. More broadly, if EMEs rely on imported green technologies and inputs in the production of green energy, and these imports are subject to tariffs or other barriers, the results in Table 7 suggest that reducing these barriers can achieve both a reduction in emissions and net gains in formal employment, output, and welfare. We stress, though, that these net gains only take place as long as the greater adoption and use of green technologies (and the resulting increase in the share of green energy) translate into a *reduction* in the equilibrium price of energy. Finally, we note that these findings remain unchanged if we assume that the self-employed also use energy as an input in production (see Table A11 in Appendix A.6).

5 Conclusion

We study the labor market and macroeconomic effects of introducing a carbon tax in emerging economies (EMEs) in a framework with equilibrium unemployment, self-employment, and endogenous salaried firm entry with selection into formality that captures the distinct employment and firm structure of EMEs. Focusing on the energy-producing sector as the source of harmful emissions, where these emissions can be taxed, we allow energy producers to choose between polluting (subject to carbon taxation) or green (costly to adopt but not subject to carbon taxation) technologies, thereby endogenizing the share of energy producers that use green technologies and the technological composition of energy production.

Our quantitative analysis delivers four main results. First, a carbon tax bolsters green technology adoption and increases the share of green energy in the total energy mix, but leads to higher energy prices. As a result, the tax reduces the number of formal firms, the share of formal employment, and the overall number of salaried firms, and increases self-employment. The resulting change in the composition of employment and production ultimately reduces consumption, GDP, and welfare, and increases unemployment. 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 a non-trivial role in explaining the adverse effects of the carbon tax on labor market and macroeconomic outcomes. Finally, we show that achieving the targeted reduction in emissions with a carbon tax need not generate output and welfare losses if the carbon tax is coupled with an empirically-plausible reduction in the cost that salaried firms must incur to become formal. This last finding suggests 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, and more research is needed to assess these welfare effects.

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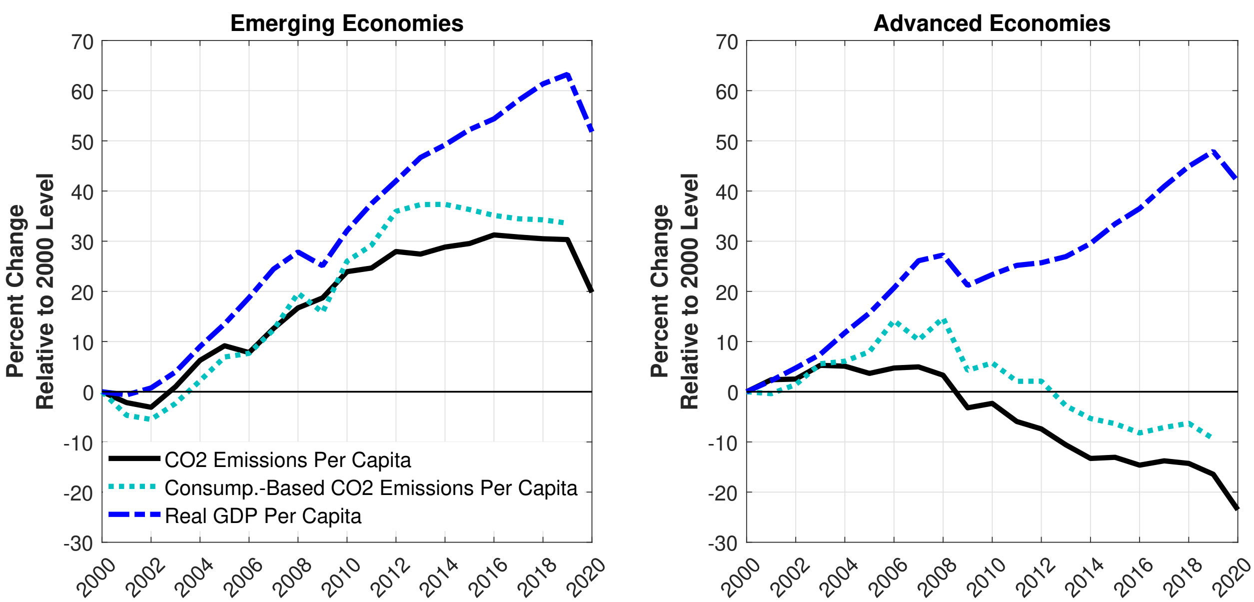
A Appendix – Not For Publication

A.1 Additional Facts

Figure A1: Growth in Carbon Dioxide Emissions Per Capita and Real GDP Per Capita—Emerging Economies vs. Advanced 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.2 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 $\{Y_t, p_{s,t}, p_{o,t}, Y_{s,t}, Y_{o,t}, k_{f,t}, k_{i,t}, v_{f,t}, v_{i,t}, e_{f,t}, e_{i,t}, N_{f,t}, N_{i,t}, \overline{a}_{s,t}, \widetilde{\pi}_{s,t}, \widetilde{\pi}_{f,t}, \widetilde{\pi}_{i,t}, \pi_{f,t}(\overline{a}_{s,t})\}$,

$\left\{\pi_{i,t}(\overline{a}_{s,t}), \rho_{f,t}(\overline{a}_{s,t}), \rho_{i,t}(\overline{a}_{s,t}), y_{f,t}(\overline{a}_{s,t}), y_{i,t}(\overline{a}_{s,t}), mc_{f,t}, mc_{i,t}, \widetilde{\rho}^{f}_{s,t}, \widetilde{\rho}^{i}_{s,t}, \rho_{e,t}, E_t, \overline{a}_{e,t}, \widetilde{\rho}^{r}_{e,t}, \widetilde{\rho}^{g}_{e,t}\right\}$, $\left\{\pi^{r}_{e,t}(\overline{a}_{e,t}), \pi^{g}_{e,t}(\overline{a}_{e,t}), \rho^{r}_{e,t}(\overline{a}_{e,t}), \rho^{g}_{e,t}(\overline{a}_{e,t}), e_{r,t}(\overline{a}_{e,t}), e_{g,t}(\overline{a}_{e,t}), mc^{r}_{e,t}, mc^{g}_{e,t}, em_t, x_t, k^{r}_{e,t}, \mu_t, k^{g}_{e,t}\right\}$, $\left\{k_t, n_{f,t}, n_{i,t}, n_{o,t}, N_{s,t}, e_{h,t}, A_{s,t}, r_{k,t}, s_{f,t}, s_{i,t}, s_{o,t}, w_{f,t}, w_{i,t}, \widetilde{e}_{r,t}, \widetilde{e}_{g,t}, \widetilde{y}_{f,t}, \widetilde{y}_{i,t}, c_t, \widetilde{a}^{f}_{s,t}, \widetilde{a}^{i}_{s,t}\right\}$, and $\left\{\widetilde{a}^{r}_{e,t}, \widetilde{a}^{g}_{e,t}, \Gamma_t, ur_t, lfp_t\right\}$ satisfy:

$$Y_t = \left[Y_{s,t}^{\frac{\phi_y - 1}{\phi_y}} + Y_{o,t}^{\frac{\phi_y - 1}{\phi_y}}\right]^{\frac{\phi_y}{\phi_y - 1}}, \tag{34}$$

$$p_{s,t} = \left[N_{f,t}\left(\widetilde{\rho}_{f,t}\right)^{1-\varepsilon} + N_{i,t}\left(\widetilde{\rho}_{i,t}\right)^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}}, \tag{35}$$

$$Y_{s,t} = \left(p_{s,t}\right)^{-\phi_y} Y_t, \tag{36}$$

$$Y_{o,t} = \left(p_{o,t}\right)^{-\phi_y} Y_t, \tag{37}$$

$$Y_{o,t} = D(x_t) z_{o,t} n_{o,t}, \tag{38}$$

$$mc_{f,t} D(x_t) z_{f,t} H_{k_f,t} = r_{k,t}, \tag{39}$$

$$mc_{i,t} D(x_t) z_{i,t} F_{k_i,t} = r_{k,t}, \tag{40}$$

$$\frac{\psi_f}{q_{f,t}} = mc_{f,t} D(x_t) z_{f,t} H_{n_f,t} - w_{f,t} + (1-\rho_s)\Xi_{t+1|t}\left(\frac{\psi_f}{q_{f,t+1}}\right), \tag{41}$$

$$\frac{\psi_i}{q_{i,t}} = mc_{i,t} D(x_t) z_{i,t} F_{n_i,t} - w_{i,t} + (1-\rho_s)\Xi_{t+1|t}\left(\frac{\psi_i}{q_{i,t+1}}\right), \tag{42}$$

$$mc_{f,t} D(x_t) z_{f,t} H_{e_f,t} = \rho_{e,t}, \tag{43}$$

$$mc_{i,t} D(x_t) z_{i,t} F_{e_i,t} = \rho_{e,t}, \tag{44}$$

$$N_{f,t} = \left[1 - G(\overline{a}_{s,t})\right] N_{s,t}, \tag{45}$$

$$N_{i,t} = G(\overline{a}_{s,t}) N_{s,t}, \tag{46}$$

$$\pi_{i,t}(\overline{a}_{s,t}) = \pi_{f,t}(\overline{a}_{s,t}), \tag{47}$$

$$\widetilde{\pi}_{s,t} = \left(\frac{N_{f,t}}{N_{s,t}}\right)\widetilde{\pi}_{f,t} + \left(\frac{N_{i,t}}{N_{s,t}}\right)\widetilde{\pi}_{i,t}, \tag{48}$$

$$\widetilde{\pi}_{f,t} = \left[\widetilde{\rho}^{f}_{s,t} - \frac{mc_{f,t}}{\widetilde{a}^{f}_{s,t}}\right]\widetilde{y}_{f,t} - \psi_f, \tag{49}$$

$$\widetilde{\pi}_{i,t} = \left[\widetilde{\rho}^{i}_{s,t} - \frac{mc_{i,t}}{\widetilde{a}^{i}_{s,t}}\right]\widetilde{y}_{i,t}, \tag{50}$$

$$\pi_{i,t}(\overline{a}_{s,t}) = \left[\rho_{i,t}(\overline{a}_{s,t}) - \frac{mc_{i,t}}{\overline{a}_{s,t}}\right] y_{i,t}(\overline{a}_{s,t}), \tag{51}$$

$$\pi_{f,t}(\overline{a}_{s,t}) = \left[\rho_{f,t}(\overline{a}_{s,t}) - \frac{mc_{f,t}}{\overline{a}_{s,t}}\right] y_{f,t}(\overline{a}_{s,t}) - \varphi_f, \tag{52}$$

$$\rho_{f,t}(\overline{a}_{s,t}) = \frac{\varepsilon}{\varepsilon - 1}\frac{mc_{f,t}}{\overline{a}_{s,t}}, \tag{53}$$

$$\rho_{i,t}(\overline{a}_{s,t}) = \frac{\varepsilon}{\varepsilon - 1}\frac{mc_{i,t}}{\overline{a}_{s,t}}, \tag{54}$$

$$y_{f,t}(\overline{a}_{s,t}) = (\rho_{f,t}(\overline{a}_{s,t})/p_{s,t})^{-\varepsilon}\, Y_{s,t}, \tag{55}$$

$$y_{i,t}(\overline{a}_{s,t}) = (\rho_{i,t}(\overline{a}_{s,t})/p_{s,t})^{-\varepsilon}\, Y_{s,t}, \tag{56}$$

$$\widetilde{y}_{f,t} = \left(\widetilde{\rho}^{f}_{s,t}/p_{s,t}\right)^{-\varepsilon} Y_{s,t}, \tag{57}$$

$$\widetilde{y}_{i,t} = \left(\widetilde{\rho}^{i}_{s,t}/p_{s,t}\right)^{-\varepsilon} Y_{s,t}, \tag{58}$$

$$\widetilde{\rho}^{f}_{s,t} = \frac{\varepsilon}{\varepsilon - 1}\frac{mc_{f,t}}{\widetilde{a}^{f}_{s,t}}, \tag{59}$$

$$\widetilde{\rho}^{i}_{s,t} = \frac{\varepsilon}{\varepsilon - 1}\frac{mc_{i,t}}{\widetilde{a}^{i}_{s,t}}, \tag{60}$$

$$\rho_{e,t} = \left(G(\overline{a}_{e,t})\left(\widetilde{\rho}^{r}_{e,t}\right)^{1-\varepsilon_e} + \left[1 - G(\overline{a}_{e,t})\right]\left(\widetilde{\rho}^{g}_{e,t}\right)^{1-\varepsilon_e}\right)^{\frac{1}{1-\varepsilon_e}}, \tag{61}$$

$$E_t = e_{h,t} + e_{f,t} + e_{i,t}, \tag{62}$$

$$\pi^{r}_{e,t}(\overline{a}_{e,t}) = \pi^{g}_{e,t}(\overline{a}_{e,t}), \tag{63}$$

$$\widetilde{\rho}^{r}_{e,t} = \frac{\varepsilon_e}{\varepsilon_e - 1}\frac{mc^{r}_{e,t}}{\widetilde{a}^{r}_{e,t}}, \tag{64}$$

$$\widetilde{\rho}^{g}_{e,t} = \frac{\varepsilon_e}{\varepsilon_e - 1}\frac{mc^{g}_{e,t}}{\widetilde{a}^{g}_{e,t}}, \tag{65}$$

$$\pi^{r}_{e,t}(\overline{a}_{e,t}) = \left[(1 - \tau_{e,t})\,\rho^{r}_{e,t}(\overline{a}_{e,t}) - \frac{mc^{r}_{e,t}}{\overline{a}_{e,t}}\right] e_{r,t}(\overline{a}_{e,t}), \tag{66}$$

$$\pi^{g}_{e,t}(\overline{a}_{e,t}) = \left[\rho^{g}_{e,t}(\overline{a}_{e,t}) - \frac{mc^{g}_{e,t}}{\overline{a}_{e,t}}\right] e_{g,t}(\overline{a}_{e,t}) - \varphi_e, \tag{67}$$

$$\rho^r_{e,t}(\overline{a}_{e,t}) = \frac{\varepsilon_e}{\varepsilon_e - 1}\frac{mc^r_{e,t}}{\overline{a}_{e,t}}, \tag{68}$$

$$\rho^g_{e,t}(\overline{a}_{e,t}) = \frac{\varepsilon_e}{\varepsilon_e - 1}\frac{mc^g_{e,t}}{\overline{a}_{e,t}}, \tag{69}$$

$$e_{r,t}(\overline{a}_{e,t}) = \left(\rho^r_{e,t}(\overline{a}_{e,t})/\rho_{e,t}\right)^{-\varepsilon_e} E_t, \tag{70}$$

$$e_{g,t}(\overline{a}_{e,t}) = \left(\rho^g_{e,t}(\overline{a}_{e,t})/\rho_{e,t}\right)^{-\varepsilon_e} E_t, \tag{71}$$

$$\widetilde{e}_{r,t} = \left(\widetilde{\rho}^r_{e,t}/\rho_{e,t}\right)^{-\varepsilon_e} E_t, \tag{72}$$

$$\widetilde{e}_{g,t} = \left(\widetilde{\rho}^g_{e,t}/\rho_{e,t}\right)^{-\varepsilon_e} E_t, \tag{73}$$

$$em_t = (1 - \mu_{e,t})\left[D(x_t) z^r_{e,t} k^r_{e,t}\right]^{1-\nu_e}, \tag{74}$$

$$x_t = \rho_x x_{t-1} + em_t + em^{row}_t, \tag{75}$$

$$D(x_t) mc^r_{e,t} z^r_{e,t} = r_{k,t} + \Big((1-\nu_e)\,\tau_{e,t}(1-\mu_{e,t})\left[D(x_t) z^r_{e,t} k^r_{e,t}\right]^{-\nu_e} + \mu^\eta_{e,t}\Big) D(x_t) z^r_{e,t}, \tag{76}$$

$$\eta\gamma\mu^{\eta-1}_{e,t} = \tau_{e,t}\left[D(x_t) z^r_{e,t} k^r_{e,t}\right]^{-\nu_e}, \tag{77}$$

$$D(x_t) mc^g_{e,t} z^g_{e,t} = r^g_{k,t}, \tag{78}$$

$$k_t = k_{f,t} + k_{i,t} + k^r_{e,t}, \tag{79}$$

$$n_{f,t} = (1-\rho_s) n_{f,t-1} + s_{f,t}\varrho_{f,t}, \tag{80}$$

$$n_{i,t} = (1-\rho_s) n_{i,t-1} + s_{i,t}\varrho_{i,t}, \tag{81}$$

$$n_{o,t} = (1-\rho_o) n_{o,t-1} + s_{o,t}\phi_o, \tag{82}$$

$$N_{s,t+1} = (1-\delta_s)\left(N_{s,t} + A_{s,t}\right), \tag{83}$$

$$\mathbf{u}_{e_h,t} = \rho_{e,t}\mathbf{u}_{c,t}, \tag{84}$$

$$\varphi_s = (1-\delta_s)\Xi_{t+1|t}\left[\widetilde{\pi}_{s,t+1} + \varphi_s\right], \tag{85}$$

$$1 = \Xi_{t+1|t}\left[r_{k,t+1} + (1-\delta)\right], \tag{86}$$

$$\frac{\mathbf{h}_{lfp_{f,t}}}{\mathbf{u}_{c,t}} = \varrho_{f,t}\left[w_{f,t} + (1-\rho_s)\Xi_{t+1|t}\left(\frac{1-\varrho_{f,t+1}}{\varrho_{f,t+1}}\right)\left(\frac{\mathbf{h}_{lfp_{f,t+1}}}{\mathbf{u}_{c,t+1}}\right)\right], \tag{87}$$

$$\frac{\mathbf{h}_{lfp_{i,t}}}{\mathbf{u}_{c,t}} = \varrho_{i,t}\left[w_{i,t} + (1-\rho_s)\Xi_{t+1|t}\left(\frac{1-\varrho_{i,t+1}}{\varrho_{i,t+1}}\right)\left(\frac{\mathbf{h}_{lfp_{i,t+1}}}{\mathbf{u}_{c,t+1}}\right)\right], \tag{88}$$

$$\frac{\mathbf{h}_{lfp_{o,t}}}{\mathbf{u}_{c,t}} = \phi_o\left[p_{o,t}D(x_t)z_{o,t} + (1-\rho_o)\Xi_{t+1|t}\left(\frac{1-\phi_o}{\phi_o}\right)\left(\frac{\mathbf{h}_{lfp_{o,t+1}}}{\mathbf{u}_{c,t+1}}\right)\right], \tag{89}$$

$$w_{f,t} = \nu_n\left(mc_{f,t}D(x_t)z_{f,t}H_{n_f,t} + (1-\rho_s)\,\mathbb{E}_t\Xi_{t+1|t}\psi_f\theta_{f,t+1}\right), \tag{90}$$

$$w_{i,t} = \nu_n\left(mc_{i,t}D(x_t)z_{i,t}F_{n_i,t} + (1-\rho_s)\,\mathbb{E}_t\Xi_{t+1|t}\psi_i\theta_{i,t+1}\right), \tag{91}$$

$$D(x_t)z^r_{e,t}k^r_{e,t} = G(\overline{a}_{e,t})\left(\frac{\widetilde{e}_{r,t}}{\widetilde{a}^r_{e,t}}\right), \tag{92}$$

$$D(x_t)z^g_{e,t}k^g_{e,t} = [1-G(\overline{a}_{e,t})]\left(\frac{\widetilde{e}_{g,t}}{\widetilde{a}^g_{e,t}}\right), \tag{93}$$

$$D(x_t)z_{f,t}H(n_{f,t},k_{f,t},e_{f,t}) = N_{f,t}\left(\frac{\widetilde{y}_{f,t}}{\widetilde{a}^f_{s,t}}\right), \tag{94}$$

$$D(x_t)z_{i,t}F(n_{i,t},k_{i,t},e_{i,t}) = N_{i,t}\left(\frac{\widetilde{y}_{i,t}}{\widetilde{a}^i_{s,t}}\right), \tag{95}$$

$$Y_t = c_t + (k_{t+1}-(1-\delta)k_t) + \psi_f v_{f,t} + \psi_i v_{i,t} + \varphi_s A_{s,t} + \varphi_f N_{f,t} + \varphi_e\left[1-G(\overline{a}_{e,t})\right] + \Gamma_t + r^g_{k,t}k^g_{e,t}, \tag{96}$$

$$\widetilde{a}^i_{s,t} = \widetilde{a}^f_{s,t}\left(\frac{\overline{a}_{s,t}^{k_p-(\varepsilon-1)} - a_{s,min}^{k_p-(\varepsilon-1)}}{\overline{a}_{s,t}^{k_p} - a_{s,min}^{k_p}}\right)^{\frac{1}{\varepsilon-1}} a_{s,min}, \tag{97}$$

$$\widetilde{a}^f_t = \left(\frac{k_p}{k_p-(\varepsilon-1)}\right)^{\frac{1}{\varepsilon-1}}\overline{a}_{s,t}, \tag{98}$$

$$\widetilde{a}^r_{e,t} = \widetilde{a}^g_{e,t}\left(\frac{\overline{a}_{e,t}^{k^e_p-(\varepsilon_e-1)} - a_{e,min}^{k^e_p-(\varepsilon_e-1)}}{\overline{a}_{e,t}^{k^e_p} - a_{e,min}^{k^e_p}}\right)^{\frac{1}{\varepsilon_e-1}} a_{e,min}, \tag{99}$$

$$\widetilde{a}^g_{e,t} = \left(\frac{k^e_p}{k^e_p-(\varepsilon_e-1)}\right)^{\frac{1}{\varepsilon_e-1}}\overline{a}_{e,t}, \tag{100}$$

$$\Gamma_t = \gamma\mu^\eta_{e,t}D(x_t)z^r_{e,t}k^r_{e,t}, \tag{101}$$

$$ur_t = \frac{(1-\varrho_{f,t})\,s_{f,t} + (1-\varrho_{i,t})\,s_{i,t} + (1-\phi_o)\,s_{o,t}}{lfp_t}, \tag{102}$$

$$lfp_t = n_{f,t} + n_{i,t} + n_{o,t} + (1-\varrho_{f,t})\,s_{f,t} + (1-\varrho_{i,t})\,s_{i,t} + (1-\phi_o)\,s_{o,t}. \tag{103}$$

A.3 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 $\widetilde{p}_{f,t} \equiv p_{f,t}(\widetilde{a}_{s,t}^{f})$ and $\widetilde{p}_{i,t} \equiv p_{i,t}(\widetilde{a}_{s,t}^{i})$ are average nominal prices. Recalling that $N_{f,t} = \left[1 - G(\overline{a}_{s,t})\right] N_{s,t}$ and $N_{i,t} = G(\overline{a}_{s,t})N_{s,t}$, we can write the expression for $P_{s,t}$ as

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

Thus, we can write this last expression as

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

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_t^m into a data-consistent model variable λ_t^d is $\lambda_t^d = \lambda_t^m \Theta_t$ where $\Theta_t = \left(N_{s,t}^{\frac{1-\phi_y}{1-\varepsilon}} + 1\right)^{\frac{1}{1-\phi_y}}$ (see Cacciatore, Duval, Fiori, and Ghironi, 2016, or Finkelstein Shapiro and Nuguer, 2022, for a similar expression).

A.4 Model Validation: Growth in Emissions and Change in Self-Employment Shares

Table A1: 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 A2: 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 CO_2 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

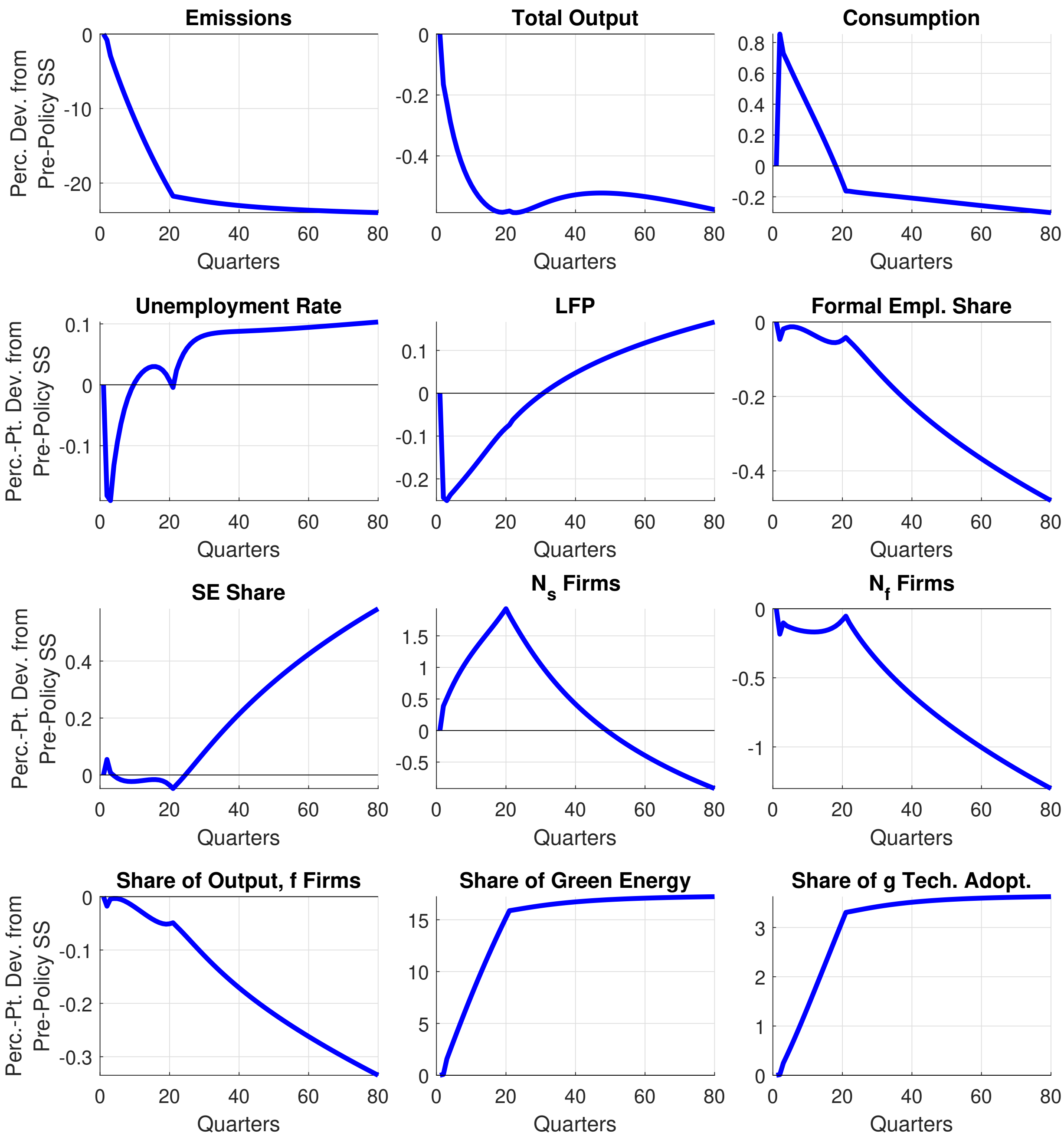
b. Advanced Economies

Change in SE Share$_{t,t-1}$	(1)	(2)	(3)	(4)
Percent Change in CO_2 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.5 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 A3: 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.
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

Table A4: 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 Change Relative to Baseline	**Percent Change** Relative to Baseline	**Percent Change** Relative to Baseline
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
	Perc.-Pt. Change Relative to Baseline	**Perc.-Pt. Change** Relative to Baseline	**Perc.-Pt. Change** Relative to Baseline
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. Perc.-Pt. Change denotes Percentage-Point Change.

Table A5: 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 Change Relative to Baseline	**Percent Change** Relative to Baseline	**Percent Change** Relative to Baseline
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
	Perc.-Pt. Change Relative to Baseline	**Perc.-Pt. Change** Relative to Baseline	**Perc.-Pt. Change** Relative to Baseline
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. Perc.-Pt. Change denotes Percentage-Point Change.

Table A6: 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 Change Relative to Baseline	**Percent Change** Relative to Baseline	**Percent Change** Relative to Baseline
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
	Perc.-Pt. Change Relative to Baseline	**Perc.-Pt. Change** Relative to Baseline	**Perc.-Pt. Change** Relative to Baseline
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. Perc.-Pt. Change denotes Percentage-Point Change.

Table A7: 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 Change Relative to Baseline	**Percent Change** Relative to Baseline	**Percent Change** Relative to Baseline
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
	Perc.-Pt. Change Relative to Baseline	**Perc.-Pt. Change** Relative to Baseline	**Perc.-Pt. Change** Relative to Baseline
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. Perc.-Pt. Change denotes Percentage-Point Change.

Table A8: 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 Change Relative to Baseline	**Percent Change** Relative to Baseline	**Percent Change** Relative to Baseline
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
	Perc.-Pt. Change Relative to Baseline	**Perc.-Pt. Change** Relative to Baseline	**Perc.-Pt. Change** Relative to Baseline
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. Perc.-Pt. Change denotes Percentage-Point Change.

Table A9: 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 Change Relative to Baseline	**Percent Change** Relative to Baseline	**Percent Change** Relative to Baseline
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
	Perc.-Pt. Change Relative to Baseline	**Perc.-Pt. Change** Relative to Baseline	**Perc.-Pt. Change** Relative to Baseline
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. Perc.-Pt. Change denotes Percentage-Point Change.

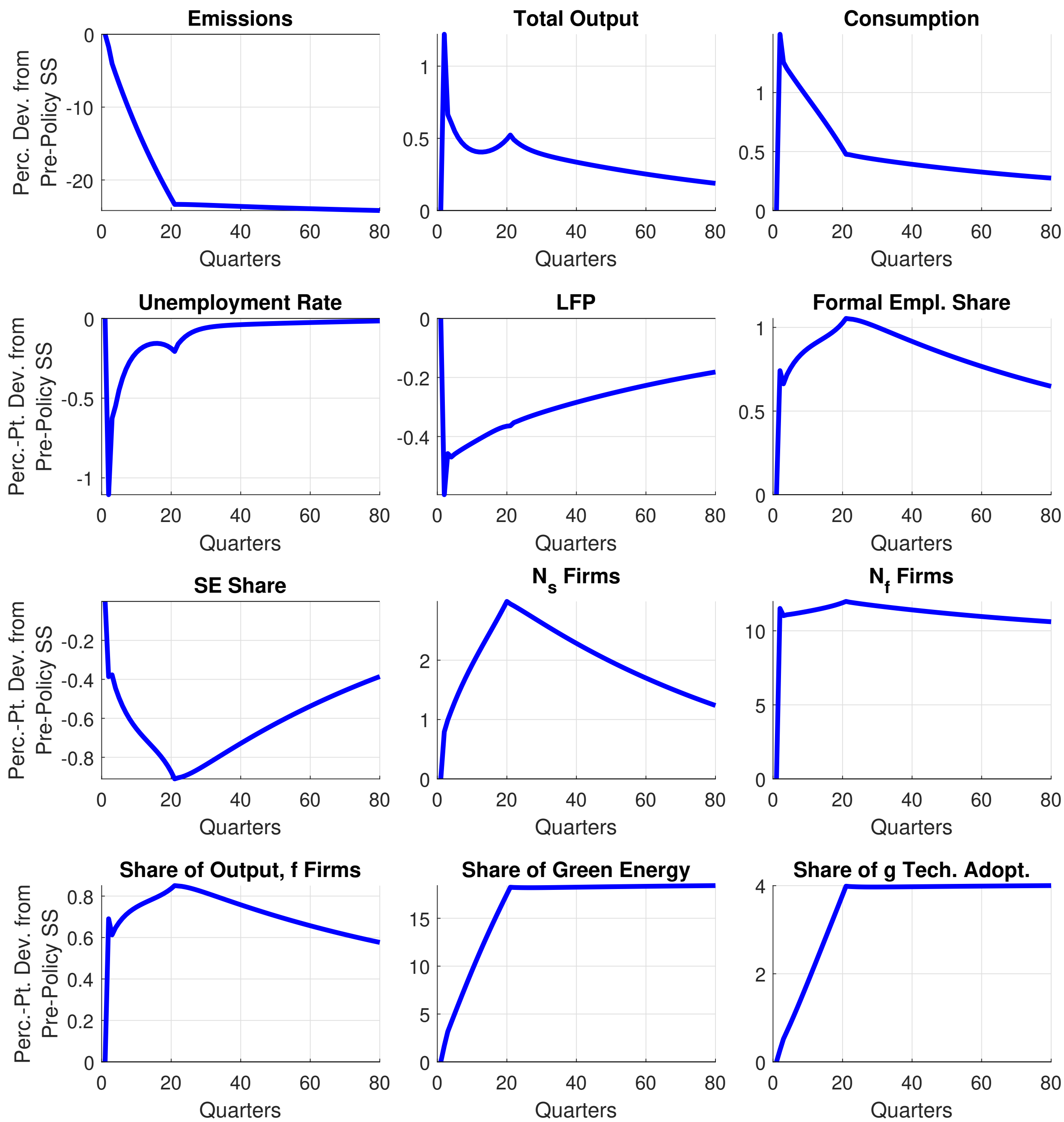
A.6 Additional Model Results

Table A10: 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 Change Relative to Baseline	**Percent Change** Relative to Baseline	**Percent Change** Relative to Baseline
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
	Perc.-Pt. Change Relative to Baseline	**Perc.-Pt. Change** Relative to Baseline	**Perc.-Pt. Change** Relative to Baseline
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

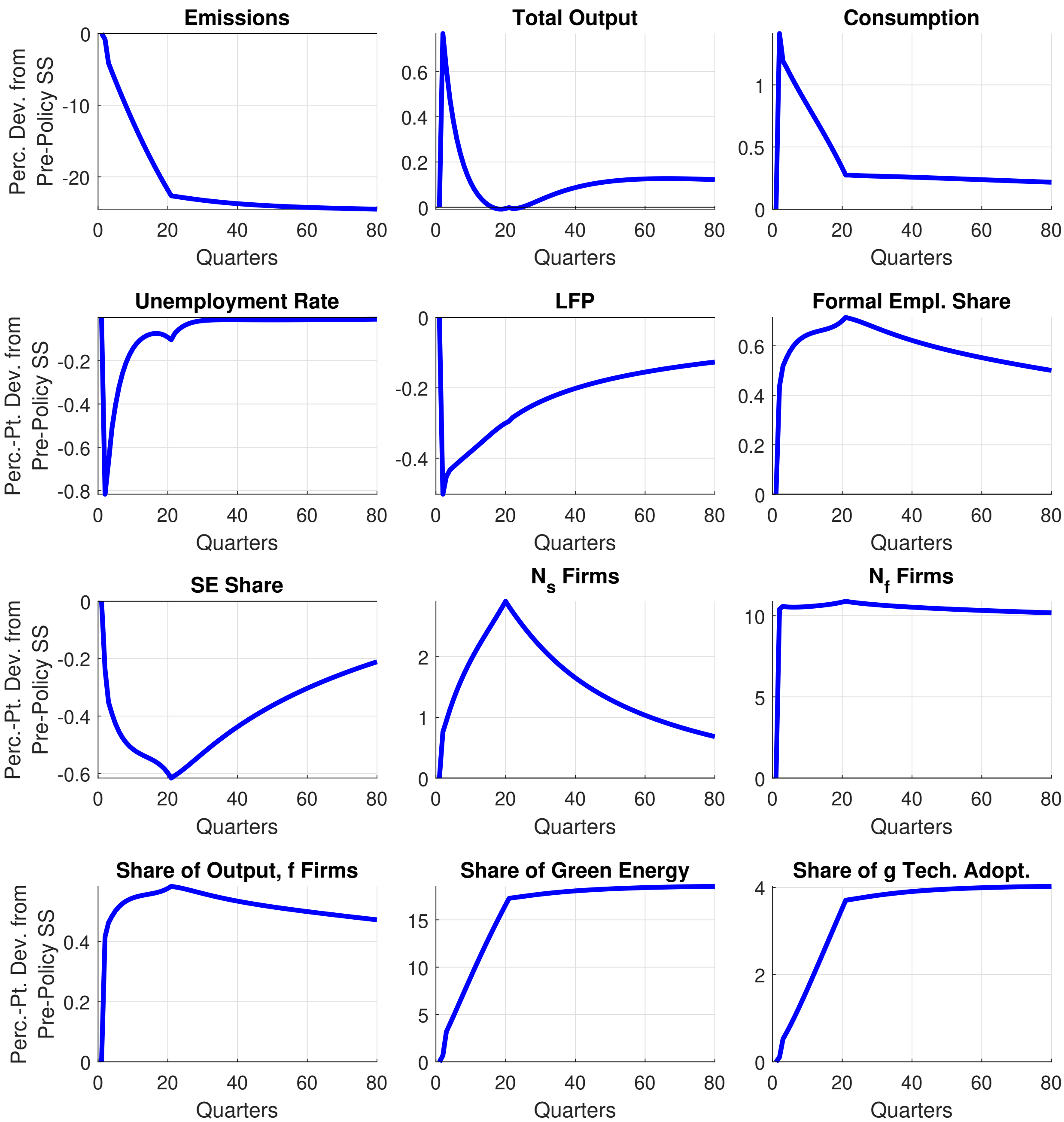
Note: Average salaried firm productivity (Ave. Salaried Firm Prod.) is defined as $(N_f/N_s)\, z_f \widetilde{a}_s^f + (N_i/N_s)\, z_i \widetilde{a}_s^i$. The formal employment share, $(n_f)\,/\,(n_f + n_i + n_o)$, is the mirror image of the informal employment share. The self-employment share is defined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

Figure A3: 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 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 with i- and f-Firm Capital Adjustment Costs



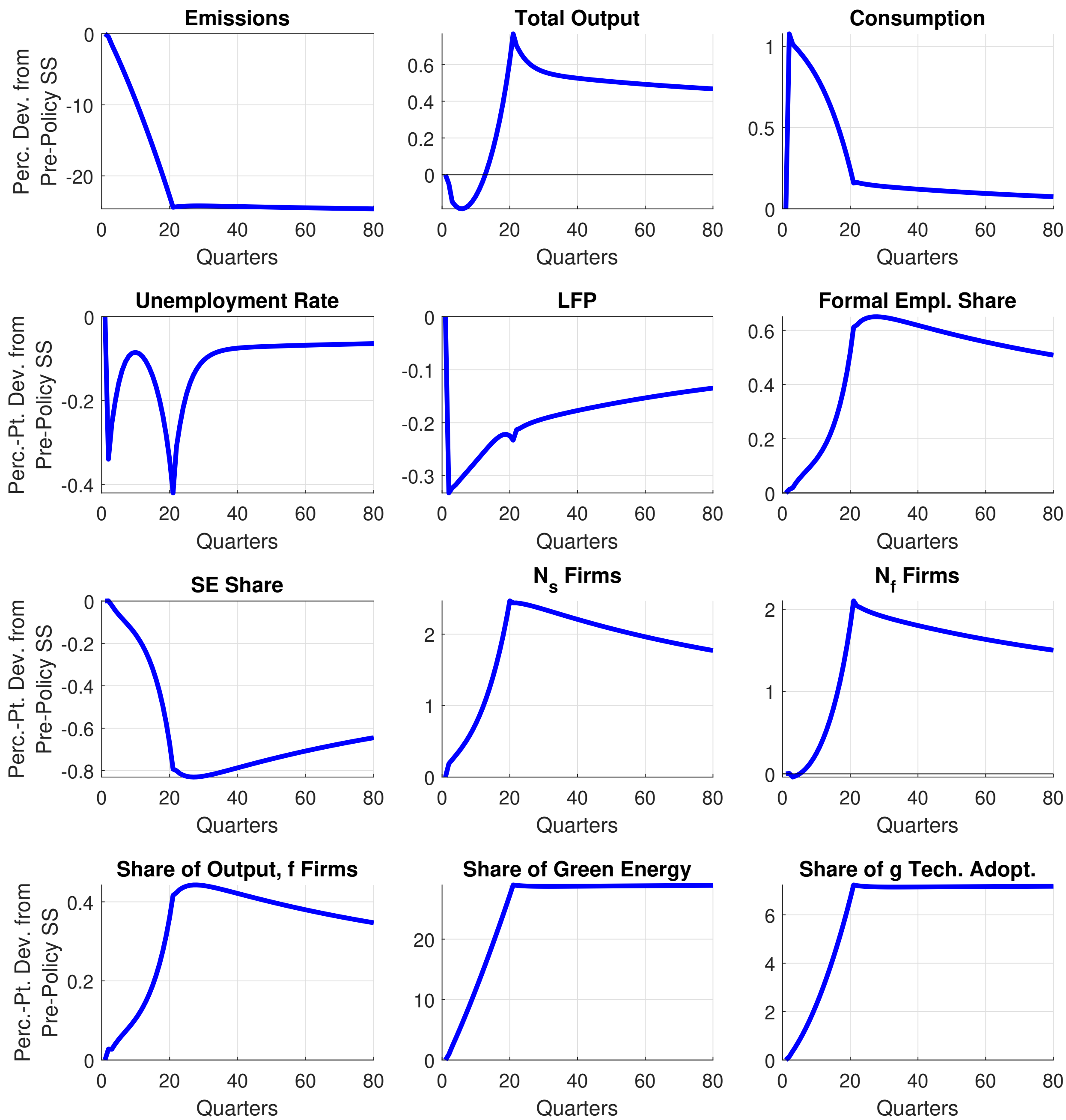
Note: The formal employment share, $(n_f)/(n_f+n_i+n_o)$, is the mirror image of the informal employment share. The self-employment share is defined as $(n_o)/(n_f+n_i+n_o)$. Perc. Dev. denotes percent deviations and Perc.-Pt. Dev. denotes percentage-point deviations. We assume that i and f firms face 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 A11: Long-Run Effects of Climate Policies in Benchmark Model (25-Percent Reduction in Emissions)—Carbon Tax vs. Reduction in Cost of Green Technology Adoption φ_e vs. Reduction in Cost of Green Capital r_k^g

Variable	**Benchmark Model, SE Use Energy**	**Benchmark Model, SE Use Energy**	**Benchmark Model, SE Use Energy**
	Carbon Tax	**Reduction in Cost of Green Tech. Adopt.** φ_e	**Reduction in Price** r_k^g **of** k_e^g
	(1)	(2)	(3)
	Percent Change Relative to Baseline	**Percent Change** Relative to Baseline	**Percent Change** Relative to Baseline
Total Output	-0.857	-0.258	0.490
Consumption	-0.491	-0.490	0.045
Capital Investment	-9.467	-11.790	-11.300
Total Employment (Level)	0.417	0.267	-0.066
Real Wage f	-0.402	-0.339	0.299
Real Wage i	-0.398	-0.338	0.297
Salaried Firms (N_s)	-2.888	-0.716	1.217
f Firms (N_f)	-2.751	-0.711	1.161
i Firms (N_i)	-5.859	-0.717	1.219
Ave. Salaried Firm Prod.	0.008	0.000	-0.003
Price of Energy	19.351	7.327	-2.628
Welfare Gain (% of Consumption)	-1.848	-1.033	0.514
	Perc.-Pt. Change Relative to Baseline	**Perc.-Pt. Change** Relative to Baseline	**Perc.-Pt. Change** Relative to Baseline
Share of f Firms (N_f/N_s)	0.005	0.000	-0.002
Share of f Output in Total Output	-0.732	-0.161	0.212
f Employment Share	-1.047	-0.231	0.311
i Salaried Employment Share	-0.250	-0.045	0.080
Self-Employment Share	1.297	0.276	-0.391
Unemployment Rate	0.153	0.036	-0.049
LFP Rate	0.368	0.193	-0.075
Emissions Abate. Rate (μ_e)	3.461	0.000	0.000
Share of e Producers Using g Tech.	3.666	16.359	7.141
Share of Green Energy	17.515	28.217	28.880
Tax Revenue-Output Ratio	0.144	0.000	0.000

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. Perc.-Pt. Change denotes Percentage-Point Change.

Figure A5: Transitional Dynamics with Gradual Increase in Carbon Tax (25 Percent Reduction in Emissions)—Benchmark Model with Reduction in Cost of Green Capital



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.