THE HETEROGENEOUS EFFECTS OF CARBON PRICING: MACRO AND MICRO EVIDENCE[☆]

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Abstract

This paper studies the macroeconomic and firm-level effects of carbon pricing shocks in the European Union Emissions Trading System. We find that carbon pricing increases inflation and reduces economic activity and equity prices on average across countries. These average effects mask substantial heterogeneity: more carbon-intensive countries experience significantly larger contractions. Using granular firm-level data, we show that firms with higher carbon intensity respond more strongly to carbon pricing shocks. Aggregating firm-level responses reveals attenuation at the macroeconomic level, highlighting the role of general-equilibrium adjustments. A model with heterogeneous green and brown firms rationalizes these findings and provides a structural interpretation of the general-equilibrium attenuation we document.

Keywords: Business Cycles, Carbon Pricing Shocks, Heterogeneity, Asset Prices.

JEL Codes: E32, E50, E60, H23, Q54

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1 Introduction

In order to achieve the objectives of the Paris Agreement, governments around the world need to increase the stringency of climate change mitigation policies.[1] Cap-and-trade schemes, which set overall limits on greenhouse-gas emissions and allow their price to be determined by market forces, are likely to remain an important part of the climate-policy mix. The European Union Emissions Trading System (EU ETS), introduced in 2005 under the Kyoto Protocol, is one such scheme and has reduced emissions in covered sectors in the EU by over 40 percent. Moreover, in July 2021 the European Commission announced that the emissions limits defined by the ETS would be made stricter in order to reduce GHG emissions in the EU by at least 55 percent relative to 1990 levels by 2030. While cap-and-trade schemes are well studied as pollution-control tools, their broader micro and macroeconomic effects—and the mechanisms through which they propagate—remain less understood.

The aim of this paper is to provide empirical evidence on the economic effects of carbon pricing shocks and to shed light on their transmission. Our key innovation is to exploit heterogeneity in CO_2 intensity to trace the effects of carbon pricing shocks from firms to the macroeconomy. In particular, we show (i) that there is significant heterogeneity in the economic effects of carbon pricing shocks at aggregate ('macro') and firm ('micro') levels, which is related to carbon intensity, and (ii) that heterogeneous responses at the micro level do not translate one-for-one into macro outcomes: general-equilibrium forces—such as substitution in demand and reallocation across firms and sectors—systematically attenuate the aggregate impact of carbon pricing shocks. This evidence advances our understanding of how carbon pricing affects activity, prices, and asset valuations.

Our analysis consists of three steps. First, we document the macroeconomic effects of carbon pricing shocks for a panel of 15 euro area countries. We isolate carbon pricing shocks from movements in EU ETS carbon futures prices around regulatory events following Känzig (2026). Using these shocks in a panel local projection framework, we show that they are contractionary, inflationary, and are associated with a fall in equity prices. Importantly, we document substantial cross-country heterogeneity: more CO_2-intensive economies experience larger declines in output and asset prices, and stronger inflationary pressures.

Second, we use granular firm-level data to both validate and sharpen these results, and to

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[1] For example, see the 2022 G7 Leaders' Communiqué.

study how micro-level heterogeneity maps into aggregate responses. We show that emissions-intensive firms experience significantly larger and more persistent equity price declines than their greener counterparts within narrowly defined country–sector–time cells. We then exploit the fact that different fixed-effect structures isolate different sources of variation: a saturated specification that absorbs country–sector–time shocks delivers a partial-equilibrium benchmark, while a less demanding specification that relies on cross-country variation in average emissions intensity allows substitution and reallocation within countries to shape relative outcomes. Comparing the two, we find evidence of general-equilibrium attenuation: the differential response associated with emissions intensity is smaller when identified from cross-country variation than in within-cell firm-level variation.

Third, we develop a two-good DSGE model with green and brown firms to rationalize these findings. A positive carbon pricing shock leads to a contraction in output, a rise in inflation, and declines in equity valuations, consistent with the empirical evidence. The mechanism is straightforward. A higher price of emissions raises firms' effective marginal costs, compresses profits, and leads them to cut production and raise prices. Because brown firms are more CO_2-intensive, their costs and profits respond more strongly to the shock, leading to a larger fall in equity valuations, in line with the micro evidence. However, general-equilibrium forces dampen the aggregate contraction: the resulting increase in the price of brown goods induces substitution toward greener goods and reallocation across firm types.

Beyond matching the key empirical patterns, the model serves three purposes. First, it provides a structural analog to our empirical comparison of partial- and general-equilibrium effects: by shutting down cross-sector interactions, we can isolate how much of the aggregate response reflects reallocation and substitution versus mechanical composition. Second, it traces attenuation to three structural determinants: the size of the brown sector, households' willingness to substitute between brown and green goods, and the emissions intensity of brown production. Third, it offers a disciplined environment for counterfactuals: calibrating the model to the range of carbon intensities observed in the data, we show that browner economies exhibit sharper responses to carbon-pricing shocks, consistent with the cross-country evidence.

Related literature Our paper contributes to the growing literature on the macroeconomic effects of climate mitigation policies. Känzig (2026) shows that positive carbon pricing shocks raise inflation, reduce activity, and depress stock markets. Cross-country evidence points to substantial pass-through to energy prices but more mixed effects on core inflation and output: Moessner (2022) finds strong energy pass-through with limited core inflation effects, while Konradt and di Mauro (2021) document modest inflationary (and possibly deflationary) effects of carbon taxes. Evidence from Europe and British Columbia shows that carbon taxes reduce emissions with quantitatively limited effects on output and employment (Metcalf, 2019; Metcalf and Stock, 2020; Bernard et al., 2018). Using a panel of 24 OECD countries, Ciccarelli and Marotta (2021) finds that climate change, environmental policies, and green technologies have significant but modest macroeconomic effects. Mangiante (2024) documents heterogeneous regional effects of carbon pricing in Europe, while Känzig and Konradt (2023) compare carbon pricing and carbon taxes in a unified framework and show that the former have more severe macroeconomic consequences.

By considering firm-level equity prices and the financial transmission of climate policy, we also relate to the climate finance literature (see Giglio et al., 2021, for a survey). A broad set of studies links exposure to transition risk and carbon intensity to asset prices and risk premia (e.g. Bolton and Kacperczyk, 2021; Hsu et al., 2022; Choi et al., 2020; Barnett, 2020; Ilhan et al., 2021). Closest to our approach, Hengge et al. (2023) show that, for European firms, carbon pricing shocks generate negative abnormal returns that increase with firms' carbon intensity.

Finally, we contribute to the macro-climate modeling literature that embeds the carbon cycle and climate policy into DSGE frameworks and studies the business-cycle implications of alternative regimes (see Annicchiarico et al., 2022, for a survey). This literature typically contrasts cap-and-trade and carbon taxes in response to economic shocks (e.g. Fischer and Springborn, 2011) and characterizes optimal policy over the cycle (Heutel, 2012; Angelopoulos et al., 2013). In contrast, we focus on the transmission of exogenous climate policy shocks in the presence of firm heterogeneity, and on how general-equilibrium forces attenuate micro-level effects in the aggregate.

2 Data

We compile our dataset by combining several sources: carbon pricing shocks from emission allowances futures prices (as in Känzig, 2026); country-level macroeconomic, financial, and CO_2 emissions data for EU ETS member countries; and firm-level equity prices and CO_2

emissions for constituents of major stock indices. Below, we briefly describe each data source; additional details and summary statistics are provided in Appendix A.

Identification of Carbon Pricing Shocks. A key challenge in measuring carbon pricing shocks is that most variation in carbon prices reflects their endogenous response to aggregate economic conditions. To address this, we use the structural carbon policy shocks constructed by Känzig (2026). His identification strategy exploits high-frequency variation in EU ETS carbon futures prices around 114 regulatory events affecting the supply of emission allowances. To ensure exogeneity, he first orthogonalizes raw price surprises with respect to macroeconomic and financial data pre-dating each policy announcement, then uses these purged surprises as external instruments in a monthly VAR to recover structural carbon policy shocks.

Country-level ('Macro') Data. Our analysis uses monthly macroeconomic and financial data for a panel of 15 EU ETS member countries: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Italy, Ireland, the Netherlands, Norway, Portugal, Spain, Sweden, and the United Kingdom, the same set of countries as in Känzig (2026). From Datastream, we obtain quarterly measures of real GDP and real investment;[2] the Harmonised Index of Consumer Prices (HICP) and its energy component; the two-year government bond yield; and equity price indices. We also collect annual country-level CO_2 intensity (kg CO_2e per constant 2015 US$ of GDP) from the World Bank.[3]

Firm-level ('Micro') Data We obtain equity price data for firm j in country i at monthly frequency for the constituents of the main equity indices of the countries in our sample. We complement the equity price data with firm-level proxies for 'carbon intensity', which we denote by $CO2_{ij,t}$. Specifically, we consider both Scope 1 and Scope 2 CO_2 emissions at the firm level from Datastream, which are available at the annual frequency. Scope 1 emissions include greenhouse gases (GHG) emissions that emanate from the operation of capital directly owned by the firms. Scope 2 emissions are indirect emissions associated with the purchase of electricity, steam, heat, or cooling. As the two measures are complementary, we consider a measure that sums Scope 1 and Scope 2 emissions.[4] Finally, we use quarterly firm-level controls from Datastream, including leverage (defined as total debt over total

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[2] Monthly series are constructed by interpolating quarterly data using shape-preserving piecewise cubic interpolation, following Miranda-Agrippino and Rey (2020).

[3] Table B.1 provides summary statistics on our country-level measures of carbon intensity.

[4] Table B.2 provides summary statistics on our firm-level measures of carbon intensity, as well as additional information about the data coverage.

assets), net sales, and total assets.

Final sample. Our baseline data set runs from July 1999 to December 2019, covers 114 regulatory events about the supply allowances of carbon emissions within the EU, includes country-level macroeconomic data for 15 countries, and has firm-level information on equity prices, balance sheet data, and CO_2 emissions for 521 unique firms.

3 Macro Evidence: Country-level Local Projections

This section examines the macroeconomic effects of carbon pricing shocks using aggregate country-level data. We proceed in two steps. First, we estimate average effects on macroeconomic variables and asset prices. Second, we investigate heterogeneous effects across countries based on their CO_2 intensity.

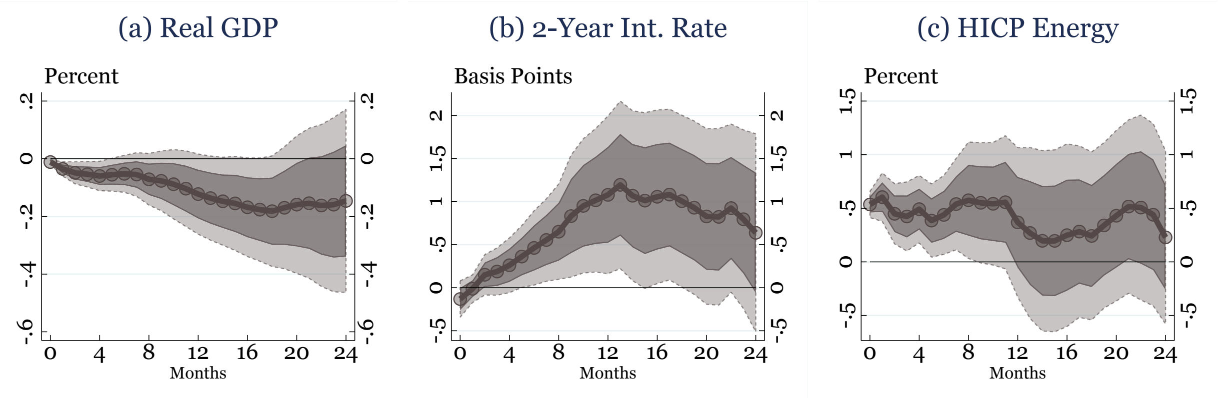
Response of the Average Economy. To estimate the average effects of carbon pricing shocks, we employ a panel local projections approach. Letting $y_{i,t+h}$ denote a generic outcome variable for country i observed h periods ahead, we estimate:

$$y_{i,t+h} - y_{i,t-1} = \alpha_i^h + \beta^h CPS_t + \sum_{p=1}^{P} \Gamma_p^h X_{i,t-p} + u_{i,t+h}, \tag{1}$$

where α_i^h is a country fixed effect at horizon h capturing permanent cross-country differences; CPS_t is the carbon pricing shock described in Section 2; and $X_{i,t}$ collects additional controls including lags of the outcome variable and other macro aggregates (log real GDP, log headline HICP, log energy HICP, log equity price index, two-year interest rate, and investment). We set the maximum number of lags to $P = 12$, standard for monthly data, and compute standard errors following Driscoll and Kraay (1998) to account for both serial and cross-sectional correlation.

Figure 1 plots the estimated coefficients β^h, which capture the dynamic effects of a one standard deviation carbon pricing shock at horizon h for the average country. Consistent with Känzig (2026), carbon pricing shocks resemble negative supply shocks: real GDP gradually decreases to around -0.2 percent below trend after 18 months, while the energy component of HICP rises persistently by about 0.5 percent on impact and headline HICP increases by 0.1 percent. Monetary policy barely moves, with the two-year interest rate increasing by about one basis point after 12 months. Equity prices fall by just under 1 percent on impact, reaching a trough of around −2 percent after 12 months, while investment declines by around −0.5 percent after 20 months.

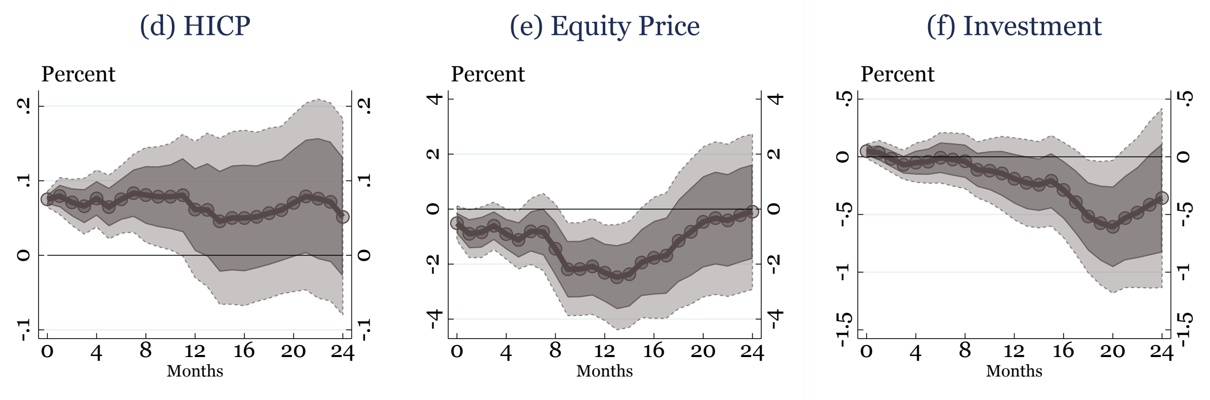
Figure 1 THE EFFECT OF CARBON PRICING SHOCKS: AVERAGE ECONOMY



(a) Real GDP

(b) 2-Year Int. Rate

(c) HICP Energy



(d) HICP

(e) Equity Price

(f) Investment

NOTE. Average effect of a one standard deviation increase in the carbon pricing shock on $y_{i,t+h} - y_{i,t-1}$, as captured by the coefficients β^h in equation (1). Shaded areas display 68 and 90 percent confidence intervals computed with heteroskedasticity and autocorrelation robust standard errors based on Driscoll and Kraay (1998).

Cross-country Heterogeneity. The average responses in Figure 1 may mask important cross-country heterogeneity. We now investigate whether more carbon-intensive countries experience larger effects from carbon pricing shocks.[5]

To estimate heterogeneous effects based on a country's CO_2 intensity, we specify:

$$y_{i,t+h} - y_{i,t-1} = \alpha_i^h + \alpha_t^h + \gamma^h \left(CPS_t \times CO2_{i,t-1}^{High} \right) + \sum_{p=1}^{P} \Gamma_p^h X_{i,t-p} + u_{i,t+h}, \tag{2}$$

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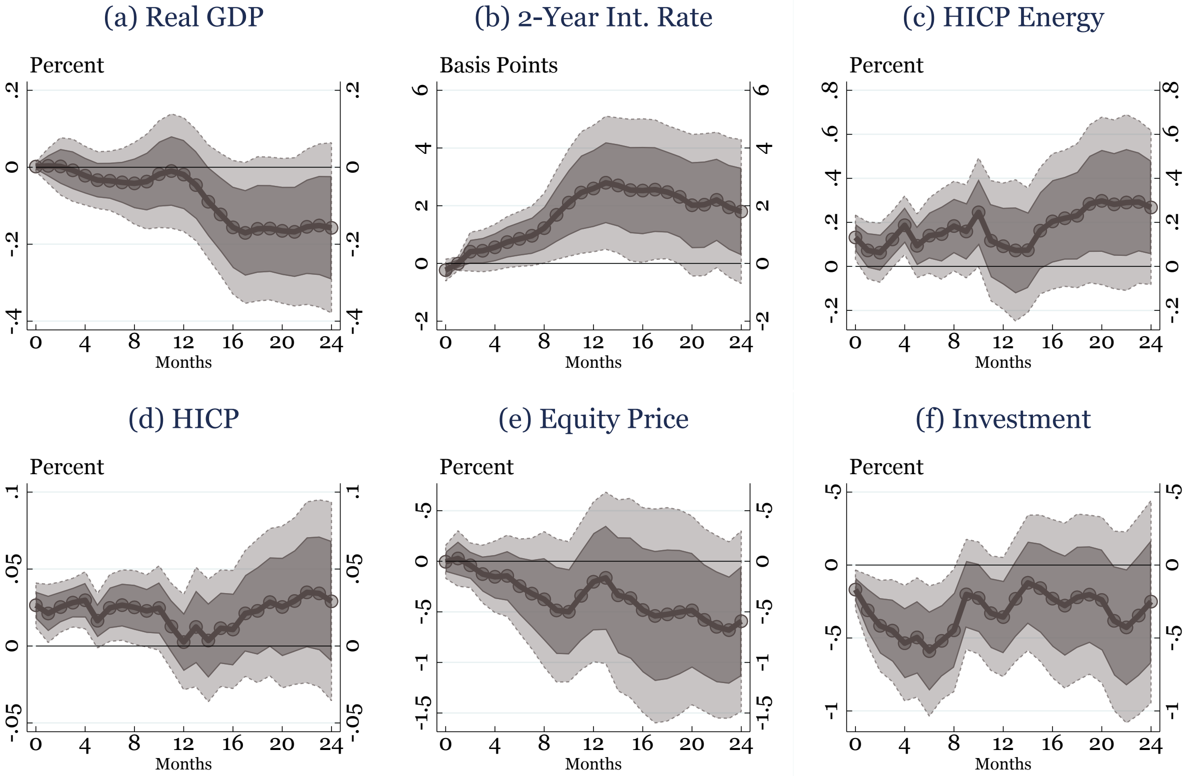
[5] Our analysis complements Känzig (2026) by considering a broader set of macroeconomic outcomes (rather than just output), and Ciccarelli and Marotta (2021) by using alternative data frequencies, country samples, and shock series.

where α_i^h and α_t^h are country and time fixed effects at horizon h; $CO2_{i,t}^{High}$ is a dummy variable equal to one if country i's CO_2 intensity is above the cross-country median; and $X_{i,t}$ includes the same controls as before. The time fixed effects absorb common shocks, ensuring that γ^h identifies differential responses based on carbon intensity. Standard errors are computed following Driscoll and Kraay (1998).

Figure 2 plots the estimated coefficients γ^h, which capture differential effects for high-emission countries relative to low-emission countries. The results show that higher CO_2 intensity countries experience significantly larger drops in output, investment, and equity prices, as well as larger increases in HICP, energy prices, and interest rates. These patterns confirm that carbon intensity shapes the magnitude of carbon pricing shock transmission at the aggregate level: browner countries suffer more severe effects than greener ones.[6]

Figure 2 THE EFFECT OF CARBON PRICING SHOCKS: HIGH-EMISSION COUNTRIES



NOTE. Differential effect of a one standard deviation carbon pricing shock on $y_{i,t+h} - y_{i,t-1}$ for countries with above-median CO_2 intensity relative to below-median countries, as captured by γ^h in equation (2). Shaded areas display 68 and 90 percent confidence intervals computed with heteroskedasticity and autocorrelation robust standard errors based on Driscoll and Kraay (1998).

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[6] Appendix C reports an extensive battery of robustness checks for the country-level results presented in this section.

This heterogeneity, however, can arise from two distinct mechanisms. The first is a compositional effect: if brown firms respond more strongly than green firms to carbon pricing—as one would expect given their direct exposure to emission costs—then high-emission countries respond more simply because a larger share of their firms are brown or more CO_2-intensive. Under this interpretation, aggregate responses are just a weighted average of underlying firm-level effects, with no additional general equilibrium forces at work.

The second mechanism involves general equilibrium forces: carbon pricing may trigger demand switching, relative price adjustments, and resource reallocation that either amplify or dampen what simple aggregation of firm-level responses would predict. Under this interpretation, aggregate responses differ systematically from a weighted average of firm-level effects because substitution and reallocation alter the transmission through the economy.

Distinguishing between these two interpretations is crucial for understanding how carbon pricing shocks propagate from individual firms to aggregate outcomes. The country-level analysis alone cannot make this distinction. In the next section, we use firm-level data to provide direct empirical evidence on whether general-equilibrium attenuation is present, and—if so—how large it is. We then return to these aggregation issues in Section 5, where we develop a theoretical framework to further clarify the interplay between compositional and general equilibrium forces.

4 Micro Evidence: Firm-level Local Projections

This section uses granular firm-level data on equity prices and emissions to examine heterogeneous responses to carbon pricing shocks. We focus on equity prices because they provide a high-frequency, forward-looking measure of firm performance available for many firms across countries. By comparing specifications with different levels of fixed effects, this firm-level analysis also allows us to provide evidence on how general equilibrium forces shape the transmission from the micro to the aggregate level.

4.1 Average and Heterogeneous Firm-Level Responses

We begin by verifying that firm-level data yield average effects consistent with the country-level analysis. We estimate a panel local projection analogous to equation (1). Letting $q_{ij,t}$

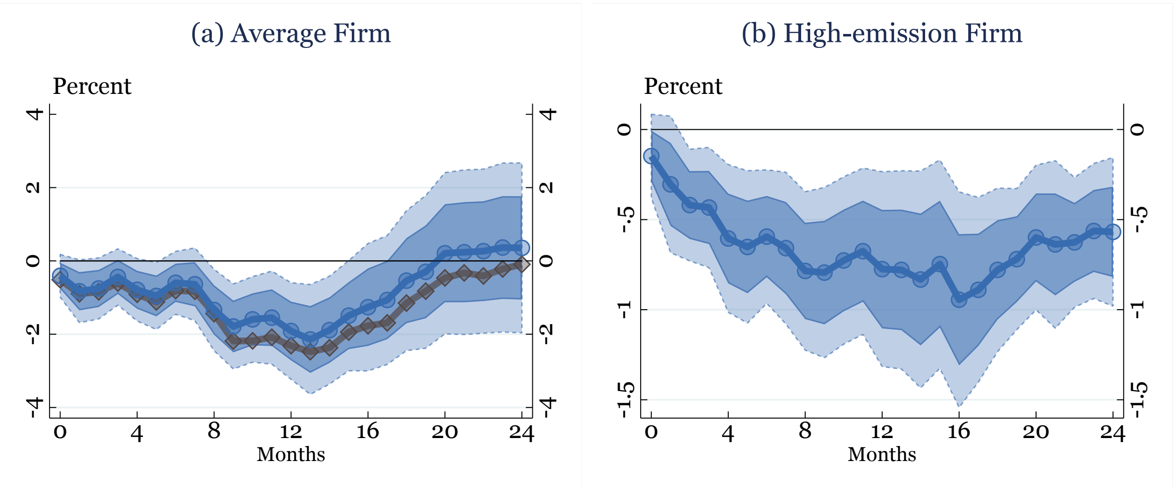
denote the log equity price of firm j in country i at time t, we estimate:

$$q_{ij,t+h} - q_{ij,t-1} = \alpha_j^h + \lambda^h CPS_t + \sum_{p=1}^{P} \Gamma_p^h X_{i,t-p} + \sum_{p=1}^{P} \Theta_p^h Z_{ij,t-p} + u_{ij,t+h}, \tag{3}$$

where α_j^h is a firm fixed effect at horizon h; CPS_t is the carbon pricing shock; $X_{i,t}$ includes lags of country-level macro aggregates (real GDP, headline HICP, energy HICP, aggregate equity index, two-year interest rate, and investment); and $Z_{ij,t}$ includes firm-level controls (leverage, sales, and lags of the dependent variable). We set $P = 12$ and compute standard errors following Driscoll and Kraay (1998).

Figure 3 panel (a) plots λ^h (in blue), which captures the average response in the firm-level data. Reassuringly, the firm-level impulse responses closely match the country-level results: equity prices fall by approximately 1 percent on impact, reaching a trough of around -2 percent after 12 months. The figure overlays the country-level estimates (β^h, in black) from panel (e) of Figure 1, showing that the average effects estimated in firm-level data yield virtually identical results to the country-level analysis.

Figure 3 The Effect of Carbon Pricing Shocks: Firm-level Equity Prices


(a) Average Firm

(b) High-emission Firm

Note. Effect of a one standard deviation carbon pricing shock on firm-level equity prices. Panel (a) plots the average firm response, λ^h from equation (3), and overlays the corresponding country-level response, β^h from equation (1). Panel (b) plots the differential response of high-CO$_2$-intensity firms relative to low-CO$_2$-intensity firms, ϕ^h from equation (4). Shaded areas display 68 and 90 percent confidence intervals computed with heteroskedasticity and autocorrelation robust standard errors based on Driscoll and Kraay (1998).

We now investigate whether carbon-intensive firms experience larger effects from carbon pricing shocks, paralleling the cross-country analysis from Section 3. We estimate:

$$q_{ij,t+h} - q_{ij,t-1} = \alpha_j^h + \alpha_{t,i,s}^h + \phi^h(CPS_t \times CO2_{ij,t-1}^{High}) + \sum_{p=1}^{P} \Theta_p^h Z_{ij,t-p} + u_{ij,t+h}, \tag{4}$$

where α_j^h is a firm fixed effect; $\alpha_{t,i,s}^h$ is a time-by-country-by-sector fixed effect which controls for any time-varying factors at the country-sector level;[7] $Z_{ij,t}$ includes firm-level controls (leverage, sales, and lags of the dependent variable); and $CO2_{ij,t}^{High}$ is a dummy variable equal to one if firm j's CO_2 intensity is above the median across firms in that country-sector pair. We define carbon intensity at the firm level as the sum of Scope 1 and Scope 2 CO_2 emissions (in thousands of tonnes) divided by net sales, providing a firm-level analog to the country-level measure (CO_2 per GDP).[8]

Our choice of time-by-country-by-sector fixed effects is guided by identification concerns. As emphasized in the literature on heterogeneous firm responses to monetary policy shocks (e.g., Ottonello and Winberry, 2020), identifying heterogeneity within sectors tends to be more robust than identifying heterogeneity across sectors, where unobserved sectoral differences are more pervasive and can confound inference. At the same time, one may worry that fully interacted fixed effects are overly restrictive and absorb much of the time-series and cross-sectional variation relevant for identification. Appendix C addresses this concern by showing that the results are robust to a more parsimonious fixed-effect structure that includes time-by-country and time-by-sector fixed effects separately.

Figure 3 panel (b) plots ϕ^h, which shows that high-emission firms experience equity price declines approximately 1 percent larger than low-emission firms, with effects peaking around 16 months. These firm-level patterns not only corroborate the cross-country heterogeneity documented in Section 3, but also complement it by addressing identification concerns that arise at the country level—namely, that national CO2 intensity may correlate with other economy-wide characteristics which would independently affect responses to carbon shocks. Obviously, disaggregation does not resolve identification concerns *per se*—it changes their nature. However, the granularity of firm-level data allows us to exploit within-sector variation and control for sector-specific shocks, country-specific policy changes, and their interactions

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[7] We use the S&P 11 industry classification. Appendix Table B.4 reports the number of firms in each sector and summarizes sector–country coverage, including the distribution of firms per sector–country cell.

[8] In Appendix C, we consider an alternative normalization by market value, as well as a large number of additional robustness checks.

that could confound country-level estimates. The two levels of analysis are thus complementary: each provides a distinct perspective on how carbon intensity shapes responses to carbon pricing shocks at multiple levels of aggregation.

Having established that micro-level heterogeneity in emissions intensity generates differential responses to carbon pricing shocks, we now turn to the question raised at the end of Section 3, namely whether general-equilibrium forces attenuate or amplify these firm-level effects when aggregated to the country level.

4.2 From Micro to Macro: General-Equilibrium Attenuation

The firm-level evidence above shows that carbon pricing shocks have systematically larger effects on the equity values of more CO_2-intensive firms. We now ask how these heterogeneous micro responses translate into aggregate outcomes. Under purely mechanical aggregation, country-level effects would be a weighted average of firm-level responses. In contrast, if general-equilibrium adjustments are important—for instance, due to demand switching toward cleaner producers, relative-price movements, or reallocation of resources—then the country-level response associated with a given CO_2 gap should be attenuated relative to the within-sector, within-country firm-level benchmark.

Our empirical strategy exploits the fact that specifications with different fixed-effect structures isolate fundamentally different sources of variation. Consider two firms with different CO_2 intensities operating in the same country and sector. The firm-level coefficient ϕ^h from equation (4)—which includes time-by-country-by-sector fixed effects—measures how much more the high-emission firm's equity price falls relative to the low-emission firm within the same country–sector–time cell. By construction, this comparison nets out all shocks that are common to firms in that cell, including any equilibrium movements at the country–sector level. What remains is the differential exposure to carbon costs. We thus interpret ϕ^h as a partial-equilibrium benchmark.

Now consider two countries whose *average* firm-level CO_2 intensity differs by the same amount as in the firm-level comparison above. If we interact the carbon pricing shock with a country-level high-intensity indicator and include time fixed effects only, the resulting coefficient captures how much more equity prices fall in the high-intensity country relative to the low-intensity country. Unlike the within country–sector–month comparison underlying

ϕ^h, this cross-country comparison leaves room for within-country adjustment forces to affect relative outcomes. In particular, a carbon pricing shock that raises the relative price of brown goods could induce substitution toward cleaner goods and reallocate demand and resources toward greener firms within each country. Such reallocation would partially offset losses for brown firms with gains for greener firms, so that the country-level differential response associated with a given CO_2 gap is attenuated relative to the within-cell firm-level benchmark.

This logic delivers a direct test: if general-equilibrium adjustments dampen the transmission of the shock, then the differential response estimated from aggregate (country-level) variation should be smaller in magnitude than the partial-equilibrium benchmark. To implement this test, we construct $\overline{CO2}^{High}_{i,t-1}$ by averaging the firm-level CO_2 intensity data from equation (4) to the country level, then estimating:

$$q_{ij,t+h} - q_{ij,t-1} = \alpha_i^h + \alpha_t^h + \bar{\gamma}^h(CPS_t \times \overline{CO2}^{High}_{i,t-1}) + \sum_{p=1}^{P} \Theta_p^h Z_{ij,t-p} + u_{ij,t+h}, \tag{5}$$

where $\overline{CO2}^{High}_{i,t-1}$ is a dummy variable equal to one if country i's average firm-level CO_2 intensity is above the cross-country median. This specification uses the identical firm-level sample and firm-based intensity measure as equation (4). The only difference is the source of cross-sectional variation in the interaction: in (4) the "high CO_2" indicator varies across firms within a given country–sector, whereas in (5) it varies only across countries.[9] Any systematic gap between ϕ^h and $\bar{\gamma}^h$ therefore reflects general-equilibrium forces rather than differences in measurement or coverage.[10]

Panel (a) of Figure 4 reports the comparison between the partial- and general-equilibrium responses. The partial-equilibrium differential effect, ϕ^h (in blue), is more negative than the corresponding general-equilibrium effect, $\bar{\gamma}^h$ (in yellow), implying attenuation when moving from within-sector firm comparisons to country-level comparisons. Quantitatively, the partial-equilibrium response troughs at around -1 percent, while the general-equilibrium trough is roughly half as large.

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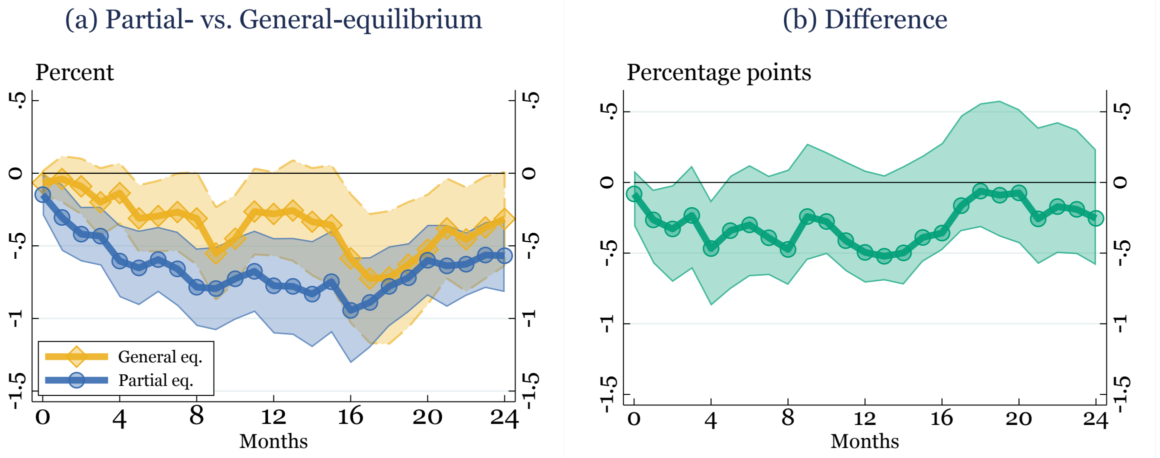
[9] The average CO_2 intensity across the high-CO_2 and low-CO_2 groups is virtually identical in the two specifications: 0.13 versus 0.41 for the firm-level interaction and 0.15 versus 0.41 for the country-level interaction.

[10] As a complementary check, we also compare ϕ^h to γ^h from equation (2), which uses the broader, economy-wide CO_2 intensity measure from the World Bank.)

Figure 4 General-Equilibrium Attenuation


(a) Partial- vs. General-equilibrium

(b) Difference

Note. Comparing partial-equilibrium and general-equilibrium effects of a one standard deviation carbon pricing shock on equity prices. Panel (a) plots the partial-equilibrium effect, ϕ^h (blue line) from equation (4), which includes time-by-country-by-sector fixed effects; and the general-equilibrium effect, $\bar{\gamma}^h$ (yellow line) from equation (5), which includes time fixed effects only. Shaded areas display 68 percent confidence intervals (Driscoll–Kraay standard errors). Panel (b) plots the difference, $\phi^h - \bar{\gamma}^h$, with confidence intervals based on the bootstrap procedure described in Appendix D.

To assess statistical significance, we conduct inference directly on the gap, $d^h \equiv \phi^h - \bar{\gamma}^h$, using the time-cluster bootstrap procedure described in Appendix D. Panel (b) reports d^h with its bootstrap confidence intervals. Since both differential effects are negative, $d^h < 0$ means that the firm-level benchmark is more negative than the country-level response, consistent with attenuation. While statistical precision is limited, the estimates are suggestive: the gap is negative and economically meaningful for about one year, before gradually closing at longer horizons.

Overall, this pattern provides direct empirical support for general-equilibrium attenuation, and motivates asking what mechanisms could generate such attenuation in general equilibrium. We turn next to a model that allows us to discipline this interpretation and connect it to the broader set of empirical findings.

5 Making Sense of the Evidence

In this section, we rationalize our empirical findings using a two-good DSGE model with climate policies. The model is designed to capture how carbon pricing affects firms asymmetrically depending on their emissions intensity, and how these heterogeneous firm-level responses aggregate out at the macroeconomic level. We first outline the key features of the model and its sources of heterogeneity. We then study the dynamic responses to exogenous changes in carbon prices to clarify the mechanisms underpinning our empirical results. Finally, we assess the role of carbon intensity in shaping these responses and dig deeper into the drivers of the attenuation effects documented in the empirical analysis.

5.1 Model Overview

We develop a model with two types of firms—green and brown—that share identical technology and market structure but differ in their emissions intensity. This design mirrors our empirical strategy, which exploits within-sector variation in emissions intensity across firms. The full exposition of the model is deferred to Appendix E, which contains a detailed description of the agents' problems, equilibrium conditions, and calibration. We focus here on the basic structure, the novel features that allow us to capture the effects of carbon pricing shocks, and the ingredients that we have added to provide a better match, in particular, with the equity price responses documented in the empirical analysis (a dimension that standard DSGE models struggle to match quantitatively).

Firms, Production, and Heterogeneity in Emissions. Firms produce with a CES production–emissions technology that allows for imperfect substitution between emissions and value added (capital and labor), nesting common specifications as special cases (e.g. Copeland and Taylor, 2004). Firm heterogeneity is captured parsimoniously by allowing emission intensity to differ across two types. Brown firms use emissions more intensively than green firms ($\gamma_B > \gamma_G$) and therefore face a larger increase in effective marginal costs when carbon prices rise. When it is difficult for firms to substitute emissions with other inputs, carbon pricing primarily affects firms through profits rather than quantities. This contributes to larger firm-level equity price responses. Emissions from production accumulate in the atmosphere and feed back onto both type of firms' aggregate productivity through a damage function in a slow, but persistent way. Finally, firms operate under monopolistic competition and prices are sticky due to nominal rigidities.

Households. Households make consumption, labor supply, investment, and portfolio decisions. They consume both brown and green goods, combined through a CES aggregator with elasticity of substitution η and preference weight of brown goods ν. To better match the equity-price responses in the data, the model features equity held through mutual funds, an exogenous firm exit risk, and firm-type-specific capital subject to adjustment costs. These capital frictions limit households' ability to smooth consumption through rapid reallocation of capital, strengthening the transmission of firm-level shocks to aggregate demand and amplifying equity price responses.

Climate and Other Macroeconomic Policies. We model carbon policy as a persistent exogenous stochastic process for the price of emissions facing firms. This is consistent the carbon pricing shocks in our empirical analysis. Carbon tax revenues are rebated to households, ensuring a balanced government budget. Monetary policy follows a standard Taylor rule targeting inflation and the output gap.

5.2 Rationalizing the results

This section analyzes the impact of an exogenous increase in the price of emissions in the model, corresponding to the empirical shock described in previous sections.[11] We first show that the model's responses are consistent with the empirical evidence for the aggregate responses for the average economy (reported in Section 3), as well as the relative responses of brown versus green firms (reported in Section 4). We then discuss the economic mechanisms underlying the model's response to the shock, shedding light on the partial- and general-equilibrium effects documented in the empirics.

Figure 5 shows the impulse responses of aggregate and firm-specific macroeconomic and financial variables to a carbon pricing shock. Consistent with the aggregate empirical results in Figure 1, the shock is contractionary for output and investment, it is inflationary, and leads to a decline in aggregate asset prices. Short rates rise, as the central bank reacts to higher inflation. In line with the firm-level empirical results in Figure 3, equity prices for both green and brown firms decline, with the latter experiencing a larger fall.

As discussed in Section 4, aggregate responses to carbon pricing reflect both partial-equilibrium effects (the direct impact on firms' costs, holding other things equal) and general-equilibrium effects (the indirect impact arising from spillovers and reallocation across firms with heterogeneous emissions intensity). To build intuition, we describe the partial- and general-equilibrium effects in turn.[12]

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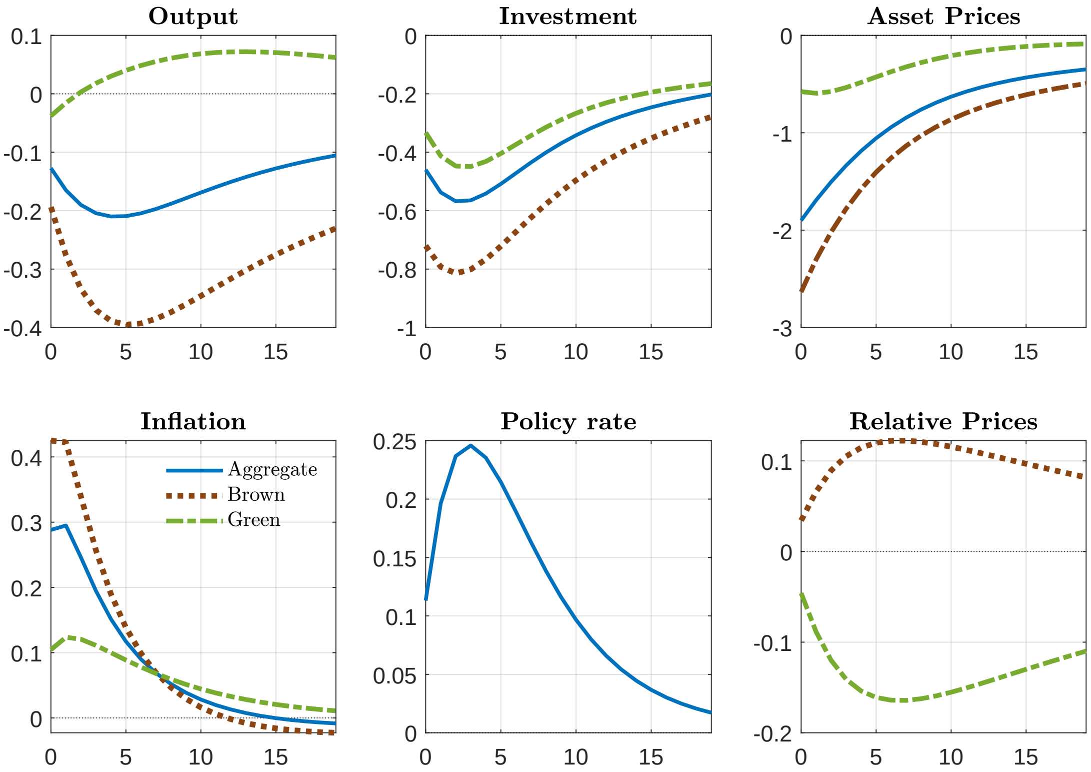
[11] The economy is initially at its steady state. As carbon pricing is modeled as an exogenous process, the results do not reflect endogenous policy feedback or anticipatory effects. Moreover, climate damages play a negligible role at business-cycle frequencies and mainly affect medium- to long-run dynamics through persistence.

[12] As is standard in climate-macro models, the carbon-price shock also affects dynamics through its indirect

Figure 5 Impulse Responses to a Carbon Pricing Shock



Note. Impulse responses of aggregate and firm-specific variables to a one-standard-deviation innovation to the carbon price. Solid blue lines denote aggregate responses; dash-dotted green lines correspond to green firms; brown dotted lines correspond to brown firms. Firm-level responses are averages across firms of each type. Responses are expressed as percentage deviations from steady-state values.

A higher emissions price raises marginal costs for both firm types. Output falls and inflation rises, squeezing profits and lowering equity prices through a standard asset-pricing channel (i.e. discounted sum of expected future profits). Several features amplify the equity response relative to quantities: fixed costs make profits more sensitive to output declines; equity values incorporate survival risk through an exogenous exit probability; capital adjustment costs slow reallocation and depress Tobin's Q; and habit formation increases risk premia when consumption falls. Together, these mechanisms bring the model's equity price response close to what we estimate in the data.[13] Because brown firms are more emissions-intensive,

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impact on productivity via the damage function (see equation (E.17)). As carbon prices increase, firms reduce emissions by increasing abatement, which slowly lowers atmospheric carbon and raises aggregate productivity. Over a longer horizon, in contrast to the short-run dynamics, the slow rise in aggregate productivity starts to exert downward pressure on green, brown, and aggregate prices.

[13] While the model generates an immediate asset-price reaction, the data show a more gradual adjustment. Matching asset-price dynamics precisely is a well-known challenge for DSGE models more broadly (Fernández-Villaverde, 2010).

the direct cost impact is larger for them (we return to this wedge in Section 5.4).

Differences in emissions intensity generate spillovers between brown and green firms through goods and factor markets. On the goods-market side, the higher relative price of brown goods induces expenditure switching toward green goods, boosting demand for green output. On the factor-market side, this demand reallocation tightens labor markets: green firms expand and raise labor demand, while brown firms also increase labor demand as they substitute away from emissions toward labor. Wages therefore rise, partly offsetting the demand boost by raising green firms' marginal costs. In the model, the goods-market effect dominates: after an initial dip, green output increases persistently from the second quarter onward. Green profitability nevertheless falls despite higher output, as compressed markups (from lower relative prices) and rising factor costs (especially wages) more than offset the quantity gains.

As we will discuss below, three parameters play a particularly important role in the model's response to the shock: the preference weight for brown goods (ν); the emissions intensity in firms' production (γ_i, where $i \in \{B, G\}$); and the elasticity of substitution between brown and green goods for households (η).[14] These parameters govern (i) the steady state CO_2 intensity and (ii) the strength of the partial- and general-equilibrium effects. By allowing them to vary, therefore, we can speak to both the cross-country evidence of Section 3 and the partial- versus general-equilibrium evidence in Section 4.

5.3 Heterogeneity in model responses to carbon pricing shock

To investigate how economy-wide CO_2 intensity shapes the aggregate response to carbon pricing shocks, as documented in the empirical analysis in Section 3, we conduct an exercise in which we compute model responses for different aggregate carbon intensities. We obtain these by varying the model parameters that most directly shape emissions intensity: γ_B, ν, and η.[15] Specifically, we adjust the parameters so that the model's steady-state emissions intensity lies within the range of country-specific carbon intensities in the data (roughly

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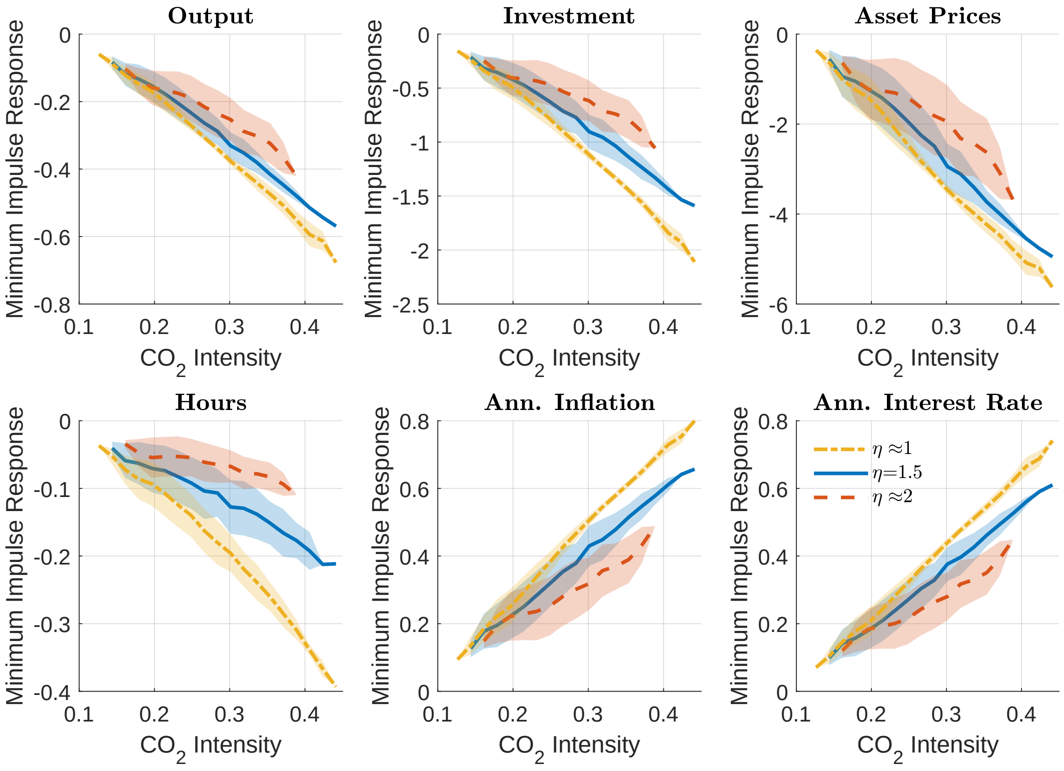
[14] Another parameter shaping carbon intensity is the elasticity of substitution between emissions and value added, ζ. As carbon prices rise, firms substitute away from emissions toward other inputs, especially labor (which adjusts faster than capital). When $\zeta < 1$ (gross complements), emissions and value added move together, so both emission demand and output fall sharply, raising brown firms' marginal costs and depressing valuations.

[15] Note that varying γ_B we change the degree of heterogeneity between brown and green firms, as it widens the gap between γ_G and γ_B.

0.1 to 0.5 kg of CO_2e per constant 2015 US USD of GDP). All other parameters remain unchanged. We then compute the macroeconomic responses to the carbon-pricing shock under these different calibrations.

Figure 6 Peak/Trough Responses By CO_2 Intensity



Note. Peak (trough) impulse responses of the main macroeconomic variables as a function of steady-state CO_2 emissions intensity under alternative model parameterizations. Steady-state emissions intensity is jointly pinned down by three parameters: the elasticity of substitution (η), the preference weight of brown goods (ν), and the brown firms' emissions intensity (γ_B). Solid lines report mean responses holding η fixed while varying γ_B and ν. Different colors correspond to alternative values of η. Shaded areas represent +/- one standard deviation around the mean for each η, computed over variations in the other two parameters.

Figure 6 plots the minimal impulse responses of aggregate output (also in investment and hours) and equity prices, along with the maximal responses of aggregate inflation and the policy rate, against their corresponding steady-state CO_2 intensities, for a range of values for γ_B and ν, and η. The solid lines show the mean response of the macroeconomic variables and mean steady-state CO_2 intensities for different combination of γ_B and ν, where different colors stand for different elasticities (yellow: near Cobb-Douglas; blue: $\eta = 1.5$; red: $\eta \approx 2$). Higher values for γ_B and/or ν give rise to higher steady-state CO_2 intensities. The colored swathes show one standard deviation either side of the mean. The figure indicates that, in the model, the higher the emissions intensity of production, the larger the contraction in output and equity valuations, and the larger the rise in inflation. This is consistent with the empirical findings reported in Figure 2.

The figure also highlights how model parameters shape both steady-state CO_2 intensity and the macro response to a carbon price shock. Parameters that raise exposure—in particular a higher emissions share for brown firms, γ_B, and a higher preference weight on brown goods, ν—increase steady-state CO_2 intensity and amplify the contractionary effects of the shock. By contrast, greater substitutability mitigates the aggregate impact, because households and firms can reallocate away from emissions-intensive production and consumption more easily. This attenuation is strongest when exposure is high: when brown goods are important in expenditure (high ν) and carbon costs are more salient (high γ_B), the scope for substitution plays a larger cushioning role.

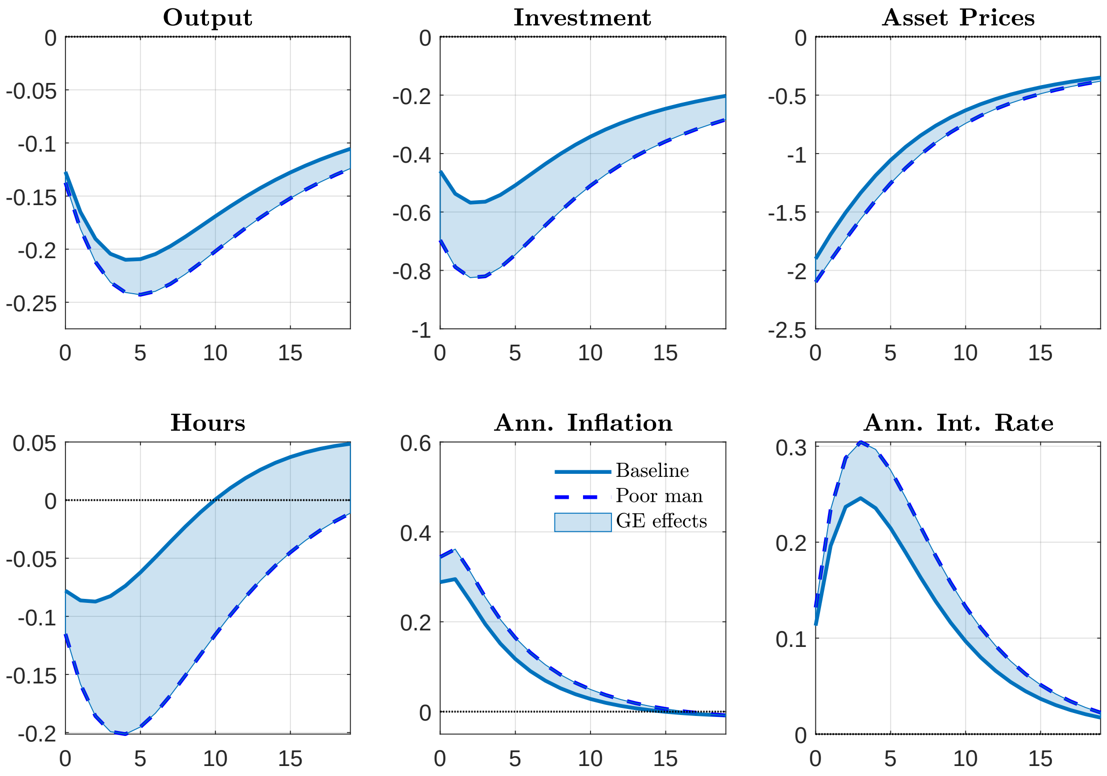
Second, even for a given level of steady-state CO_2 intensity, the model can generate materially different responses to a carbon price shock. The reason is that the same intensity can arise from different parameter combinations, which in turn shift the balance between partial-equilibrium cost effects and general-equilibrium adjustment. As a result, observing the aggregate response does not pin down a unique mechanism. This mirrors the empirical identification issue discussed above and motivates using the model as a laboratory to investigate the structural determinants of attenuation.

5.4 Aggregation and the Drivers of Attenuation

In this section, we isolate the partial- and general-equilibrium effects in the model's response to the shock. We then examine how the relative size of these effects depends on the three key parameters governing aggregate emissions intensity: brown firms' emissions intensity, the preference weight of brown goods in aggregate expenditure, and the elasticity of substitution between brown and green goods.

Figure 7 compares the impulse responses of the baseline economy (solid pale blue lines) to those from a hypothetical environment in which green and brown firms do not interact (dashed dark blue lines). We construct this benchmark—which we call the ”poor-man” aggregation—by solving two separate single-type economies (one with only brown firms and one with only green firms) and then mechanically combining their impulse responses using the same steady-state expenditure shares of brown and green goods as in the baseline.[16] Each single-type economy is solved in general equilibrium internally, but there are no interactions across types, i.e. no relative-price adjustment between green and brown goods, nor labor and capital reallocate between firm types. This partial-equilibrium benchmark isolates compositional effects from general-equilibrium adjustments. We interpret the gap between the baseline and this benchmark as the contribution of substitution and reallocation—analogous to the within-sector versus aggregate comparison in the empirical analysis.

Figure 7 AGGREGATION AND ATTENUATION



NOTE. The figure shows impulse responses to a carbon pricing shock. Solid light blue lines denote responses in the baseline model. The dark blue dashed line represents a "poor-man's" economy, constructed as a weighted average (using the baseline model's share of brown goods) of two polar cases: an economy populated entirely by green firms ($\nu = 0$) and one populated entirely by brown firms ($\nu = 1$). The shaded area illustrates attenuation arising from general-equilibrium forces that are present in the baseline but absent in the partial-equilibrium benchmark. Responses are expressed as percentage deviations from steady-state values.

In particular, Figure 7 shows that output, investment, hours, asset prices, inflation, and

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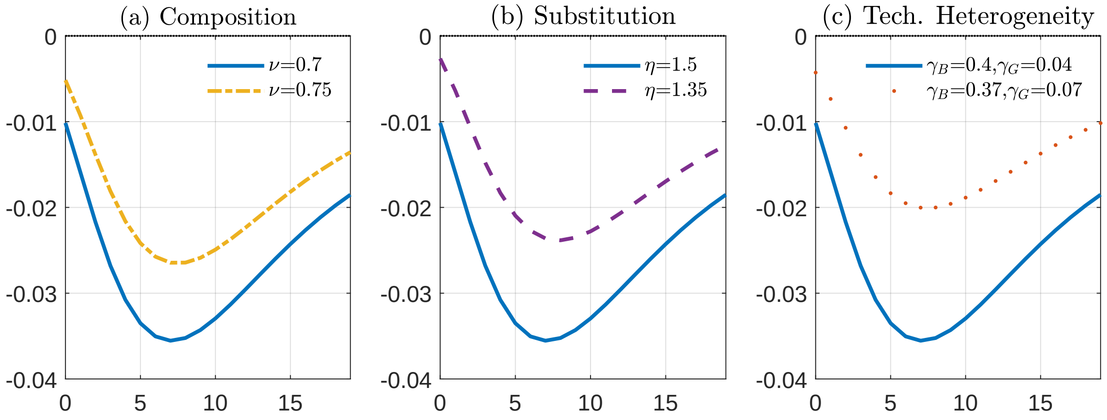
[16] We use the steady-state expenditure share of brown goods to construct the "poor man's" measure. Using the weight of brown goods in the aggregator instead does not affect the qualitative results but generates stronger attenuation, since with non-unit prices the expenditure share is smaller than the corresponding aggregator weight. See Figure G.3 in the Appendix for an example weight brown weights are used.

the policy rate all respond more strongly in the poor-man economy (dashed dark blue) than in the baseline (solid pale blue). General-equilibrium effects in the model (shaded areas) therefore attenuate the response to the shock, consistent with the empirics (Figure 4).[17]

To shed light on how general-equilibrium attenuation depends on the preference weight of brown goods, the elasticity of substitution between brown and green goods, and the emissions intensity in firms' production, we re-compute our measure of attenuation—the difference between the baseline and poor-man economies—while varying the relevant parameters one at a time.[18] Figure 8 plots output attenuation under alternative calibrations for the parameters in turn.[19]

Figure 8 DRIVERS OF OUTPUT ATTENUATION



NOTE. The figure illustrates the degree of output attenuation resulting from alternative model parameterizations. Attenuation is defined as the difference between the responses in the poor-man economy and those in the full model. Carbon intensity is held constant at 0.22 by adjusting aggregate productivity. The solid blue line shows attenuation in the baseline calibration. The yellow dash-dotted line in panel (a) corresponds to a higher weight of brown goods ($\nu = 0.75$). The purple dashed line in panel (b) shows attenuation when the elasticity of substitution between brown and green goods is reduced ($\eta = 1.35$). The red dotted line in panel (c) illustrates the effect of reduced technological heterogeneity between brown and green firms ($\gamma_B = 0.37$, $\gamma_G = 0.07$). Responses are expressed in percentage points.

Panel (a) shows that attenuation is reduced as the economy's composition becomes

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[17] Reallocation across firm types in the baseline operates primarily through labor and capital markets and is constrained by capital adjustment costs; while we do not vary these frictions independently in the exercises below, they are essential for generating attenuation in quantities and amplification in asset prices.

[18] In doing so, we also adjust the level of aggregate technology to hold steady state emissions intensity fixed in order to isolate the contribution of the parameters of interest to attenuation separately from their effects on steady-state CO_2 intensity (as discussed in Section 5.3). Interestingly, we find that whether or not carbon intensity is held fixed does not alter the qualitative insights; the patterns seen here mirror those obtained when intensity is allowed to vary.

[19] For brevity, we report the responses of output only here. Additional variables can be found in Figure G.5 in the Appendix.

browner (rising ν), while keeping aggregate intensity constant. As the green sector shrinks, its capacity to absorb reallocation when the carbon price rises diminishes. What matters for attenuation is the availability of a sufficiently large green sector capable of absorbing demand shifts. Indeed, as the share of brown firms approaches one, general-equilibrium attenuation vanishes altogether.

Panel (b) of Figure 8 shows that attenuation is reduced when the elasticity of substitution between green and brown goods η is lower, again while keeping aggregate intensity constant. Lower substitutability makes it harder to shift expenditure away from the relatively more expensive brown good, so relative-price movements generate weaker demand shifts.

Panel (c) shows that reducing the technological gap between brown and green firms—thus compressing their emission intensities—also reduces attenuation, again holding aggregate intensity constant.[20] When firms resemble each other more closely, carbon price movements induce smaller relative price fluctuations, weakening substitution as an attenuation mechanism. This confirms that heterogeneity in emission intensities is a key driver of general-equilibrium attenuation: less heterogeneity means less attenuation.

5.5 Extensions

Policy. In the baseline model, carbon revenues are recycled in a lump-sum fashion via the budget constraint. In addition, even if government spending is assumed to be constant, the government reallocates spending toward green goods (and away from brown goods) as they become relatively cheaper. By keeping the overall level of public expenditure constant, fiscal policy dampens the aggregate impact of the carbon pricing shock without altering its underlying transmission. As an alternative, we assume that carbon revenues subsidize green activity, yielding results broadly consistent with the baseline. However, when subsidies are targeted directly to green firms and financed by reducing household transfers, green output rises while total consumption (green and brown) falls, reflecting redistribution rather than an amplification of aggregate demand (see Figure G.6 in Appendix G). Monetary policy also shapes the adjustment: when the central bank places greater weight on the output gap relative to inflation in its Taylor rule, the contraction in activity is smaller relative to the

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[20] In this experiment, we reduce γ_B and raise γ_G relative to the baseline, rather than focus on γ_B as we do in Section 5.3. This experiment implements a mean-preserving compression of emission intensities: we reduce the gap between brown and green firms by lowering γ_B and raising γ_G such that the aggregate emissions intensity remains constant.

baseline; with zero weight on the output gap, the contraction is larger. Overall, however, differences across policy responses are relatively small. We conclude that our main results are robust to these alternative monetary and fiscal policy frameworks.

Transition. We next assess the robustness of our results when the economy transitions gradually toward a greener long-run equilibrium. Figure G.8 in Appendix G illustrates two cases: one in which the emissions intensity of brown firms (γ_B) declines over time, and another in which the preference weight on brown goods (ν) is progressively reduced.[21] In both cases, impulse responses at business-cycle frequencies are virtually indistinguishable from those in the baseline model, with small differences emerging only over the medium run. This implies that, while the transition path is central for long-run emissions reductions, it does not materially affect the short-run propagation of carbon pricing shocks.

6 Conclusion

This paper studies the macroeconomic and firm-level effects of carbon pricing shocks, with a focus on how heterogeneity in emissions intensity shapes their transmission. Using country-level and firm-level local projections for EU ETS economies, we show that carbon pricing shocks are contractionary, inflationary, and lead to declines in asset prices. These effects are highly heterogeneous: countries and firms with higher carbon intensity experience substantially larger responses, with emissions-intensive firms exhibiting pronounced and persistent equity price declines.

A key contribution of the paper is to show that strong microeconomic responses do not translate one-for-one into aggregate outcomes. Comparing firm-level partial-equilibrium estimates with aggregate responses reveals that aggregate effects are systematically attenuated relative to the most exposed firms. We rationalize this wedge using a model featuring green and brown firms, where higher carbon prices compress profits disproportionately for emissions-intensive producers, but relative price adjustments induce demand reallocation toward greener goods, dampening the aggregate contraction.

These results carry important policy implications. First, assessments abstracting from heterogeneity and reallocation may overstate carbon pricing's aggregate impact. Second, economies with limited substitution opportunities—whether more carbon-intensive or fea-

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[21] We examine these scenarios while maintaining the degree of substitutability across goods constant.

turing stronger complementarities—face larger short-run adjustment costs. Third, policies preserving relative price signals and facilitating reallocation strengthen general-equilibrium attenuation, mitigating macroeconomic costs without weakening emission reductions. Our empirical evidence on attenuation is a first step; future research should unpack its sources more systematically, distinguishing between mechanical diversification and active economic substitution.

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Appendix

The Heterogeneous Effects of Carbon Pricing: Macro and Micro Evidence

A Data

The source of the macroeconomic, financial, and enviromental data is as follows:

- Real GDP: Index.
  Source: Datastream.
- Harmonised Index of Consumer Prices (index).
  Source: Eurostat.
- Energy component of the HICP (index).
  Source: Eurostat.
- 2-year rate (monthly average).
  Source: Datastream.
- Equity price index.
  Source: Datastream.
- Crude oil price - Brent Europe.
  Source: FRED.
- Country-level CO_2 intensity (kg CO2e/ GDP at constant 2015 US$).
  Ticker: `EN.GHG.CO2.RT.GDP.KD`. *Source*: World Bank.
- Firm-level CO_2 emissions. Scope 1 and Scope 2 emissions ($1,000$ tonnes).
  Tickers: `ENERDP024` and `ENERDP025`. *Source*: LSEG.
- Net sales.
  Ticker: `WC01001`. *Source*: LSEG.
- Total assets.
  Ticker: `WC02999`. *Source*: LSEG.
- Leverage.
  Ticker: `WC08236`. *Source*: LSEG.

B Summary Statistics & Data Coverage

This appendix reports summary statistics for the measures of CO_2 intensity used in the macro and micro analyses, together with basic information on firm-level emissions coverage and sectoral composition. We distinguish between an economy-wide measure based on national emissions per unit of GDP and a measure constructed from firm-level emissions normalized by net sales.

Economy-wide CO_2 intensity. Table B.1 reports country-level summary statistics for economy-wide CO_2 intensity, measured as kilograms of CO_2e per constant 2015 US$ of GDP. This measure captures cross-country differences in aggregate carbon intensity and is used to define the 'high-" versus 'low-" CO_2 intensity groups in the country-level heterogeneity exercises.

Firm-level emissions and coverage. Table B.2 reports summary statistics for firm-level Scope 1 and Scope 2 emissions by country, as well as coverage rates in the underlying firm sample. These statistics provide context for the firm-level heterogeneity analysis and for the construction of country-level intensity measures from listed firms.

Country-level CO_2 intensity constructed from firm data. Table B.3 reports summary statistics for a country-level CO_2 intensity measure obtained by aggregating firm-level emissions per unit of sales (Scope 1+2 scaled by net sales) within each country. Because this measure is built from publicly listed firms, it differs from the economy-wide intensity in Table B.1. We use the firm-aggregated measure when we want the country-level heterogeneity split to be defined using the same underlying firm sample employed in the micro analysis.

Sectoral composition and sector–country coverage. Finally, Table B.4 summarizes the distribution of firms across sectors and the coverage of sector–country cells. This information is useful for interpreting specifications that include rich fixed effects and for assessing how broadly the firm-level results are represented across industries and countries.

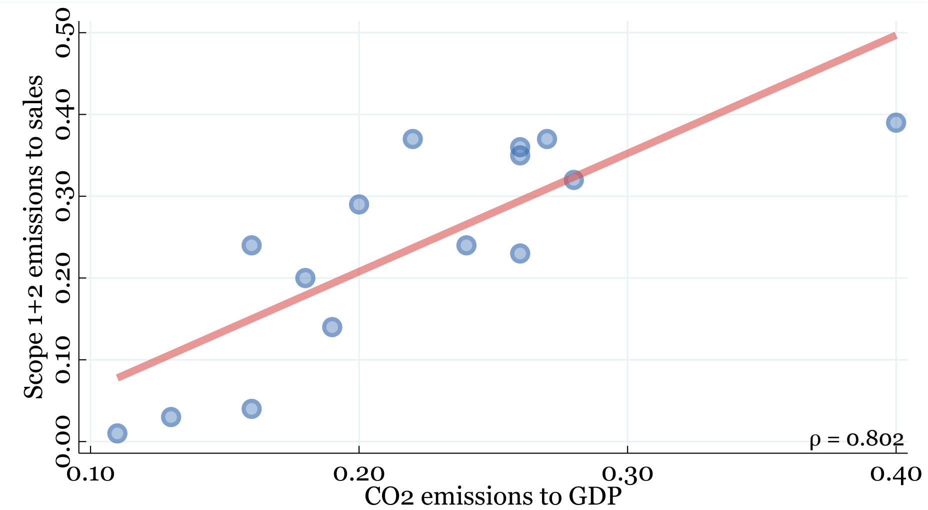
Aggregate versus firm-based measures. Figure B.1 compares the economy-wide CO_2 intensity measure in Table B.1 to the country-level measure aggregated from firm-level data in Table B.3. The strong positive relationship indicates that, despite differences in coverage and scaling (GDP versus sales), the firm-based aggregation captures meaningful cross-country variation in carbon intensity.

Table B.1 COUNTRY-LEVEL CO_2 INTENSITY: ECONOMY-WIDE EMISSIONS PER GDP

	Mean	Median	P95	P05	SD
Austria	0.20	0.21	0.24	0.17	0.03
Belgium	0.26	0.26	0.34	0.21	0.05
Germany	0.26	0.26	0.30	0.21	0.03
Denmark	0.16	0.17	0.22	0.10	0.04
Spain	0.27	0.25	0.32	0.21	0.04
Finland	0.26	0.25	0.32	0.19	0.05
France	0.16	0.16	0.20	0.13	0.02
United Kingdom	0.18	0.19	0.24	0.12	0.04
Greece	0.40	0.40	0.48	0.33	0.05
Ireland	0.19	0.20	0.27	0.10	0.05
Italy	0.22	0.22	0.25	0.18	0.03
Netherlands	0.24	0.24	0.28	0.20	0.03
Norway	0.13	0.13	0.14	0.12	0.01
Portugal	0.28	0.28	0.34	0.24	0.04
Sweden	0.11	0.12	0.16	0.07	0.03

NOTE. This table provides summary statistics on the country-level CO_2 intensity variable (kg of CO_2e per constant 2015 US USD of GDP) for the 15 countries in our sample. This aggregate measure captures economy-wide carbon dioxide emissions stemming from the burning of fossil fuels, the manufacture of cement, and gas flaring. It includes carbon dioxide produced during consumption of solid, liquid, and gas fuels. Ticker: `EN.GHG.CO2.RT.GDP.KD`. Source: World Bank.

Figure B.1 CO_2 INTENSITY: AGGREGATE VS. FIRM-LEVEL MEASURES



NOTE. Each point represents a country. The x-axis shows aggregate CO_2 intensity from World Bank data (kg CO_2e per constant 2015 US$ of GDP). The y-axis shows country-level CO_2 intensity aggregated from firm-level data (thousands of tonnes of CO_2 (Scope 1+2) divided by net sales in millions of USD, which simplifies to kg CO2 per USD, comparable to the country-level measure.

Table B.2 Firm-level CO_2 Emissions: Summary Statistics

			Scope 1 CO2				Scope 2 CO2				
Country	Firms	Obs.	Mean	Median	p95	SD	Mean	Median	p95	SD	Coverage CO2
AUT	19	4009	306	50	1290	472	29	8	110	37	89.5%
BEL	20	4220	154	5	1040	319	62	6	300	114	75%
DEU	39	8229	1103	37	9170	3356	178	43	602	293	97.4%
DNK	43	5275	490	4	3702	1253	14	4	46	20	83.7%
ESP	14	2954	823	30	3546	1352	79	33	285	124	100%
FIN	38	5275	208	7	1060	628	48	10	267	89	84.2%
FRA	40	8440	1004	21	5705	3105	157	28	800	351	100%
GBR	94	19834	376	8	2380	1235	94	11	700	259	96.8%
GRC	25	5275	382	3	3257	1027	32	6	134	53	76%
ITA	71	8440	707	16	5826	2193	44	11	204	79	70.4%
IRL	33	6963	476	7	3240	905	48	2	260	78	100%
NLD	25	5275	1355	6	10500	3922	174	20	1100	416	100%
NOR	44	9284	256	8	1560	507	42	1	215	123	88.6%
PRT	15	3165	274	6	1805	573	30	13	103	40	93.3%
SWE	29	6119	27	3	87	79	22	12	71	31	96.6%

Note: This table provides summary statistics and coverage information on the firm-level CO_2 emission variables for the 15 countries in our sample. The CO_2 emission variable is expressed in $1,000$ tonnes. Source: Datastream.

Table B.3 Country-Level CO_2 Intensity: Firm-Level Emissions per Sales

	Mean	Median	P95	P05	SD
Austria	0.29	0.03	1.18	0.00	0.44
Belgium	0.23	0.04	1.35	0.00	0.46
Germany	0.36	0.03	3.38	0.00	1.11
Denmark	0.04	0.01	0.15	0.00	0.06
Spain	0.37	0.07	1.62	0.00	0.60
Finland	0.35	0.03	2.46	0.00	0.87
France	0.24	0.03	1.45	0.00	0.61
United Kingdom	0.20	0.04	1.10	0.00	0.49
Greece	0.39	0.06	2.06	0.00	1.26
Ireland	0.14	0.05	0.46	0.00	0.18
Italy	0.37	0.04	1.55	0.00	1.04
Netherlands	0.24	0.03	2.69	0.00	0.73
Norway	0.03	0.00	0.16	0.00	0.07
Portugal	0.32	0.06	1.52	0.02	0.55
Sweden	0.01	0.00	0.04	0.00	0.01

Note. This table provides summary statistics on country-level CO2 intensity constructed by aggregating firm-level data for the 15 countries in our sample. Firm-level CO2 intensity is defined as the sum of Scope 1 (direct emissions from owned or controlled sources) and Scope 2 (indirect emissions from purchased energy) emissions in thousands of tonnes, divided by net sales (ticker: `WC01001`) in millions of USD. Firm-level CO2 intensity thus simplifies to kg CO2 per USD, comparable to the country-level measure. Country-level statistics are computed as mean across publicly traded firms in each country. Source: LSEG.

Table B.4 Firms by Sector & Sector–Country Coverage

	Total Firms	Mean	25th Percentile	75th Percentile
Basic Materials	50	3.57	2	4
Consumer Discretionary	89	5.93	2	8
Consumer Staples	47	3.36	1	4
Energy	28	2.15	1	2
Financials	107	7.13	4	9
Health Care	40	4.00	2	6
Industrials	129	8.60	4	13
Real Estate	21	1.75	1	2
Technology	33	2.75	2	4
Telecommunications	23	1.64	1	3
Utilities	36	3.00	2	4

Note. Total number of distinct firms in each sector and the distribution of firms across sector–country cells. “Mean”, “25th percentile”, and “75th percentile” refer to the number of firms in a given sector–country pair, computed across all countries in which the sector is represented.

C Robustness

C.1 Robustness: Macro Local Projections

We run an extensive battery of robustness checks for the macro local projections, covering both the average responses (equation (1)) and the differential responses by country-level CO_2 intensity (equation (2)). Figures C.1–C.9 show that our results are stable across alternative lag structures, samples, control sets, and estimators.

First, we assess the sensitivity of the impulse responses to the dynamic specification. Figures C.1 and C.2 report estimates obtained with a shorter lag structure (six lags) for the average and relative effects, respectively. The responses are very close to the baseline across all variables, indicating that our findings are not driven by a particular choice of lag length.

Second, Figures C.3 and C.4 show that restricting the sample to 2005–2019 yields impulse responses that are again highly similar to the baseline, alleviating concerns that the results reflect the earlier part of the sample or specific episodes.

Third, Figure C.5 reports estimates from a specification where the shocks series is used as an instrument for HICP energy. The resulting average and relatoive impulse responses are virtually identical to the baseline.

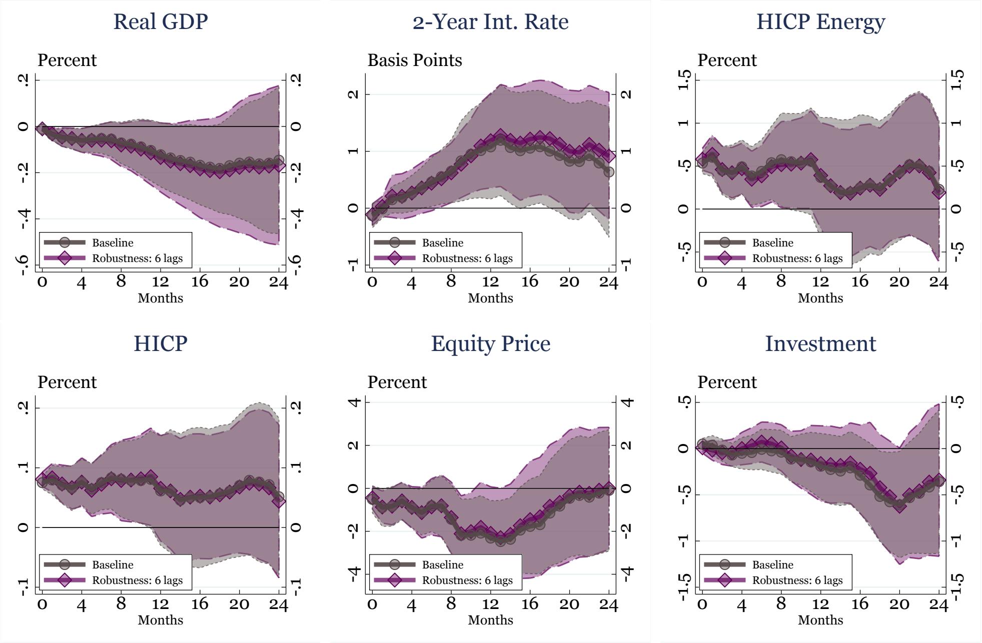
Fourth, we consider alternative control sets. Figure C.7 adds the oil price to the baseline controls and compares the resulting average impulse responses to the baseline. Since the oil price does not vary across countries, it would be absorbed by time fixed effects in the relative-effect specification; we therefore report this check only for the average effect. The estimated responses remain essentially unchanged, and if anything are slightly more precisely estimated, suggesting that our carbon pricing shock is not proxying for contemporaneous oil-price movements.

Fifth, we verify that the heterogeneity results are not mechanically driven by common shocks absorbed by time effects. Figure C.8 re-estimates the relative-effect specification without time fixed effects. The overall pattern of differential responses is preserved, supporting the interpretation that the interaction results reflect systematic differences across high- versus low-intensity countries rather than being an artifact of time effects absorbing relevant variation.

Finally, we explore an alternative way of parameterizing heterogeneity. Figure C.9 replaces the baseline discrete high/low CO_2 intensity interaction with a linear interaction in country-level CO_2 intensity. The qualitative patterns are comparable, but the linear specification tends to deliver less sharp separation, consistent with the idea that the relevant cross-country heterogeneity is concentrated in the upper tail of the intensity distribution and is therefore better captured by our baseline non-linear design.

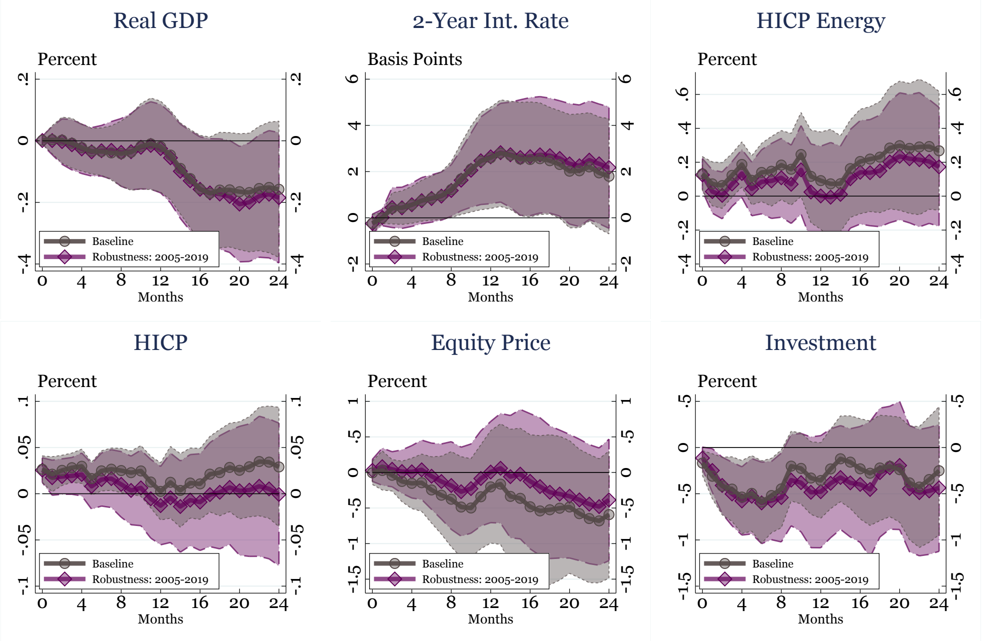
Overall, across all checks, the main macro findings—both for the average effects and for the differential effects by CO_2 intensity—remain stable in sign, magnitude, and timing.

Figure C.1 Country-level Average Effect - Robustness: 6 Lags



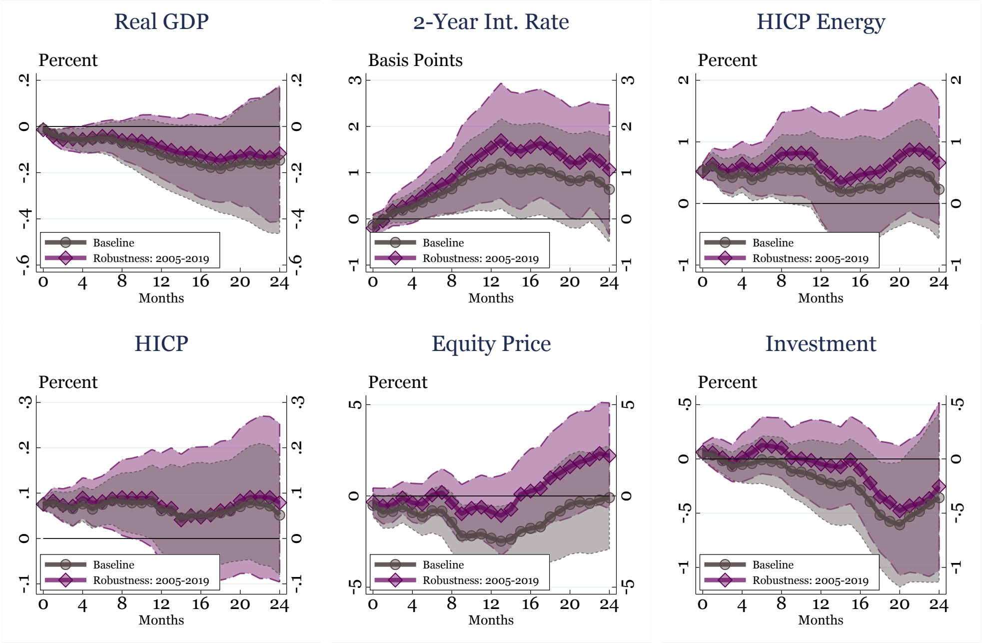
Note. Average effect of a one standard deviation increase in the carbon policy surprise (CPS) series on $y_{i,t+h}$, as captured by the coefficients β^h in equation (1). Shaded areas display 90 percent confidence intervals computed with heteroskedasticity and autocorrelation robust standard errors based on Driscoll and Kraay (1998).

Figure C.2 Country-level Relative Effect - Robustness: 6 Lags



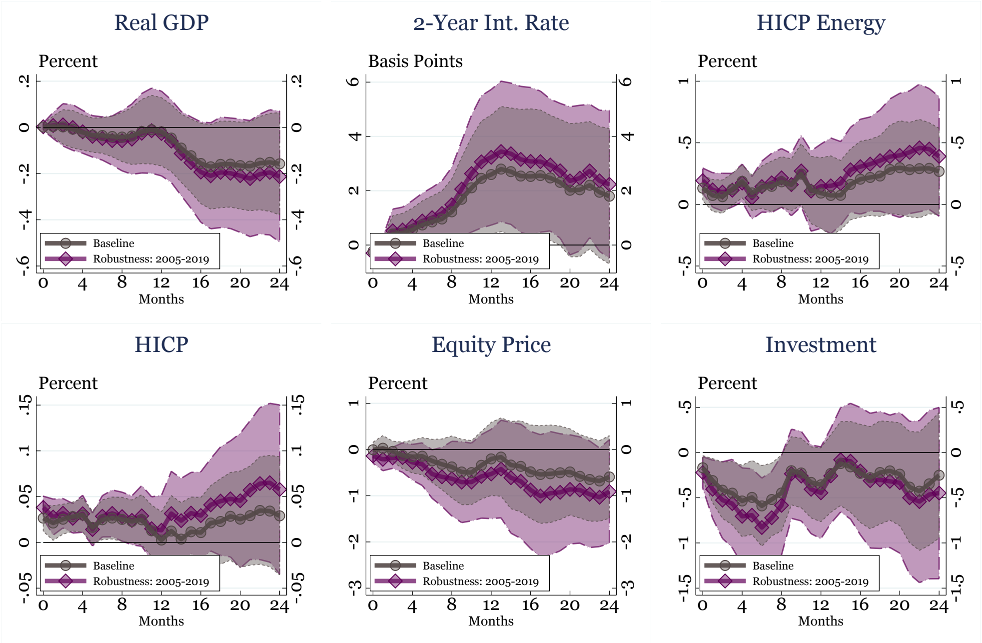
Note. Differential effect of a one standard deviation carbon pricing shock on $y_{i,t+h} - y_{i,t-1}$ for countries with above-median CO_2 intensity relative to below-median countries, as captured by γ^h in equation (2). Shaded areas display 90 percent confidence intervals computed with heteroskedasticity and autocorrelation robust standard errors based on Driscoll and Kraay (1998).

Figure C.3 Country-level Average Effect - Robustness: 2005-2019



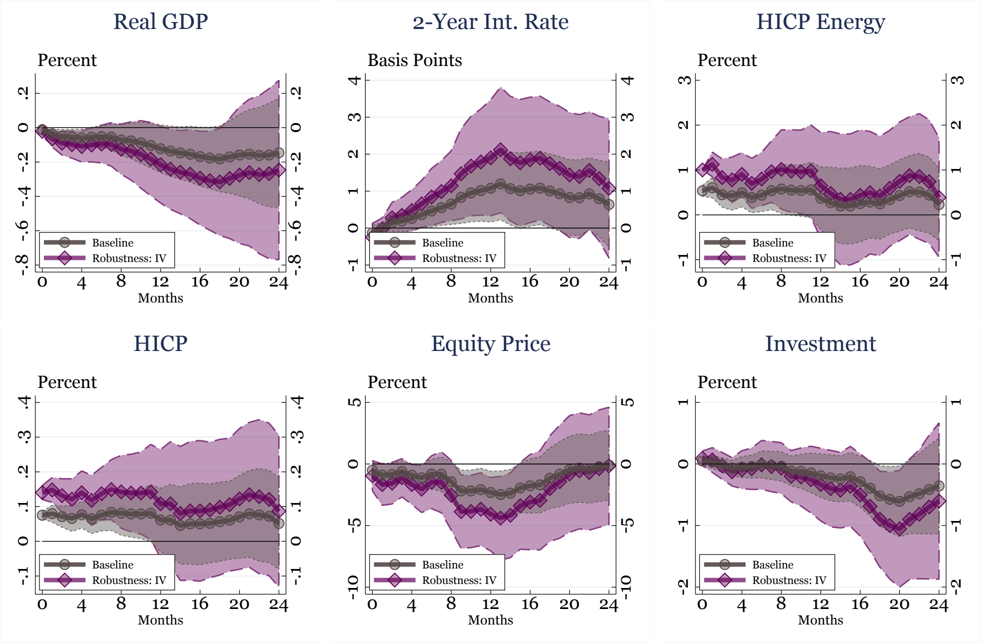
Note. Average effect of a one standard deviation increase in the carbon policy surprise (CPS) series on $y_{i,t+h}$, as captured by the coefficients β^h in equation (1). Shaded areas display 90 percent confidence intervals computed with heteroskedasticity and autocorrelation robust standard errors based on Driscoll and Kraay (1998).

Figure C.4 Country-level Relative Effect - Robustness: 2005-2019 Sample



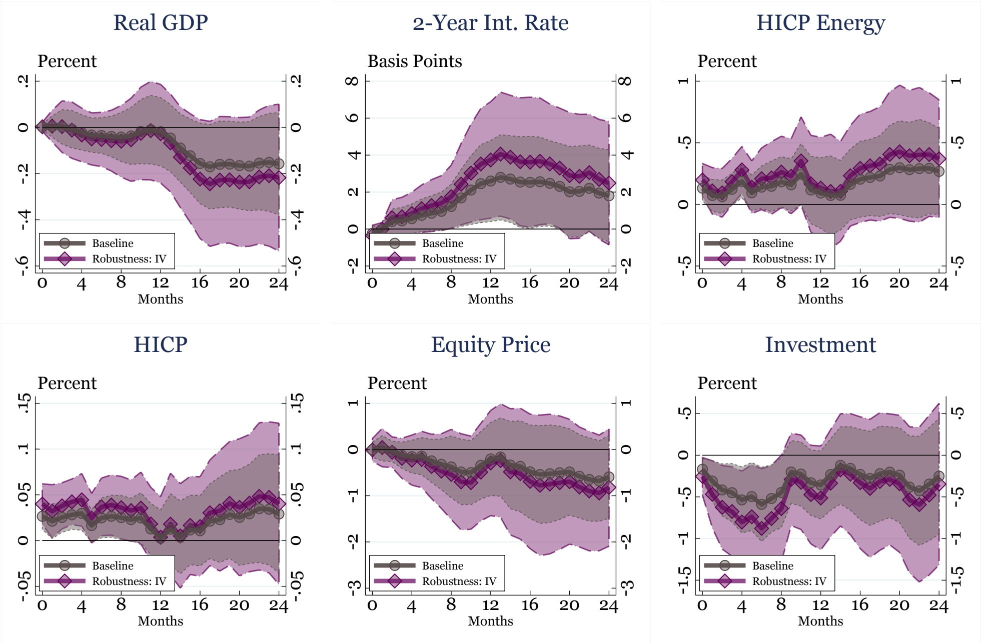
Note. Differential effect of a one standard deviation carbon pricing shock on $y_{i,t+h} - y_{i,t-1}$ for countries with above-median CO_2 intensity relative to below-median countries, as captured by γ^h in equation (2). Shaded areas display 90 percent confidence intervals computed with heteroskedasticity and autocorrelation robust standard errors based on Driscoll and Kraay (1998).

Figure C.5 Country-level Average Effect - Robustness: IV



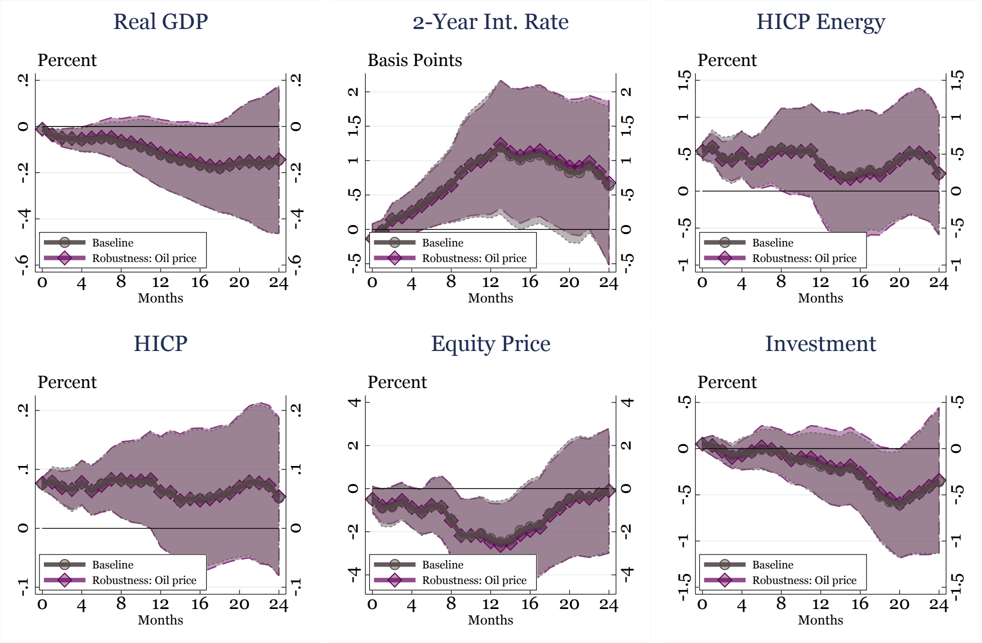
Note. Average effect of a one standard deviation increase in the carbon policy surprise (CPS) series on $y_{i,t+h}$, as captured by the coefficients β^h in equation (1). Shaded areas display 90 percent confidence intervals computed with heteroskedasticity and autocorrelation robust standard errors based on Driscoll and Kraay (1998).

Figure C.6 Country-level Relative Effect - Robustness: IV



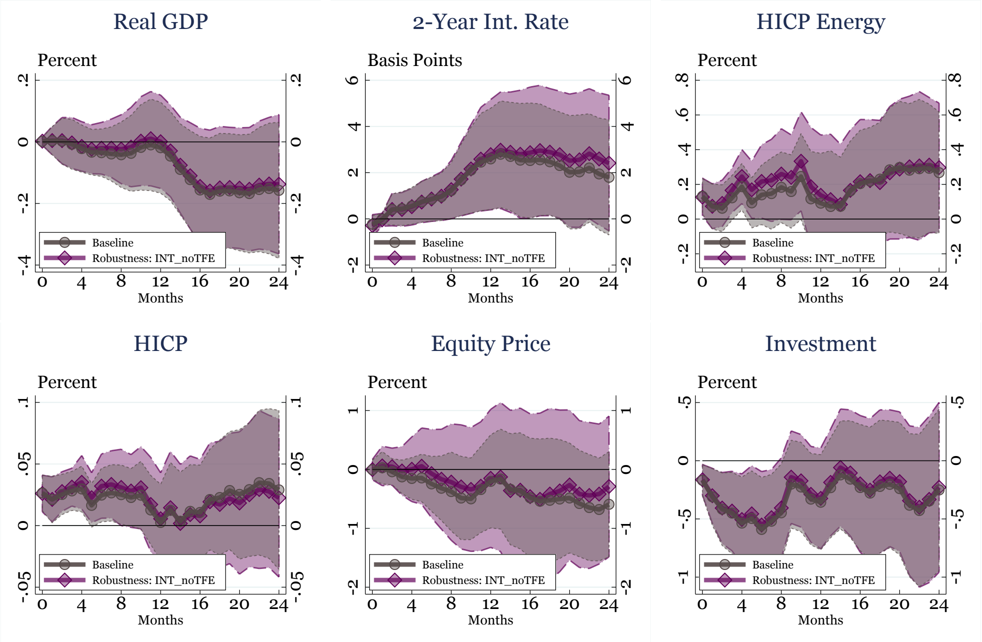
Note. Differential effect of a one standard deviation carbon pricing shock on $y_{i,t+h} - y_{i,t-1}$ for countries with above-median CO_2 intensity relative to below-median countries, as captured by γ^h in equation (2). Shaded areas display 90 percent confidence intervals computed with heteroskedasticity and autocorrelation robust standard errors based on Driscoll and Kraay (1998).

Figure C.7 Country-level Average Effect - Robustness: Controlling for Oil



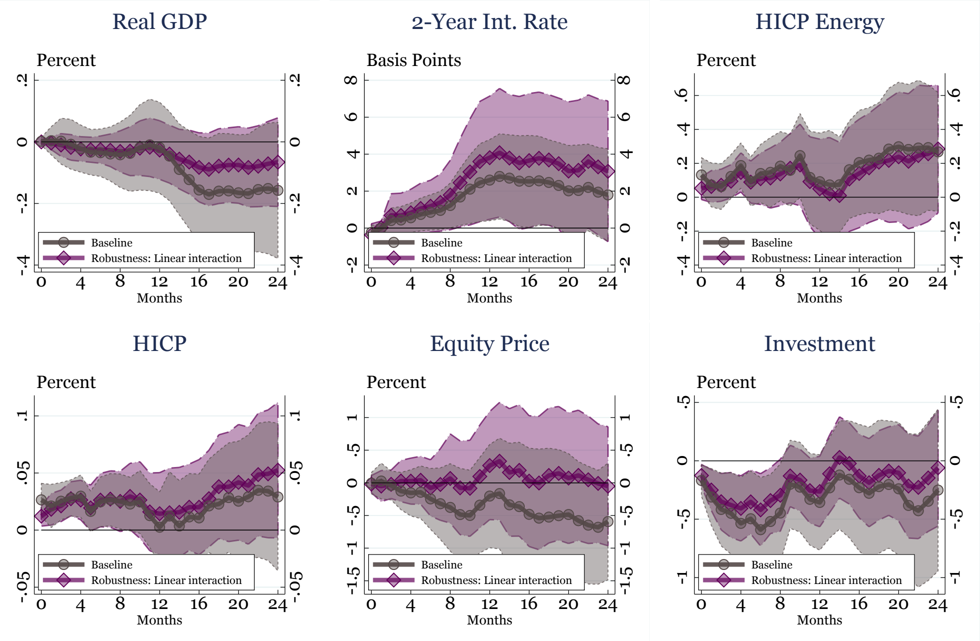
Note. Average effect of a one standard deviation increase in the carbon policy surprise (CPS) series on $y_{i,t+h}$, as captured by the coefficients β^h in equation (1). Shaded areas display 90 percent confidence intervals computed with heteroskedasticity and autocorrelation robust standard errors based on Driscoll and Kraay (1998).

Figure C.8 Country-level Relative Effect - Robustness: No Time FE



Note. Average effect of a one standard deviation increase in the carbon policy surprise (CPS) series on $y_{i,t+h}$, as captured by the coefficients β^h in equation (1). Shaded areas display 90 percent confidence intervals computed with heteroskedasticity and autocorrelation robust standard errors based on Driscoll and Kraay (1998).

Figure C.9 Country-level Relative Effect - Robustness: Linear Interaction



Note. Average effect of a one standard deviation increase in the carbon policy surprise (CPS) series on $y_{i,t+h}$, as captured by the coefficients β^h in equation (1). Shaded areas display 90 percent confidence intervals computed with heteroskedasticity and autocorrelation robust standard errors based on Driscoll and Kraay (1998).

C.2 Robustness: Micro Local Projections

We run an extensive battery of robustness checks on out firm-level results. Since the average firm-level response closely mirrors the country-level evidence, we focus here on the *relative* effect—i.e., how the equity price response differs for high-emission firms relative to the average firm (the coefficients γ^h in equation (4)). Figure C.10 overlays the baseline estimates with a range of alternative specifications and sample choices.

Panels (a) and (b) show that the results are not sensitive to standard time-series choices. Decreasing the number of lags to 6 (Panel a) leaves the relative impulse response essentially unchanged. Likewise, restricting the sample to 2005–2019 (Panel b) delivers an almost identical profile.

Panel (c) relaxes the fixed-effects saturation by replacing the time×country×sector fixed effects with separate time×country and time×sector fixed effects. The point estimates remain very similar, with somewhat wider confidence bands, suggesting that the baseline results are not an artifact of an overly restrictive fixed-effects structure.

Panels (d) and (e) consider alternative ways of capturing heterogeneity. Panel (d) replaces the baseline non-linear exposure design with a linear interaction in CO_2 intensity; the resulting relative response is noticeably smaller and flatter, consistent with the idea that the pricing of carbon exposure is concentrated in the upper tail of the emissions distribution, and therefore better captured by our baseline non-linear specification. Panel (e) shows that using an alternative normalization of emissions—CO_2 emissions scaled by market value rather than total assets—yields similar impulse responses, but with larger confidence intervals.

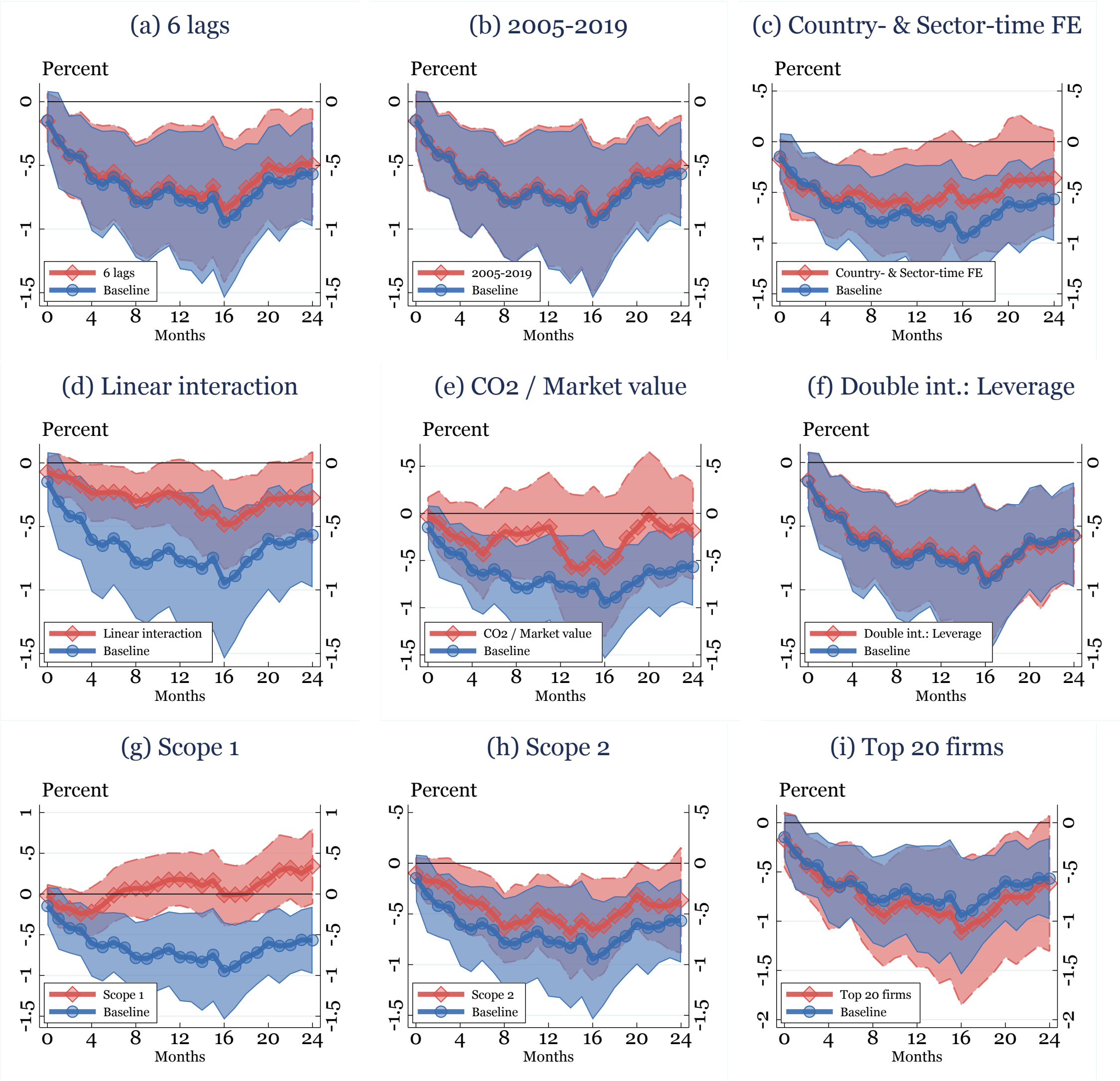
Panel (f) augments the baseline by adding a second interaction with leverage (CPS interacted with a high-leverage indicator). The estimated CO_2 differential response is essentially unchanged, indicating that the emissions-based heterogeneity is not simply proxying for balance-sheet risk.

Panels (g) ad (h) consider alternative emissions definitions and sample composition. Panels (g) and (h) reconstruct CO_2 intensity using Scope 1 and Scope 2 emissions separately. Using Scope 2 emissions produces a relative response very close to (and if anything slightly larger than) the baseline, whereas using Scope 1 alone yields a weaker and less precisely estimated differential response.

Panel (i) addresses concerns that countries with more listed firms might receive disproportionate weight by restricting the sample to the top 20 firms (by market value) in each country; the resulting impulse responses are nearly identical to the baseline.

Overall, the robustness exercises confirm the main message: carbon pricing surprises generate a systematically larger decline in equity valuations for high-emission firms relative to the average firm, and this result is stable across a broad set of specification, measurement, and sample choices.

Figure C.10 FIRM-LEVEL RELATIVE EFFECT - ROBUSTNESS

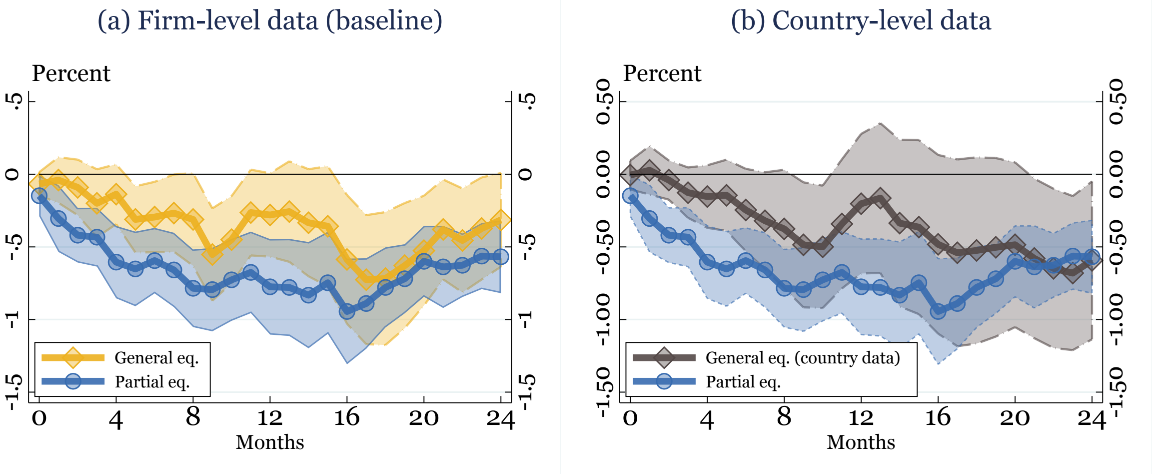


NOTE. Effect of a one standard deviation increase in the carbon policy surprise (CPS) series on equity prices for high-emission firms (i.e. whose CO_2 emissions are above the median) relative to low-emission firms, as captured by the coefficients γ^h in equation (4). Shaded areas 90 percent confidence intervals computed with heteroskedasticity and autocorrelation robust standard errors based on Driscoll and Kraay (1998).

C.3 Robustness: General Equilibrium Attenuation

This subsection provides a robustness check on our comparison between partial-equilibrium (PE) and general-equilibrium (GE) responses to carbon pricing shocks. In our baseline firm-level analysis, we isolate PE effects using a saturated fixed-effects specification, and contrast them with GE effects from a more parsimonious specification that allows for substitution in demand and reallocation across firms and sectors. The results show that the PE response is substantially larger than the GE response, consistent with systematic general-equilibrium attenuation. As a complementary check, we compare the firm-level general-equilibrium response, $\bar{\gamma}^h$, to γ^h from equation (2), which is estimated using economy-wide CO_2 intensity from the World Bank. This measure captures emissions from households, government, and unlisted firms, and therefore provides a broader notion of carbon exposure than the firm-level data used in the micro analysis. Panel (b) of Figure C.11 reports the results. The macro-based estimate γ^h closely mirrors the firm-level general-equilibrium response $\bar{\gamma}^h$ shown in Panel (a), both in magnitude and dynamics. This confirms that the attenuation of firm-level partial-equilibrium effects at the aggregate level is not driven by the coverage of listed firms, but reflects economy-wide general-equilibrium forces.

Figure C.11 General-Equilibrium Attenuation: Robustness


(a) Firm-level data (baseline)

(b) Country-level data

Note. Comparing partial-equilibrium and general-equilibrium effects of a one standard deviation carbon pricing shock on equity prices. Panel (a) is identical to panel (a) of Figure 4: it plots the partial-equilibrium effect, ϕ^h (blue line) from equation (4), which includes time-by-country-by-sector fixed effects; and the general-equilibrium effect, $\bar{\gamma}^h$ (yellow line) from equation (5), which includes time fixed effects only. Panel (b) plots again the partial equilibrium effect ϕ^h (blue line) from equation (4); and the general-equilibrium effect, γ^h (black line) from equation (2), which is estimated with macro data and includes time fixed effects only. Shaded areas display 68 percent confidence intervals (Driscoll–Kraay standard errors).

D Testing for General-Equilibrium Attenuation

This appendix describes our procedure for testing whether the difference between the partial-equilibrium and general-equilibrium impulse responses documented in Section 4 is statistically significant.

Setup The test compares impulse responses from equations (4) and (5), which differ in both the level of aggregation of the CO_2 intensity measure and the fixed-effects structure.

Equation (4) classifies firms as high-emission based on whether their CO_2 intensity exceeds the median within their country-sector pair, yielding the indicator $CO2_{ij,t-1}^{High}$. With time-by-country-by-sector fixed effects, this specification isolates within-sector variation—a partial-equilibrium object that holds fixed cross-sectoral and cross-country reallocation. The coefficient ϕ^h measures how much more high-emission firms' equity prices fall relative to low-emission firms within narrowly defined cells.

Equation (5) classifies firms based on their country's average CO_2 intensity, using the indicator $\overline{CO2}_{i,t-1}^{High}$. With only country and time fixed effects, general-equilibrium forces—demand switching, relative price adjustments, resource reallocation—can influence the estimated response. The coefficient $\bar{\gamma}^h$ captures how much more firms in high-emission countries experience equity declines relative to firms in low-emission countries.

Our object of interest is the horizon-specific difference:

$$d^h \equiv \widehat{\phi}^h - \widehat{\bar{\gamma}}^h. \tag{D.1}$$

Positive values of d^h indicate that the partial-equilibrium effect is larger in magnitude than the general-equilibrium effect—consistent with general-equilibrium forces attenuating the aggregate response.

Why Direct Inference on d^h is Necessary Comparing whether the separate confidence bands for $\widehat{\phi}^h$ and $\widehat{\bar{\gamma}}^h$ overlap is not a valid test. The variance of the difference satisfies:

$$\operatorname{Var}\left(d^h\right) = \operatorname{Var}\left(\widehat{\phi}^h\right) + \operatorname{Var}\left(\widehat{\bar{\gamma}}^h\right) - 2\operatorname{Cov}\left(\widehat{\phi}^h, \widehat{\bar{\gamma}}^h\right). \tag{D.2}$$

Because both impulse responses are estimated from the same underlying firm-level data, the covariance is likely positive and substantial. This reduces $\mathrm{Var}(d^h)$, so the difference can be precisely estimated even when the individual impulse responses have wide, overlapping bands.

Bootstrap Procedure We construct confidence bands for d^h using a time-cluster bootstrap. Let $\mathcal{T}$ denote the set of months in the sample. For each replication $b = 1, \ldots, B$:

1. Draw $|\mathcal{T}|$ months with replacement from $\mathcal{T}$.
2. Retain all firm-level observations in each selected month.
3. Recompute $CO2^{High}_{ij,t-1}$ and $\overline{CO2}^{High}_{i,t-1}$ on the resampled data.
4. Re-estimate equations (4) and (5), and compute:

$$d^{h,*(b)} = \widehat{\phi}^{h,*(b)} - \widehat{\widetilde{\gamma}}^{h,*(b)}, \qquad h = 0, \ldots, H. \tag{D.3}$$

Pointwise confidence bands are the 16th–84th percentiles of $\{d^{h,*(b)}\}_{b=1}^{B}$. By re-estimating both specifications jointly within each bootstrap draw, the procedure captures the covariance between $\widehat{\phi}^h$ and $\widehat{\widetilde{\gamma}}^h$ without requiring analytic estimation. This approach is consistent with the Driscoll–Kraay standard errors used throughout the main analysis.

Because equation (4) includes high-dimensional time-by-country-by-sector fixed effects, some bootstrap draws yield non-estimable coefficients at particular horizons. We construct bands using only replications where both coefficients are successfully estimated, and report the number of valid replications at each horizon. We set $B = 500$ and $H = 24$.

E Model

Our model has two types of firms—"brown" and "green"—which are distinguished by the extent to which they pollute, consistent with Copeland and Taylor (2004) and Shapiro and Walker (2018). We assume that emissions are associated with production, that firms are subject to environmental policies that make polluting costly, and that, as a result, they undertake abatement activities to limit their pollution. Whether firms are brown or green is determined by the value of one parameter, which, as described below, can be viewed as the firm's emission intensity. This is assumed to be larger for brown firms than for green firms. This way of modelling heterogeneity is consistent with the empirical approach described in Section 4, where we estimate the differences in firm responses depending on emissions, while controlling for other factors, including time-by-sector fixed effects. The model has an endogenous carbon cycle, in which atmospheric pollution feeds back onto aggregate productivity, as well as a number of more standard nominal and real rigidities such as monopolistic competition, habit formation, capital adjustment costs, and firm death shocks. While households are modeled in a largely standard way, their portfolio and capital accumulation decisions are crucial for transmitting firm-level carbon pricing shocks into asset prices and aggregate demand. The rest of this section outlines the model in more detail.

E.1 Households

Households, denoted by the index $\omega \in [0,1]$, make consumption and investment (savings) decisions, and supply labor and capital services to producing firms. We assume that households can insure themselves against idiosyncratic changes in their wage incomes. Households hold government bonds, make investment decisions in physical capital and buy/sell stocks in mutual funds. Households maximize their life-time utility:

$$\mathcal{V}_0(\omega) = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \mathcal{U}\left(C_t(\omega), N_t(\omega)\right),$$

where $\mathbb{E}_t$ is an expectation operator and the period utility is given by:

$$\mathcal{U}\left(C_t(\omega), N_t(\omega)\right) = \frac{\left(C_t(\omega) - \phi C_{t-1}\right)^{1-\sigma} - 1}{1-\sigma} - \chi \frac{\left(N_t(\omega)\right)^{1+\varphi}}{1+\varphi}.$$

Here β is the subjective discount factor, $C_t(\omega)$ denotes individual consumption, C_t aggregate consumption, $N_t(\omega)$ hours worked, σ is the inverse of inter-temporal elasticity of substitution, ϕ the degree of external habit formation, and φ the inverse of the Frisch elasticity of labor supply. From here onwards, we drop the index ω for brevity. Consumption is a CES composite that combines brown goods, C_t^B, and green goods, C_t^G:

$$C_t = \left\{\nu^{\frac{1}{\eta}} \left(C_t^B\right)^{\frac{\eta-1}{\eta}} + (1-\nu)^{\frac{1}{\eta}} \left(C_t^G\right)^{\frac{\eta-1}{\eta}}\right\}^{\frac{\eta}{\eta-1}}, \tag{E.1}$$

where η denotes the intra-temporal elasticity of substitution and ν the preference weight of brown goods in the aggregate consumption CES aggregator. The optimality conditions resulting from consumption expenditure minimization are given by:

$$C_t^B = \nu \left(\frac{P_t^B}{P_t} \right)^{-\eta} C_t, \tag{E.2}$$

$$C_t^G = (1 - \nu) \left(\frac{P_t^G}{P_t} \right)^{-\eta} C_t, \tag{E.3}$$

where P_t^G, P_t^B and P_t denote the nominal prices of green, brown and aggregate goods, respectively. Substituting (E.2) and (E.3) into equation (E.1) gives an expression for the aggregate price index:

$$P_t = \left\{ \nu \left(P_t^B \right)^{1-\eta} + (1 - \nu) \left(P_t^G \right)^{1-\eta} \right\}^{\frac{1}{1-\eta}}.$$

The government spending aggregator is the same as that of consumption. There are investment packers, who combine green and brown investment to produce an aggregate investment good. The intra-period problem of investment packers is similar to that of consumers and is detailed below. The evolution of capital is, however, specific to each firm type and households face costs when adjusting firm-specific investment. This means that the physical capital used by firms to produce output is made out of brown and green goods.

The budget constraint is given by:

$$\begin{aligned} C_t + \sum_{j=\{B,G\}} \left\{ \mathcal{I}_t^j + S_t^j V_t^j \right\} + B_t = R_{t-1} \frac{B_{t-1}}{\Pi_t} + \\ + w_t N_t + \sum_{j=\{B,G\}} \left\{ r_{K,t}^j K_{t-1}^j + S_{t-1}^j (1 - \delta_j) \left(V_t^j + \Phi_t^j / P_t \right) \right\} - T_t / P_t, \end{aligned}$$

where $\mathcal{I}_t^j$ denotes (real) investment by firm of type $j \in \{B, G\}$, S_t^j the stock holdings in mutual fund of firm-type j, V_t^j the real price of shares of firm of type j in the mutual fund, w_t the real wage rate, K_t^j is physical capital of firms of type j, $r_{K,t}^j$ real rental rate of capital for firms of type j, T_t nominal lump-sum transfers and Φ_t^j nominal profits. Producing firms face a death probability denoted by δ_j. We assume that dividends are only paid by surviving firms.

The law of motion of capital of type j is given by:

$$K_t^j = (1-\delta_K) K_{t-1}^j + \left[\frac{\upsilon_1^j}{1-\psi^j} \left(\frac{\mathcal{I}_t^j}{K_{t-1}^j} \right)^{1-\psi^j} + \upsilon_2^j \right] K_{t-1}^j \quad \text{for} \quad j = \{B, G\}, \tag{E.4}$$

where δ_K, ψ^j, υ_1^j and υ_2^j denote the depreciation rate of capital and adjustment cost parameters, respectively. Capital adjustment costs make it more costly to smooth consumption through changing the capital stock.

Households maximize life-time utility subject to a series of budget constraints and the two laws of motion of capital. The first order conditions with respect to C_t, B_t, K_t^B, K_t^G, $\mathcal{I}_t^B$ and $\mathcal{I}_t^G$ are given by:

$$\Lambda_t = (C_t - \phi C_{t-1})^{-\sigma}, \tag{E.5}$$

$$\Lambda_t = \beta \mathbb{E}_t \left\{ \frac{R_t}{\Pi_{t+1}} \Lambda_{t+1} \right\}, \tag{E.6}$$

$$\begin{aligned} Q_t^j = \beta \mathbb{E}_t & \left\{ \frac{\Lambda_{t+1}}{\Lambda_t} \left[r_{K,t+1}^j + (1-\delta_K) Q_{t+1}^j - Q_{t+1}^j \upsilon_1^j \left(\frac{\mathcal{I}_{t+1}^j}{K_t^j} \right)^{1-\psi_j} + \right. \right. \\ & \left. \left. + Q_{t+1}^j \left[\frac{\upsilon_1^j}{1-\psi^j} \left(\frac{\mathcal{I}_{t+1}^j}{K_t^j} \right)^{1-\psi_j} + \upsilon_2^j \right] \right] \right\} \quad \text{for} \quad j = \{B, G\}, \end{aligned} \tag{E.7}$$

$$1 = Q_t^j \upsilon_1^j \left(\frac{\mathcal{I}_t^j}{K_{t-1}^j} \right)^{-\psi^j} \quad \text{for} \quad j = \{B, G\}. \tag{E.8}$$

In addition, asset prices for j-type firms (V_t^j) can be written as:

$$V_t^j = \beta(1-\delta_j) \mathbb{E}_t \frac{\Lambda_{t+1}}{\Lambda_t} \left\{ \frac{\Phi_{t+1}^j}{P_{t+1}} + V_{t+1}^j \right\}. \tag{E.9}$$

Asset prices reflect the survival hazard: expected returns on firms reflect both dividend risk and the risk of death, so equities must command a premium relative to safe assets. We assume that the number of exiting firms equals the number of incumbents, so that the mass of brown and green firms is always equal to 1.

E.2 Labor Unions

Aggregate labor demand is given by:

$$N_t^d = \left[\int_0^1 N_t(\omega)^{\frac{\epsilon_w - 1}{\epsilon_w}} d\omega \right]^{\frac{\epsilon_w}{\epsilon_w - 1}},$$

where ϵ_w is the elasticity of substitution across labor varieties. The labor union maximizes

$$\max_{w_t^*} \mathbb{E}_t \sum_{s=t}^{\infty} (\beta \vartheta_w)^{s-t} \left\{ -\chi \frac{N_s(\omega)^{1+\varphi}}{1+\varphi} + \Lambda_s \prod_{k=t+1}^{s} \left(\frac{\Pi_{k-1}^{\iota_w} \Pi^{1-\iota_w}}{\Pi_k} \right) w_s(\omega) N_s(\omega) \right\},$$

subject to the following demand schedule:

$$N_s(\omega) = \left(\prod_{k=1}^{s} \frac{w_s(\omega)}{w_s} \frac{\Pi_{k-1}^{\iota_w} \Pi^{1-\iota_w}}{\Pi_k} \right)^{-\epsilon_w} N_s^d.$$

The problem of the union is to maximize profits,

$$\max_{w_t^*} \mathbb{E}_t \sum_{s=t}^{\infty} (\beta \vartheta_w)^{s-t} \left\{ -\chi \frac{\left[\left(\frac{w_t(\omega)}{w_s} \prod_{k=t+1}^{s} \frac{\Pi_{k-1}^{\iota_w} \Pi^{1-\iota_w}}{\Pi_k} \right)^{-\epsilon_w} N_s^d \right]^{1+\varphi}}{1+\varphi} + \right.$$
$$\left. + \Lambda_s w_s \left(\frac{w_t(\omega)}{w_s} \prod_{k=t+1}^{s} \frac{\Pi_{k-1}^{\iota_w} \Pi^{1-\iota_w}}{\Pi_k} \right)^{1-\epsilon_w} N_s^d \right\}.$$

The first order condition with respect to w_t^* can be expressed in recursive form by separating the LHS from the RHS of the first order condition.

$$\mathcal{F}_t^w = \epsilon_w \chi (\tilde{w}_t)^{-\epsilon_w(1+\varphi)} \left(N_t^d \right)^{1+\varphi} + \beta \vartheta_w \mathbb{E}_t \left(\frac{\Pi_t^{\iota_w} \Pi^{1-\iota_w}}{\Pi_{t+1}} \right)^{-\epsilon_w(1+\varphi)} \left(\frac{\tilde{w}_{t+1}}{\tilde{w}_t} \right)^{\epsilon_w(1+\varphi)} \mathcal{F}_{t+1}^w, \tag{E.10}$$

$$\mathcal{J}_t^w = (\epsilon_w - 1) \Lambda_t (\tilde{w}_t)^{1-\epsilon_w} w_t N_t^d + \beta \vartheta_w \mathbb{E}_t \left(\frac{\Pi_t^{\iota_w} \Pi^{1-\iota_w}}{\Pi_{t+1}} \right)^{1-\epsilon_w} \left(\frac{\tilde{w}_{t+1}}{\tilde{w}_t} \right)^{\epsilon_w - 1} \mathcal{J}_{t+1}^w, \tag{E.11}$$

$$\mathcal{J}_t^w = \mathcal{F}_t^w, \tag{E.12}$$

where $\tilde{w}_t = \frac{w_t^*}{w_t}$ is the optimal wage divided by the aggregate wage rate. The aggregate law of motion for wages is therefore equal to:

$$w_t^{1-\epsilon_w} = \vartheta_w \left(\frac{\Pi_{t-1}^{\iota_w} \Pi^{1-\iota_w}}{\Pi_t} w_{t-1} \right)^{1-\epsilon_w} + (1-\vartheta_w)(w_t^*)^{1-\epsilon_w}. \tag{E.13}$$

E.3 Capital Producers

Capital producers provide investment goods to brown and green firms by combining green and brown investments. Aggregate investment is thus

$$I_t = \left\{ \nu^{\frac{1}{\eta}} \left(I_t^B\right)^{\frac{\eta-1}{\eta}} + (1-\nu)^{\frac{1}{\eta}} \left(I_t^G\right)^{\frac{\eta-1}{\eta}} \right\}^{\frac{\eta}{\eta-1}}.$$

Profits are:

$$\Pi_t = I_t - p_t^B I_t^B - p_t^G I_t^G$$

and the demand schedules are given by:

$$I_t^B = \nu \left(p_t^B\right)^{-\eta} I_t, \tag{E.14}$$

$$I_t^G = (1-\nu) \left(p_t^G\right)^{-\eta} I_t. \tag{E.15}$$

E.4 Firms

Firms are indexed by $i \in [0,1]$ and produce goods of type $j = \{B, G\}$. They face a production technology given by:

$$Y_t^j(i) = \mathcal{Z} Z_t \left(1 - A_t^j(i)\right) \left(N_t^j(i)\right)^{1-\alpha_j} \left(K_{t-1}^j(i)\right)^{\alpha_j} - \Psi_j, \tag{E.16}$$

where $\mathcal{Z}$ is the level of aggregate productivity, $Z_t = 1 - \Gamma(\mathcal{CO}_t)$ denotes aggregate productivity and $\Gamma(\mathcal{CO}_t)$ is a damage function in line with Nordhaus (2008), $A_t^j(i)$ is the fraction of output devoted to abatement of pollution and α_j is the capital share in production. Here Ψ_j denotes a fixed cost of production for j-type firms. Its presence implies that the production function exhibits increasing returns to scale. For the firm to produce, then it must be that $\mathcal{Z} Z_t \left(1 - A_t^j(i)\right) \left(N_t^j(i)\right)^{1-\alpha_j} \left(K_{t-1}^j(i)\right)^{\alpha_j} > \Psi_j$. The specification of fixed costs is standard in the literature (Christiano et al., 2005). The value of Ψ_j determines steady-state profits, which are then scaled to be consistent with national accounts.

The damage function $\Gamma\left(\mathcal{CO}_t\right)$ captures the adverse impact of the physical damages associated with climate change on aggregate productivity. These damages represent an externality imposed by polluting firms on greener firms. Consistent with Heutel (2012), we assume a quadratic functional form for damages:

$$\Gamma\left(\mathcal{CO}_t\right) \equiv d_3\left(d_0 + d_1\mathcal{CO}_t + d_2\mathcal{CO}_t^2\right). \tag{E.17}$$

Firms produce emissions according to a technology in which pollution is an increasing function of output and a decreasing function of abatement:

$$\xi_t^j\left(i\right) = \mu_j \mathcal{Z} Z_t \left[\frac{\left(1 - A_t^j\left(i\right)\right)^{\frac{\zeta-1}{\zeta}} - \left(1-\gamma_j\right)}{\gamma_j}\right]^{\frac{\zeta}{\zeta-1}} \left(N_t^j\left(i\right)\right)^{1-\alpha_j}\left(K_{t-1}^j\left(i\right)\right)^{\alpha_j}, \tag{E.18}$$

with $\left(1 - A_t^j\left(i\right)\right)^{\frac{\zeta-1}{\zeta}} > \left(1-\gamma_j\right)$. Here μ_j is a scaling factor, and γ_j and ζ will be defined below.

Copeland and Taylor (2004) and Shapiro and Walker (2018) show that substituting for abatement into the production function gives rise to a Cobb-Douglas production technology that uses emissions, capital, labor, and damages to produce output. Under this formulation, emissions can be interpreted as an output of production or an input into it. We show here that using a more general firm emission's function, equation (E.18), gives rise to a more general CES production function, which is given by:

$$Y_t^j\left(i\right) = \left[\gamma_j\left(\frac{\xi_t^j\left(i\right)}{\mu_j}\right)^{\frac{\zeta-1}{\zeta}} + \left(1-\gamma_j\right)\left\{\mathcal{Z} Z_t\left(N_t^j\left(i\right)\right)^{1-\alpha_j}\left(K_{t-1}^j\left(i\right)\right)^{\alpha_j}\right\}^{\frac{\zeta-1}{\zeta}}\right]^{\frac{\zeta}{\zeta-1}} - \Psi_j. \tag{E.19}$$

In this interpretation, γ_j is the emission intensity of firm j, ζ_j the elasticity of substitution between emissions and value added, and μ_j is a scale parameter. Intuitively, γ_j measures the "dirtiness" of a firm's output. We assume that brown firms pollute more than green firms (with the latter emitting very little); i.e. $\gamma_j \in (0,1)$ and $\gamma_B > \gamma_G$. It is worth noting that, although green firms are 'green' in the sense that they generate fewer emissions than brown firms through their production, the capital stock used in production is made out of both green and brown goods, as described above. The parameter ζ determines how easy or difficult it is to substitute between emissions and other factors of production. When the value of $\zeta < 1$, emissions and value added are gross complements; when $\zeta > 1$, they are gross substitutes.

Theory and evidence do not give clear guidance on how to think about pollution emissions in the firm's environmental decisions. Is pollution a second output on which firms are taxed via environmental regulation? Or is pollution best thought of as an input to production, which has a price due to environmental regulation? Or alternatively, should we think of firms as optimizing standard production decisions subject to a constraint on pollution emissions? An advantage of this framework is that it does not require choosing one of these interpretations as correct and the others as incorrect, since these interpretations are equivalent.

For the operating firm, pollution emissions decline when firms reallocate productive factors to abatement investment. The model accounts for several ways in which firms and consumer behavior affect pollution emissions: consumption, investment and production all respond to environmental regulation, and all of these forces can interact to determine pollution emissions. One concept that is commonly discussed is that the number of workers per unit of output, $\frac{Y_t^j(i)}{N_t^j(i)}$ respond to environmental regulation. This depends on environmental regulation since it increases the shares allocated to abatement rather than producing output.

We assume pollution regulations are sufficiently stringent for firms to engage in some form of abatement. We also assume that the only abatement cost is that of the associated diverted production. In addition, this type of production technology will help generate greater cyclicality of profits, in particular in the brown sector, given its greater exposure. This feature is key for our purposes: when emissions are difficult to substitute away from value added, carbon pricing disproportionately affects profits rather than quantities, generating strong firm-level responses but muted aggregate effects, consistent with our empirical findings.

Firms are monopolistically competitive, facing downward-sloping demand. Each firm chooses prices $P_t^j(i)$ abatement investment, $A_t^j(i)$, labor, $N_t^j(i)$, and capital, $K_{t-1}^j(i)$, to maximize profits:

$$\Phi_t^j(i) = P_t^j(i)\, Y_t^j(i) - P_t w_t N_t^j(i) - P_t r_{K,t}^j K_{t-1}^j(i) - \tau P_t \theta_t \xi_t^j(i)\,.$$

The profit function involves several terms. Households, the investment packer, and the government pay the price $P_t^j(i)$ for good i of type j. Each firm receives nominal revenue $P_t^j(i)\,Y_t^j(i)$. Firms' nominal costs comprise of the nominal wage bill $P_t w_t N_t^j(i)$, the nominal cost of renting physical capital $P_t r_{K,t}^j K_{t-1}^j(i)$, and the nominal cost of emissions $\tau P_t \theta_t \xi_t^j(i)$, where τ is a tax paid on emissions and θ_t the price of emissions (e.g. per ton of carbon).

Firm i of type j solves the following problem,

$$\min_{A_t^j(i),N_t^j(i),K_{t-1}^j(i)} P_t w_t N_t^j(i) + P_t r_{K,t}^j K_{t-1}^j(i) + \tau P_t \theta_t^j \xi_t(i)$$

subject to equation (E.16). The first order conditions of brown firms are given by:

$$mc_t^j(i) = \frac{\tau\theta_t\mu_j}{p_t^j\gamma_j}\left[\frac{\left(1-A_t^j(i)\right)^{\frac{\zeta-1}{\zeta}}-(1-\gamma_j)}{\gamma_j}\right]^{\frac{\zeta}{\zeta-1}-1}\left(1-A_t^j(i)\right)^{\frac{\zeta-1}{\zeta}-1},$$

$$mc_t^j(i) = \frac{w_t N_t^j(i)}{(1-\alpha_j)\,p_t^j(Y_t^j(i)+\Psi_j)} + \frac{\tau\theta_t^j}{p_t^j}\mu_j\left[\frac{\left(1-A_t^j(i)\right)^{\frac{\zeta-1}{\zeta}}-(1-\gamma_j)}{\gamma_j}\right]^{\frac{\zeta}{\zeta-1}}\frac{1}{1-A_t^j(i)},$$

$$mc_t^j(i) = \frac{r_{K,t}^j K_{t-1}^j(i)}{\alpha_j p_t^j(Y_t^j(i)+\Psi_j)} + \frac{\tau\theta_t^j}{p_t^j}\mu_j\left[\frac{\left(1-A_t^j(i)\right)^{\frac{\zeta-1}{\zeta}}-(1-\gamma_j)}{\gamma_j}\right]^{\frac{\zeta}{\zeta-1}}\frac{1}{1-A_t^j(i)},$$

where $mc_t^j(i)$ is the real marginal cost of firm i and type j. Rearranging,

$$mc_t^j(i) = \frac{\left(1-A_t^j(i)\right)^{\frac{\zeta-1}{\zeta}} w_t N_t^j(i)}{(1-\gamma_j)\,p_t^j\,(1-\alpha_j)\left(Y_t^j(i)+\Psi_j\right)}, \tag{E.20}$$

$$mc_t^j(i) = \frac{\left(1-A_t^j(i)\right)^{\frac{\zeta-1}{\zeta}} r_{K,t}^j K_{t-1}^j(i)}{(1-\gamma_j)\,\alpha_j p_t^j\left(Y_t^j(i)+\Psi_j\right)}, \tag{E.21}$$

$$1-\gamma_j = \left(1-A_t^j(i)\right)^{\frac{\zeta-1}{\zeta}}\left[1-\gamma_j\left(\frac{p_t^j mc_t^j(i)}{\tau\theta_t\mu_j}\right)^{\zeta-1}\right]. \tag{E.22}$$

Combining these expression, we get the real marginal cost of firm i of type j:

$$mc_t^j(i) = mc_t^j = \frac{1}{p_t^j}\left[(\gamma_j)^\zeta(\tau\theta_t\mu_j)^{1-\zeta} + (1-\gamma_j)^\zeta\left[\frac{1}{Z_t\mathcal{Z}}\left(\frac{w_t}{1-\alpha_j}\right)^{1-\alpha_j}\left(\frac{r_{K,t}^j}{\alpha_j}\right)^{\alpha_j}\right]^{1-\zeta}\right]^{\frac{1}{1-\zeta}}.$$

The Phillips curve for type-j firms is given by the following set of equations,

$$\mathcal{J}_t^j = \Lambda_t mc_t^j Y_t^j + \beta \vartheta_j (1-\delta_j) \mathbb{E}_t \frac{\Pi_{t+1}^j}{\Pi_{t+1}} \left(\frac{\Pi_{t+1}^j}{\left(\Pi_t^j\right)^{\iota_j} \Pi^{1-\iota_j}} \right)^{\epsilon_j} \mathcal{J}_{t+1}^j, \tag{E.23}$$

$$\mathcal{F}_t^j = \Lambda_t \tilde{p}_t^j Y_t^j + \beta \vartheta_j (1-\delta_j) \mathbb{E}_t \frac{\Pi_{t+1}^j}{\Pi_{t+1}} \left(\frac{\Pi_{t+1}^j}{\left(\Pi_t^j\right)^{\iota_j} \Pi^{1-\iota_j}} \right)^{\epsilon_j - 1} \mathcal{F}_{t+1}^j, \tag{E.24}$$

$$\mathcal{J}_t^j = \tilde{p}_t^j \frac{\epsilon_j - 1}{\epsilon_j} \mathcal{F}_t^j, \tag{E.25}$$

$$1 = \vartheta_j \left(\frac{\Pi_t^j}{\left(\Pi_{t-1}^j\right)^{\iota_j} \Pi^{1-\iota_j}} \right)^{\epsilon_j - 1} + (1-\vartheta_j) \left(\tilde{p}_t^j\right)^{1-\epsilon_j}. \tag{E.26}$$

E.5 Aggregate Pollution

Aggregate atmospheric carbon ($\mathcal{CO}_t$) evolves according to the following law of motion:

$$\mathcal{CO}_t = (1-\varpi)\, \mathcal{CO}_{t-1} + \xi_t + \xi^*. \tag{E.27}$$

where ϖ is the depreciation of atmospheric carbon, ξ^* denotes emissions from the rest of the world, which is unmodelled, ξ_t is aggregate emissions of all firms in the economy:

$$\xi_t = \sum_{j=\{B,G\}} \xi_t^j = \mathcal{Z} Z_t \sum_{j=\{B,G\}} \mu_j \left[\frac{\left(1-A_t^j\right)^{\frac{\zeta-1}{\zeta}} - (1-\gamma_j)}{\gamma_j} \right]^{\frac{\zeta}{\zeta-1}} \left(N_t^j\right)^{1-\alpha_j} \left(K_{t-1}^j\right)^{\alpha_j}. \tag{E.28}$$

E.6 Climate Policy

We assume climate policy is exogenous and can be summarized by the carbon price, θ_t. Although the policy regime that we have in mind is a quantity-based cap-and-trade scheme like the EU ETS, in line with our empirical analysis, shifts in climate policy are modelled as exogenous changes in the carbon price. In particular, we assume carbon prices follow the following AR(1) process:

$$\log\left(\frac{\theta_t}{\theta}\right) = \varrho_\theta \log\left(\frac{\theta_{t-1}}{\theta}\right) + \varepsilon_{\theta t}, \quad \varepsilon_{\theta t} \sim N\left(0, \varsigma_\theta\right), \tag{E.29}$$

where ϱ_θ and ς_θ denote the persistence and dispersion of the shock. Market clearing is detailed below.

E.7 Monetary and Fiscal Authority

The monetary authority sets policy according to the Taylor rule:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{r_r} \left[\left(\frac{\Pi_t}{\Pi}\right)^{r_\pi} \left(\frac{Y_t}{Y_t^f}\right)^{r_y}\right]^{1-r_r}, \tag{E.30}$$

where r_r denotes the interest rate inertia, r_π and r_y capture the degree to which monetary policy responds to inflation and the output gap. The variable Y_t^f is aggregate output in the absence of nominal rigidities.

We assume that pollution tax revenues are used to finance government expenditure ($\mathcal{G}$). The government runs a balanced budget:

$$\tau \theta_t \xi_t + \frac{T_t}{P_t} = \mathcal{G}. \tag{E.31}$$

If not specified otherwise, we assume that aggregate government expenditure is constant. This means that any policy surplus is rebated to households.

E.8 Model aggregation

Aggregate production. Equations (F.22) and (F.25) entail that real marginal costs and, therefore, abatement are the same across type-j firms. This in turn implies that:

$$\begin{aligned}
\int_0^1 \mathcal{Z} Z_t \left(1 - A_t^j(i)\right) \left(N_t^j(i)\right)^{1-\alpha_j} \left(K_{t-1}^j(i)\right)^{\alpha_j} di - \Psi_j &= \int_0^1 \left(\frac{P_t^j(i)}{P_t^j}\right)^{-\epsilon} Y_t^j di, \\
\mathcal{Z} Z_t \left(1 - A_t^j\right) \int_0^1 \left(N_t^j(i)\right)^{1-\alpha_j} \left(K_{t-1}^j(i)\right)^{\alpha_j} di - \Psi_j &= \int_0^1 \left(\frac{P_t^j(i)}{P_t^j}\right)^{-\epsilon} Y_t^j di, \\
\mathcal{Z} Z_t \left(1 - A_t^j\right) N_t^j \int_0^1 \left(\frac{K_{t-1}^j}{N_t^j}\right)^{\alpha_j} di - \Psi_B &= \int_0^1 \left(\frac{P_t^j(i)}{P_t^j}\right)^{-\epsilon} Y_t^j di, \\
\mathcal{Z} Z_t \left(1 - A_t^j\right) \left(N_t^j\right)^{1-\alpha_j} \left(K_{t-1}^j\right)^{\alpha_j} - \Psi_B &= \Delta_t^j Y_t^j.
\end{aligned}$$

Market clearing. Integrating over ω gives:

$$C_t + \sum_{j=\{B,G\}} \left\{\mathcal{I}_t^j + V_t^j\right\} = w_t N_t + \sum_{j=\{B,G\}} \left\{ r_{K,t}^j K_{t-1}^j + (1-\delta_j)\left(\frac{\Phi_t^j}{P_t} + V_t^j\right)\right\} - T_t.$$

Aggregate profits of brown firms are given by:

$$\begin{aligned} D_t^j = \frac{\Phi_t^j}{P_t} &= \frac{P_t^j}{P_t}\int_0^1 \frac{P_t^j(i)}{P_t^j} Y_t^j(i)\, di - w_t N_t^j - r_{K,t}^j K_{t-1}^j - \tau\theta_t \xi_t^j, \\ \frac{\Phi_t^j}{P_t} &= p_t^j Y_t^B - w_t N_t^j - r_{K,t}^j K_{t-1}^j - \tau\theta_t\xi_t^j. \end{aligned}$$

Substituting aggregate profits into the budget constraint yields:

$$\begin{aligned} C_t + I_t + \sum_{j=\{B,G\}} \left\{\mathcal{E}_t^j\right\} &= p_t^B Y_t^B + p_t^G Y_t^G - \tau\theta_t\xi_t - T_t, \\ C_t + I_t + \sum_{j=\{B,G\}} \left\{\mathcal{E}_t^j\right\} &= p_t^B Y_t^B + p_t^G Y_t^G - \tau\theta_t\xi_t - \mathcal{G} + \tau\theta_t\xi_t^B, \\ C_t + I_t + \mathcal{G} + \sum_{j=\{B,G\}} \left\{\mathcal{E}_t^j\right\} &= p_t^B Y_t^B + p_t^G Y_t^G. \end{aligned}$$

Here, $\mathcal{E}_t^j$ denotes aggregate replacement investment for firm type j. Goods market clearing requires:

$$Y_t^G = C_t^G + \mathcal{G}_t^G + I_t^G + \frac{\mathcal{E}_t^G}{p_t^G} \tag{E.32}$$

and

$$Y_t^B = C_t^B + \mathcal{G}_t^B + I_t^B + \frac{\mathcal{E}_t^B}{p_t^B}, \tag{E.33}$$

where p_t^B and p_t^G are the relative price of brown and green goods. Firm exit at rate δ_j is offset by a replacement outlay by brown and green firms is given by:

$$\mathcal{E}_t^j = \delta_j\left(D_t^j + V_t^j\right) \text{ for } j = \{G, B\}, \tag{E.34}$$

and aggregate output by:

$$Y_t = p_t^B Y_t^B + p_t^G Y_t^G. \tag{E.35}$$

Aggregate investment is defined in the same vein as aggregate output:

$$I_t = \mathcal{I}_t^B + \mathcal{I}_t^G. \tag{E.36}$$

Finally, price inflation is:

$$\Pi_t^j = \frac{p_t^j}{p_{t-1}^j} \Pi_t \text{ for } j = \{G, B\}, \tag{E.37}$$

and wage inflation:

$$\frac{\Pi_{w,t}}{\Pi_t} = \frac{w_t}{w_{t-1}}. \tag{E.38}$$

Labor market clearing is such that:

$$N_t = \Delta_{w,t} \left(N_t^B + N_t^G \right), \tag{E.39}$$

where $\Delta_{w,t}$ denotes the wage dispersion, which evolves according to:

$$\Delta_{w,t}^{1+\varphi} = (1 - \vartheta_w) \left(\tilde{w}_t \right)^{-\epsilon_w (1+\varphi)} + \vartheta_w \left(\frac{\Pi_{t-1}^{\iota_w} \Pi^{1-\iota_w}}{\Pi_t} \frac{w_{t-1}}{w_t} \right)^{-\epsilon_w (1+\varphi)} \Delta_{w,t-1}^{1+\varphi}. \tag{E.40}$$

The price dispersion for firms of type j evolves as follows:

$$\Delta_t^j = [1 - \vartheta_j (1 - \delta_j)] \left(\tilde{p}_t^j \right)^{-\epsilon_j} + \vartheta_j (1 - \delta_j) \left(\frac{\Pi_t^j}{\left(\Pi_{t-1}^j \right)^{\iota_j} \Pi^{1-\iota_j}} \right)^{\epsilon_j} \Delta_{t-1}^j \quad \text{for} \quad j = \{B, G\}. \tag{E.41}$$

F Dynamic equations

The system of equations is given by:

$$\Lambda_t = \left(C_t - \phi C_{t-1} \right)^{-\sigma}, \tag{F.1}$$

$$\Lambda_t = \beta \mathbb{E}_t \left\{ \frac{R_t}{\Pi_{t+1}} \Lambda_{t+1} \right\}, \tag{F.2}$$

$$\begin{aligned} Q_t^B = \beta \mathbb{E}_t \Bigg\{ \frac{\Lambda_{t+1}}{\Lambda_t} \Bigg[& r^B_{K,t+1} + \left(1-\delta_K\right) Q^B_{t+1} - Q^B_{t+1} \upsilon_1^B \left(\frac{\mathcal{I}^B_{t+1}}{K^B_t} \right)^{1-\psi_B} + \\ & + Q^B_{t+1} \left[\frac{\upsilon_1^B}{1-\psi^B} \left(\frac{\mathcal{I}^B_{t+1}}{K^B_t} \right)^{1-\psi_B} + \upsilon_2^B \right] \Bigg] \Bigg\}, \end{aligned} \tag{F.3}$$

$$\begin{aligned} Q_t^G = \beta \mathbb{E}_t \Bigg\{ \frac{\Lambda_{t+1}}{\Lambda_t} \Bigg[& r^G_{K,t+1} + \left(1-\delta_K\right) Q^G_{t+1} - Q^G_{t+1} \upsilon_1^G \left(\frac{\mathcal{I}^G_{t+1}}{K^G_t} \right)^{1-\psi_G} + \\ & + Q^G_{t+1} \left[\frac{\upsilon_1^G}{1-\psi^G} \left(\frac{\mathcal{I}^G_{t+1}}{K^G_t} \right)^{1-\psi_G} + \upsilon_2^G \right] \Bigg] \Bigg\}, \end{aligned} \tag{F.4}$$

$$1 = Q_t^B \upsilon_1^B \left(\frac{\mathcal{I}^B_t}{K^B_{t-1}} \right)^{-\psi^B}, \tag{F.5}$$

$$1 = Q_t^G \upsilon_1^G \left(\frac{\mathcal{I}^G_t}{K^G_{t-1}} \right)^{-\psi^G}, \tag{F.6}$$

$$V_t^B = \beta(1-\delta_B) \mathbb{E}_t \frac{\Lambda_{t+1}}{\Lambda_t} \left\{ D^B_{t+1} + V^B_{t+1} \right\}, \tag{F.7}$$

$$V_t^G = \beta(1-\delta_G) \mathbb{E}_t \frac{\Lambda_{t+1}}{\Lambda_t} \left\{ D^G_{t+1} + V^G_{t+1} \right\}, \tag{F.8}$$

$$K_t^B = \left(1-\delta_K\right) K^B_{t-1} + \left[\frac{\upsilon_1^B}{1-\psi^B} \left(\frac{\mathcal{I}^B_t}{K^B_{t-1}} \right)^{1-\psi^B} + \upsilon_2^B \right] K^B_{t-1}, \tag{F.9}$$

$$K_t^G = \left(1-\delta_K\right) K^G_{t-1} + \left[\frac{\upsilon_1^G}{1-\psi^G} \left(\frac{\mathcal{I}^G_t}{K^G_{t-1}} \right)^{1-\psi^G} + \upsilon_2^G \right] K^G_{t-1}, \tag{F.10}$$

$$\mathcal{F}_t^w = \epsilon_w \chi \left(\tilde{w}_t\right)^{-\epsilon_w(1+\varphi)} \left(\frac{N_t}{\Delta_{w,t}} \right)^{1+\varphi} + \beta \vartheta_w \mathbb{E}_t \left(\frac{\Pi_t^{\iota_w} \Pi^{1-\iota_w}}{\Pi_{t+1}} \right)^{-\epsilon_w(1+\varphi)} \left(\frac{\tilde{w}_{t+1}}{\tilde{w}_t} \right)^{\epsilon_w(1+\varphi)} \mathcal{F}^w_{t+1}, \tag{F.11}$$

$$\mathcal{J}_t^w = \left(\epsilon_w - 1\right) \Lambda_t \left(\tilde{w}_t\right)^{1-\epsilon_w} w_t \frac{N_t}{\Delta_{w,t}} + \beta \vartheta_w \mathbb{E}_t \left(\frac{\Pi_t^{\iota_w} \Pi^{1-\iota_w}}{\Pi_{t+1}} \right)^{1-\epsilon_w} \left(\frac{\tilde{w}_{t+1}}{\tilde{w}_t} \right)^{\epsilon_w - 1} \mathcal{J}^w_{t+1}, \tag{F.12}$$

$$\mathcal{J}_t^w = \mathcal{F}_t^w, \tag{F.13}$$

$$1 = \vartheta_w \left(\frac{\Pi_{t-1}^{\iota_w} \Pi^{1-\iota_w}}{\Pi_t} \frac{w_{t-1}}{w_t} \right)^{1-\epsilon_w} + \left(1-\vartheta_w\right) \left(\tilde{w}_t\right)^{1-\epsilon_w}, \tag{F.14}$$

$$\Delta_{w,t}^{1+\varphi} = \left(1-\vartheta_w\right) \left(\tilde{w}_t\right)^{-\epsilon_w(1+\varphi)} + \vartheta_w \left(\frac{\Pi_{t-1}^{\iota_w} \Pi^{1-\iota_w}}{\Pi_t} \frac{w_{t-1}}{w_t} \right)^{-\epsilon_w(1+\varphi)} \Delta^{1+\varphi}_{w,t-1}. \tag{F.15}$$

$$\frac{\Pi_{w,t}}{\Pi_t} = \frac{w_t}{w_{t-1}}, \tag{F.16}$$

$$1 = \left\{\nu \left(p_t^B\right)^{1-\eta} + (1-\nu)\left(p_t^G\right)^{1-\eta}\right\}^{\frac{1}{1-\eta}}, \tag{F.17}$$

$$\Delta_t^B Y_t^B = \mathcal{Z} Z_t \left(1 - A_t^B\right)\left(N_t^B\right)^{1-\alpha_B}\left(K_{t-1}^B\right)^{\alpha_B} - \Psi_B, \tag{F.18}$$

$$\Delta_t^G Y_t^G = \mathcal{Z} Z_t \left(N_t^G\right)^{1-\alpha_G}\left(K_{t-1}^G\right)^{\alpha_G} - \Psi_G, \tag{F.19}$$

$$mc_t^B = \frac{\left(1 - A_t^B\right)^{\frac{\zeta-1}{\zeta}} w_t N_t^B}{(1-\gamma_B)(1-\alpha_B)\, p_t^B (Y_t^B + \Psi_B)/\Delta_t^B}, \tag{F.20}$$

$$mc_t^B = \frac{\left(1 - A_t^B\right)^{\frac{\zeta-1}{\zeta}} r_{K,t}^j K_{t-1}^B}{(1-\gamma_B)\,\alpha_B p_t^B (Y_t^B + \Psi_B)/\Delta_t^B}, \tag{F.21}$$

$$1 - \gamma_B = \left(1 - A_t^B\right)^{\frac{\zeta-1}{\zeta}}\left[1 - \gamma_B\left(\frac{p_t^B mc_t^B}{\tau\theta_t\mu_B}\right)^{\zeta-1}\right], \tag{F.22}$$

$$mc_t^G = \frac{\left(1 - A_t^G\right)^{\frac{\zeta-1}{\zeta}} w_t N_t^G}{(1-\gamma_G)(1-\alpha_G)\, p_t^G (Y_t^G + \Psi_G)/\Delta_t^G}, \tag{F.23}$$

$$mc_t^G = \frac{\left(1 - A_t^G\right)^{\frac{\zeta-1}{\zeta}} r_{K,t}^j K_{t-1}^G}{(1-\gamma_G)\,\alpha_G p_t^G (Y_t^G + \Psi_G)/\Delta_t^G}, \tag{F.24}$$

$$1 - \gamma_G = \left(1 - A_t^G\right)^{\frac{\zeta-1}{\zeta}}\left[1 - \gamma_G\left(\frac{p_t^G mc_t^G}{\tau\theta_t\mu_G}\right)^{\zeta-1}\right], \tag{F.25}$$

$$\xi_t = \sum_{j=\{B,G\}} \mu_j \mathcal{Z} Z_t \left[\frac{\left(1 - A_t^j\right)^{\frac{\zeta-1}{\zeta}} - (1-\gamma_j)}{\gamma_j}\right]^{\frac{\zeta}{\zeta-1}} \left(N_t^j\right)^{1-\alpha_B}\left(K_{t-1}^j\right)^{\alpha_j}, \tag{F.26}$$

$$\mathcal{CO}_t = (1-\varpi)\,\mathcal{CO}_{t-1} + \xi_t + \xi^*, \tag{F.27}$$

$$Z_t = \left[1 - d_3\left(d_0 + d_1\mathcal{CO}_t + d_2\mathcal{CO}_t^2\right)\right], \tag{F.28}$$

$$\mathcal{J}_t^B = \Lambda_t mc_t^B Y_t^B + \beta\vartheta_B(1-\delta_B)\mathbb{E}_t\left(\frac{\Pi_{t+1}^B}{\left(\Pi_t^B\right)^{\iota_B}\Pi^{1-\iota_B}}\right)^{\epsilon_B}\mathcal{J}_{t+1}^B, \tag{F.29}$$

$$\mathcal{F}_t^B = \Lambda_t \tilde{p}_t^B Y_t^B + \beta\vartheta_B(1-\delta_B)\mathbb{E}_t\left(\frac{\Pi_{t+1}^B}{\left(\Pi_t^B\right)^{\iota_B}\Pi^{1-\iota_B}}\right)^{\epsilon_B-1}\frac{\tilde{p}_t^B}{\tilde{p}_{t+1}^B}\mathcal{F}_{t+1}^B, \tag{F.30}$$

$$\mathcal{J}_t^B = \frac{\epsilon_B - 1}{\epsilon_B}\mathcal{F}_t^B, \tag{F.31}$$

$$1 = \vartheta_B(1-\delta_B)\left(\frac{\Pi_t^B}{\left(\Pi_{t-1}^B\right)^{\iota_B}\Pi^{1-\iota_B}}\right)^{\epsilon_B-1} + \left[1-\vartheta_B(1-\delta_B)\right]\left(\tilde{p}_t^B\right)^{1-\epsilon_B}, \tag{F.32}$$

$$\Delta_t^B = \left[1-\vartheta_B(1-\delta_B)\right]\left(\tilde{p}_t^B\right)^{-\epsilon_B} + \left[\vartheta_B(1-\delta_B)\right]\left(\frac{\Pi_t^B}{\left(\Pi_{t-1}^B\right)^{\iota_B}\Pi^{1-\iota_B}}\right)^{\epsilon_B}\Delta_{t-1}^B, \tag{F.33}$$

$$\Pi_t^B = \frac{p_t^B}{p_{t-1}^B}\Pi_t, \tag{F.34}$$

$$\mathcal{J}_t^G = \Lambda_t mc_t^G Y_t^G + \beta\vartheta_G(1-\delta_G)\mathbb{E}_t\left(\frac{\Pi_{t+1}^G}{\left(\Pi_t^G\right)^{\iota_G}\Pi^{1-\iota_G}}\right)^{\epsilon_G}\mathcal{J}_{t+1}^G, \tag{F.35}$$

$$\mathcal{F}_t^G = \Lambda_t\tilde{p}_t^G Y_t^G + \beta\vartheta_G(1-\delta_G)\mathbb{E}_t\left(\frac{\Pi_{t+1}^G}{\left(\Pi_t^G\right)^{\iota_G}\Pi^{1-\iota_G}}\right)^{\epsilon_G-1}\frac{\tilde{p}_t^G}{\tilde{p}_{t+1}^G}\mathcal{F}_{t+1}^G, \tag{F.36}$$

$$\mathcal{J}_t^G = \frac{\epsilon_G-1}{\epsilon_G}\mathcal{F}_t^G, \tag{F.37}$$

$$1 = \vartheta_G(1-\delta_G)\left(\frac{\Pi_t^G}{\left(\Pi_{t-1}^G\right)^{\iota_G}\Pi^{1-\iota_G}}\right)^{\epsilon_G-1} + \left[1-\vartheta_G(1-\delta_G)\right]\left(\tilde{p}_t^G\right)^{1-\epsilon_G}, \tag{F.38}$$

$$\Delta_t^G = \left[1-\vartheta_G(1-\delta_G)\right]\left(\tilde{p}_t^G\right)^{-\epsilon_G} + \vartheta_G(1-\delta_G)\left(\frac{\Pi_t^G}{\left(\Pi_{t-1}^G\right)^{\iota_G}\Pi^{1-\iota_G}}\right)^{\epsilon_G}\Delta_{t-1}^G, \tag{F.39}$$

$$\Pi_t^G = \frac{p_t^G}{p_{t-1}^G}\Pi_t, \tag{F.40}$$

$$N_t = \Delta_{w,t}\left(N_t^B + N_t^G\right), \tag{F.41}$$

$$I_t = \mathcal{I}_t^B + \mathcal{I}_t^G, \tag{F.42}$$

$$Y_t^G = (1-\nu)\left(p_t^G\right)^{-\eta}\left(C_t + \mathcal{G}_t + I_t\right) + \delta_G(D_t^G + V_t^G)/p_t^G, \tag{F.43}$$

$$Y_t^B = \nu\left(p_t^B\right)^{-\eta}\left(C_t + \mathcal{G}_t + I_t\right) + \delta_B(D_t^B + V_t^B)/p_t^B, \tag{F.44}$$

$$D_t^B = p_t^B Y_t^B - p_t^B mc_t^B(Y_t^B + \Psi_B), \tag{F.45}$$

$$D_t^G = p_t^G Y_t^G - p_t^G mc_t^G(Y_t^G + \Psi_G), \tag{F.46}$$

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{r_r}\left[\left(\frac{\Pi_t}{\Pi}\right)^{r_\pi}\left(\frac{Y_t}{Y}\right)^{r_y}\right]^{1-r_r}\exp\left(\varepsilon_{rt}\right), \tag{F.47}$$

$$Y_t = p_t^B Y_t^B + p_t^G Y_t^G, \tag{F.48}$$

$$\log\left(\frac{\theta_t}{\theta}\right) = \varrho_\xi\log\left(\frac{\theta_{t-1}}{\theta}\right) + \varepsilon_{\xi t}, \quad \varepsilon_{\theta t}\sim N\left(0,\varsigma_\theta\right), \tag{F.49}$$

This system of equations solves for the following variables, Λ_t, C_t, $\mathcal{I}_t^B$, $\mathcal{I}_t^G$, I_t, Y_t^B, Y_t^G ,Y_t, Π_t, R_t, Q_t^B, Q_t^G, p_t^B, p_t^G, $\mathcal{J}_t^B$, $\mathcal{J}_t^G$, $\mathcal{J}_t^w$, $\mathcal{F}_t^B$, $\mathcal{F}_t^G$, $\mathcal{F}_t^w$, Δ_t^B, Δ_t^G, Δ_t^w, mc_t^B, mc_t^G, $\tilde{w}_t$, $\tilde{p}_t^B$, $\tilde{p}_t^G$, Π_t^B, Π_t^G,, Π_t^w, ξ_t, Z_t, $\mathcal{CO}_t$, A_t^B, A_t^G, N_t^B, N_t^G, N_t, K_t^B, K_t^G, w_t, ξ_t, $r_{K,t}^B$, $r_{K,t}^G$, V_t^B, V_t^G, D_t^B, D_t^G and the shock process θ_t. Note in addition that there is a block including flexible price variables.

F.1 Steady State

The steady state is given by the following equations,

$$\Lambda = [(1-\phi)\,C]^{-\sigma}\,, \tag{F.50}$$

$$R = \frac{1}{\beta}, \tag{F.51}$$

$$r_K^B = \frac{1}{\beta} - (1-\delta_K)\,, \tag{F.52}$$

$$r_K^G = \frac{1}{\beta} - (1-\delta_K)\,, \tag{F.53}$$

$$\mathcal{G} = \frac{\mathcal{G}}{Y} Y, \tag{F.54}$$

$$Q^B = 1, \tag{F.55}$$

$$Q^G = 1, \tag{F.56}$$

$$\mathcal{I}^B = \delta_K K^B, \tag{F.57}$$

$$\mathcal{I}^G = \delta_K K^G, \tag{F.58}$$

$$\tilde{w} = 1 \tag{F.59}$$

$$\tilde{p}^B = 1 \tag{F.60}$$

$$\tilde{p}^G = 1 \tag{F.61}$$

$$\Delta^w = 1, \tag{F.62}$$

$$\Delta^B = 1, \tag{F.63}$$

$$\Delta^G = 1, \tag{F.64}$$

$$\Pi^{w} = \Pi, \tag{F.65}$$

$$\Pi^{B} = \Pi, \tag{F.66}$$

$$\Pi^{G} = \Pi, \tag{F.67}$$

$$mc^{B} = \frac{\epsilon_B - 1}{\epsilon_B}, \tag{F.68}$$

$$mc^{G} = \frac{\epsilon_G - 1}{\epsilon_G}, \tag{F.69}$$

$$1 = \left\{\nu \left(p^{B}\right)^{1-\eta} + (1-\nu)\left(p^{G}\right)^{1-\eta}\right\}^{\frac{1}{1-\eta}}, \tag{F.70}$$

$$Y^{B} = \mathcal{Z} Z \left(1 - A^{B}\right)\left(N^{B}\right)^{1-\alpha_B}\left(K^{B}\right)^{\alpha_B} - \Psi_B, \tag{F.71}$$

$$Y^{G} = \mathcal{Z} Z \left(N^{G}\right)^{1-\alpha_G}\left(K^{G}\right)^{\alpha_G} - \Psi_G, \tag{F.72}$$

$$mc^{B} = \frac{\left(1 - A^{B}\right)^{\frac{\zeta-1}{\zeta}} wN^{B}}{\left(1-\gamma_B\right)\left(1-\alpha_B\right) p^{B}(Y^{B} + \Psi_B)}, \tag{F.73}$$

$$mc^{B} = \frac{\left(1 - A^{B}\right)^{\frac{\zeta-1}{\zeta}} r_K^{B} K^{B}}{\left(1-\gamma_B\right)\alpha_B p^{B}(Y^{B} + \Psi_B)}, \tag{F.74}$$

$$1 - \gamma_B = \left(1 - A^{B}\right)^{\frac{\zeta-1}{\zeta}}\left[1 - \gamma_B\left(\frac{p^{B} mc^{B}}{\tau \mu_B \theta}\right)^{\zeta-1}\right], \tag{F.75}$$

$$mc^{G} = \frac{\left(1 - A^{G}\right)^{\frac{\zeta-1}{\zeta}} wN^{G}}{\left(1-\gamma_G\right)\left(1-\alpha_G\right) p^{G}(Y^{G} + \Psi_G)}, \tag{F.76}$$

$$mc^{G} = \frac{\left(1 - A^{G}\right)^{\frac{\zeta-1}{\zeta}} r_K^{G} K^{G}}{\left(1-\gamma_G\right)\alpha_G p^{G}(Y^{G} + \Psi_G)}, \tag{F.77}$$

$$1 - \gamma_G = \left(1 - A^{G}\right)^{\frac{\zeta-1}{\zeta}}\left[1 - \gamma_G\left(\frac{p^{G} mc^{G}}{\tau \mu_G \theta}\right)^{\zeta-1}\right], \tag{F.78}$$

$$\xi = \sum_{j=\{B,G\}} \mu_j \mathcal{Z} Z \left[\frac{(1 - A^{j})^{\frac{\zeta-1}{\zeta}} - (1-\gamma_j)}{\gamma_j}\right]^{\frac{\zeta}{\zeta-1}} \left(N^{j}\right)^{1-\alpha_j}\left(K^{j}\right)^{\alpha_j}, \tag{F.79}$$

$$\mathcal{CO} = \frac{\xi + \xi^{*}}{(1-\varpi)}, \tag{F.80}$$

$$Z_t = \left[1 - d_3\left(d_0 + d_1 \frac{\xi + \xi^{*}}{(1-\varpi)} + d_2\left(\frac{\xi + \xi^{*}}{(1-\varpi)}\right)^{2}\right)\right], \tag{F.81}$$

$$\mathcal{J}^w = \mathcal{F}^w, \tag{F.82}$$

$$\mathcal{F}^w = \frac{\epsilon_w \chi \left(N\right)^{1+\varphi}}{1-\beta\vartheta_w}, \tag{F.83}$$

$$\mathcal{J}^w = \frac{\left(\epsilon_w - 1\right) \Lambda w N}{1-\beta\vartheta_w}, \tag{F.84}$$

$$\mathcal{J}^G = \frac{\Lambda mc^G Y^G}{1-\beta\vartheta_G(1-\delta_G)}, \tag{F.85}$$

$$\mathcal{F}^G = \frac{\Lambda Y^G}{1-\beta\vartheta_G(1-\delta_G)}, \tag{F.86}$$

$$\mathcal{J}^G = \frac{\epsilon_G - 1}{\epsilon_G}\mathcal{F}^G, \tag{F.87}$$

$$\mathcal{J}_t^B = \frac{\Lambda mc^B Y^B}{1-\beta\vartheta_B(1-\delta_B)}, \tag{F.88}$$

$$\mathcal{F}_t^B = \frac{\Lambda Y^B}{1-\beta\vartheta_B(1-\delta_B)}, \tag{F.89}$$

$$\mathcal{J}^B = \frac{\epsilon_B - 1}{\epsilon_B}\mathcal{F}^B, \tag{F.90}$$

$$N = N^B + N^G, \tag{F.91}$$

$$I = \delta K^B + \delta K^G, \tag{F.92}$$

$$Y^B = \frac{\nu \left(p^B\right)^{-\eta}\left(C + \mathcal{G} + I\right) - \delta_G \frac{\epsilon_G - 1}{\epsilon_G[1-\beta(1-\delta_G)]}\Psi_G}{1 - \frac{\delta_G}{\epsilon_G[1-\beta(1-\delta_G)]}}, \tag{F.93}$$

$$Y^G = \frac{(1-\nu)\left(p^G\right)^{-\eta}\left(C + \mathcal{G} + I\right) - \delta_B \frac{\epsilon_B - 1}{\epsilon_B[1-\beta(1-\delta_B)]}\Psi_B}{1 - \frac{\delta_B}{\epsilon_B[1-\beta(1-\delta_B)]}}, \tag{F.94}$$

$$Y = p^B Y^B + p^G Y^G, \tag{F.95}$$

$$Y^B(1-d^B) = mc^B(Y^B + \Psi_B), \tag{F.96}$$

$$Y^G(1-d^G) = mc^G(Y^G + \Psi_g). \tag{F.97}$$

F.2 Calibration

This section summarizes the calibration strategy, with particular emphasis on the parameters that discipline emissions intensity, profit dynamics, and the heterogeneous responses to carbon pricing observed in the data. The full set of calibrated parameters is reported in Table F.1.

For the non-climate-related components of the model, the calibration follows standard medium-scale DSGE models at quarterly frequency (Smets and Wouters, 2007). Aside from the emissions intensity parameters (γ_j), brown and green firms are assumed to be symmetric, including with respect to nominal and real rigidities. In contrast to Ferrari and Pagliari (2021), we assume free labor mobility across firm types.

Parameters governing household behavior and asset price dynamics are chosen in line with the literature. The habit formation parameter is set to 0.75, and capital adjustment costs are assumed to be equal across sectors ($\psi_j = 0.7$), following Jermann (1998). To prevent monopolistic competition from generating unrealistically large profits, we introduce fixed production costs that absorb most markup rents, as in Christiano et al. (2005). We calibrate steady-state profits to represent 2% of GDP, ensuring that profits remain small but strictly positive so that asset prices are well defined. This calibration keeps the contribution of pure profits to aggregate income negligible while allowing for meaningful asset price fluctuations, particularly following carbon pricing shocks. We therefore set the profit-output ratio to d^B=d^G=0.02. Following Bilbiie et al. (2012), the probability of firm exit is set to $\delta_j = 0.025$.

Turning to the climate block, the depreciation rate of atmospheric carbon (ϖ) is set to 0.0021, and the parameters of the damage function follow Heutel (2012). In line with Annicchiarico and Di Dio (2015), steady-state atmospheric carbon ($\mathcal{CO}$) is calibrated to correspond to a carbon mass of approximately 800 gigatons in 2005. The steady-state level of abatement for brown firms is set to 0.1. Conditional on ϖ, the steady-state level of atmospheric carbon pins down steady-state emissions. Foreign emissions are set to $\xi^* = 0.9$ of global emissions, consistent with the EU accounting for roughly 10% of worldwide emissions.

The calibration of firms' technologies and household preferences targets observed emissions intensity in the data. Specifically, the model is calibrated so that steady-state emissions intensity, $\bar{\xi}/\bar{Y}$, matches the average emissions intensity of the countries in our empirical sample, equal to 0.22 kg of CO_2 per constant 2015 \$ of GDP. Two parameters play a central role in achieving this target. First, the steady-state expenditure share of brown goods is set to $\nu = 0.7$. Second, emissions intensity differs across firm types: the emissions intensity of brown firms' production is set to $\gamma_B = 0.4$, while that of green firms is set to $\gamma_G = 0.04$. Given these technological differences, steady-state abatement by green firms is proportionally smaller. Aggregate productivity is set to 0.68 to jointly match emissions intensity and output levels. Parameter combinations that imply implausible CO_2 intensities are discarded.

For the remaining climate-related parameters, we follow the literature. The elasticity of substitution between brown and green goods in consumption is set to 1.5 (Ferrari and Pagliari, 2021). The elasticity of substitution between emissions and other inputs, ζ, is set to 0.15, consistent with values used in Integrated Assessment Models (Luderer et al., 2020). The steady-state carbon tax is set to 0.15. The emissions scale parameters (μ_B, μ_G) and the steady-state level of carbon prices, θ, are model-dependent and chosen to be consistent with the targeted steady state.

Finally, the persistence and volatility of the carbon pricing shock are chosen to match the dynamic response of aggregate output in the model. Specifically, we set $\varrho_\theta = 0.95$ and $\varsigma_\theta = 0.006$ to replicate the trough in output observed six quarters after a carbon pricing shock.

Table F.1 MODEL CALIBRATION

Parameter	**Description**	**Value**
β	Subjective discount factor	0.99
σ	Inverse of inter-temporal elast. of subst.	2
ϕ	Degree of consumption habits	0.75
φ	Inverse of Frisch elast.	1
χ	Disutility of labor (implied)	16.94
δ_K	Capital depreciation	0.025
α_j	Capital share in j	0.33
ψ_j	Capital adj. cost in j	0.7
υ_1^j	Capital adj. cost in j (implied)	0.08
υ_2^j	Capital adj. cost in j (implied)	-0.06
$\frac{g}{y}$	Government to output ratio	0.2
ϵ_j	Elast. of subs. between goods	11
ϵ_w	Elast. of subs. between labor	11
Ψ_B	Fixed costs in B (implied)	0.02
Ψ_G	Fixed costs in G (implied)	0.05
δ_j	Death probability in j	0.025
ϑ_j	Calvo price in j	0.77
ϑ_w	Calvo wage	0.85
ι_j	Price indexation	0.25
ι_w	Wage indexation	0.25
$\mathcal{Z}$	Productivity parameter	0.67
r_r	Taylor rule inertia	0.75
r_π	Taylor rule parameter	1.5
r_y	Taylor rule parameter	0.25
η	Elast. of subs. between B and G	1.5
ν	Brown weight (preference parameter)	0.7
γ_B	Emission intensity in B	0.4
γ_G	Emission intensity in G	0.04
τ	Carbon tax rate	0.15
A^B	Steady state abatement in B	0.1
A^G	Steady state abatement in G	0.01
ζ	Elast. of subs. between emissions and value added	0.15
μ_B	Emission's scale parameter (implied)	0.53
μ_G	Emission's scale parameter (implied)	0.03
θ	Carbon price (implied)	12.58
$\frac{\bar{\xi}}{\bar{Y}}$	Carbon intensity (implied)	0.22
ϖ	Depreciation of atmospheric carbon	0.0021
d_0	Constant in damage function	$1.3950e-3$
d_1	1st order coeff. in damage function	$-6.6722e-6$
d_2	2nd order coeff. in damage function	$1.4647e-8$
d_3	Damage function shifter	1
ρ_θ	Persistence of the shock	0.95
ς_θ	Dispersion of the shock	0.006

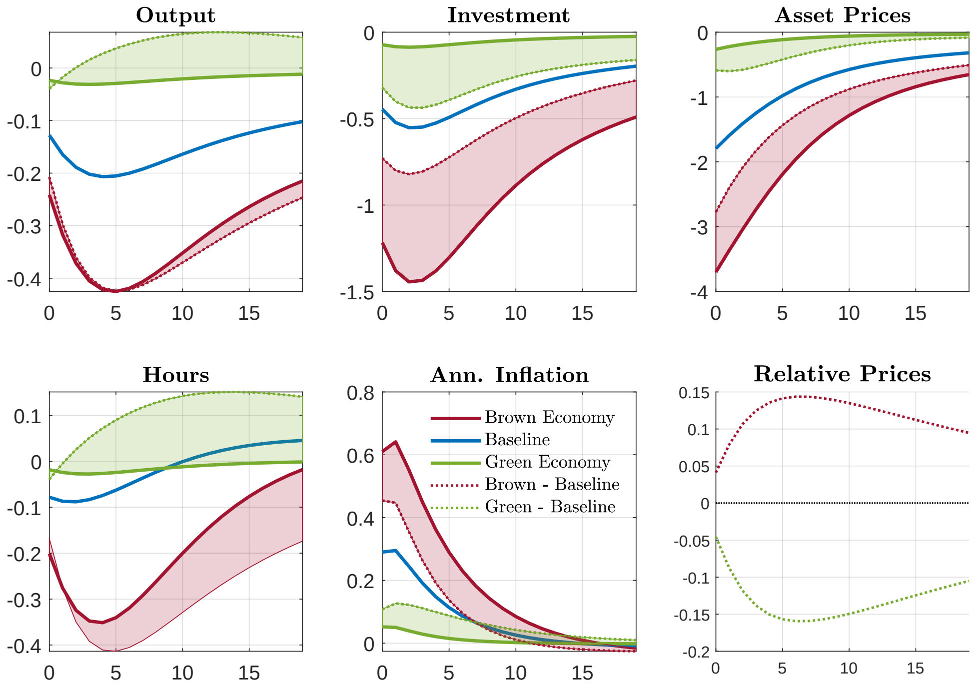
G Additional Model Figures

Figure G.1 plots the responses of the baseline economy in which brown and green firms co-exist (as discussed in Section 5.2) alongside the responses of the fully brown and fully green economies (as discussed in Section 5.4). The output response of brown firms in the baseline economy is broadly in line with that of the economy populated only by brown firms, while the output response of green firms in the baseline is above that of firms in the green economy (first period notwithstanding). In the baseline, therefore, the attenuation of output comes from the ability to shift expenditure towards the relatively cheaper green goods in general equilibrium, and the adjustment in relative prices that delivers this.

For investment and asset prices, the picture is more nuanced. Although there is overall general-equilibrium attenuation in investment in the baseline economy, in the brown economy, the fall in investment is much greater than the fall in brown firms' investment in the baseline economy; at the same time, the fall in investment in the green economy is smaller than that in green firms' investment in the baseline economy. The qualitative comparison is similar for asset prices. The large relative price adjustment in the baseline economy, and the absence of a relative price adjustment in the green (and, hence, poor man) economy is behind these differences. As noted in Section 5.2, the drop in the relative price of green goods acts to reduce green profitability in the baseline economy, reducing asset prices and investment. While investment and asset prices decline in the green economy, the absence of this relative price effect means that their falls are smaller than those experienced by green firms in the baseline.

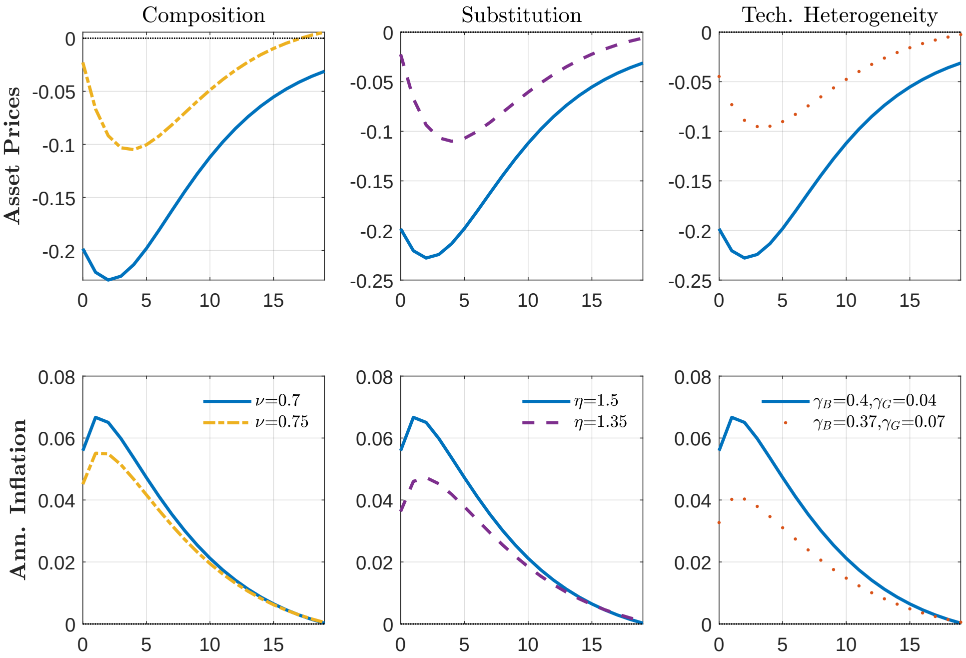
The first row of Figure G.2 shows the degree of asset price attenuation in the baseline and under an alternative parameter configuration, whilst adjusting the level of technology to target the steady state calibration of the CO_2 emissions intensity. The second row instead shows the degree of amplification of inflation under the baseline vis-à-vis alternative calibrations.

Figure G.1 Further Understanding Attenuation



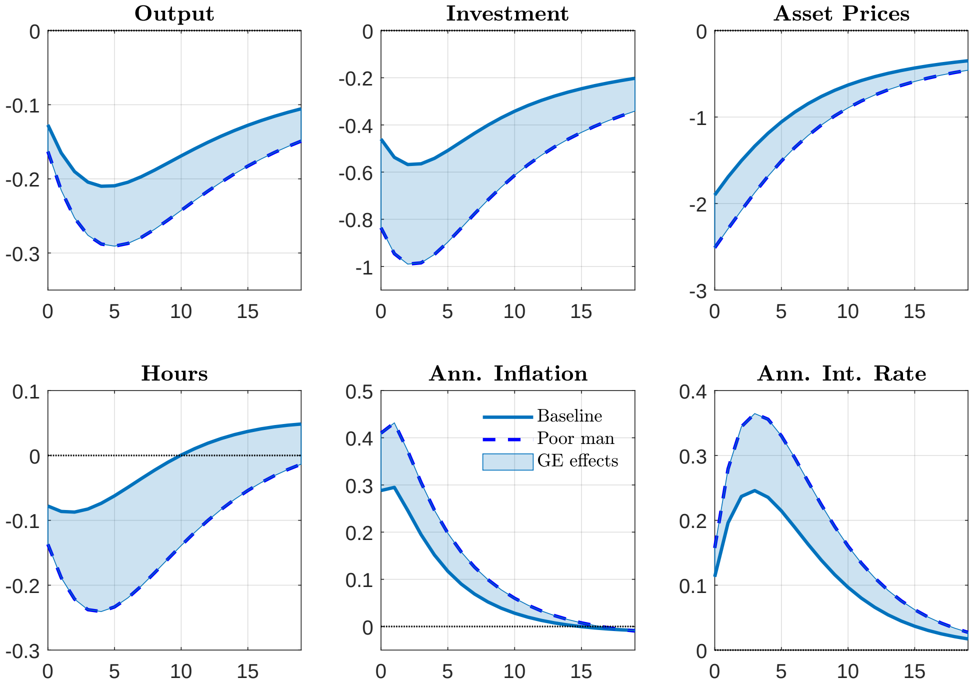
Note. Impulse responses of selected model variables to a carbon pricing shock. Solid blue: baseline aggregate variables; dotted green: green firms; brown dotted: brown firms. Green and brown solid lines correspond to the fully green ($\nu = 0$) and fully brown ($\nu = 1$) hypothetical economies. Shaded areas show differences between baseline and hypothetical economies across activities. Responses are expressed as percentage deviations from steady-state values.

Figure G.2 Drivers of Attenuation - Asset Prices& Inflation



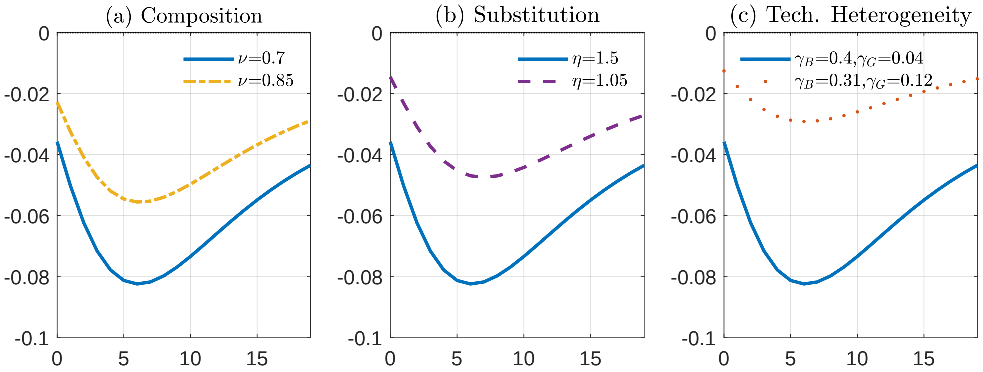
Note. The figure illustrates the degree of attenuation of asset prices and inflation resulting from alternative model parameterizations. Attenuation is defined as the difference between the responses in the poor-man economy and those in the full model. Carbon intensity is held constant at 0.22 by adjusting aggregate productivity. The solid blue line shows attenuation in the baseline calibration. Yellow dash-dotted lines correspond to a higher weight of brown goods ($\nu = 0.75$). Purple dashed lines show attenuation when the elasticity of substitution between brown and green goods is reduced ($\eta = 1.35$). Red dotted lines illustrate the effect of reduced technological heterogeneity between brown and green firms ($\gamma_B = 0.37$, $\gamma_G = 0.07$). Responses are expressed in percentage points.

Figure G.3 AGGREGATION AND ATTENUATION - ν AS WEIGHT



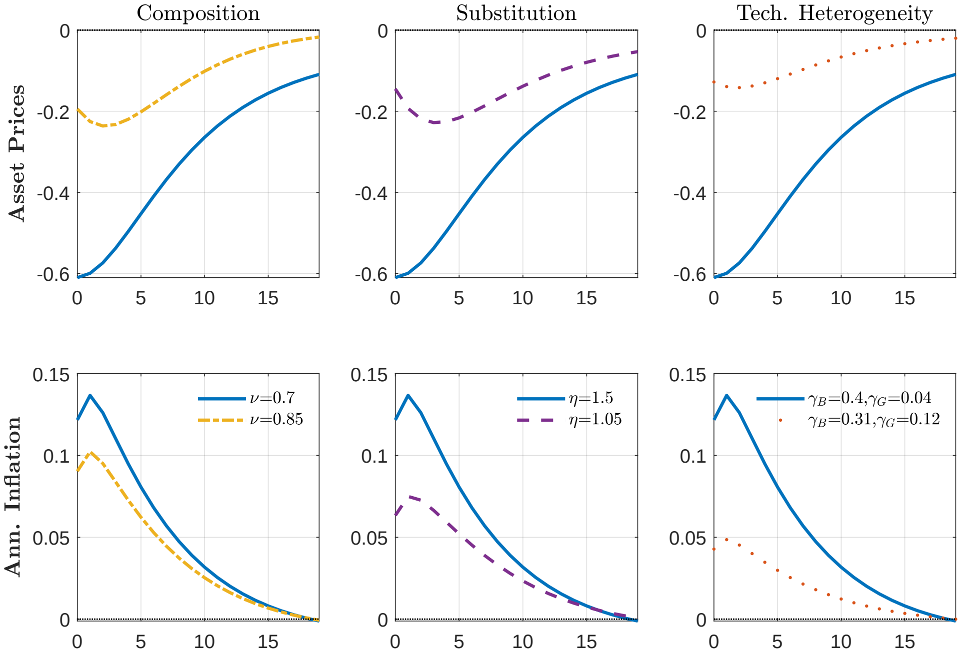
NOTE. The figure shows impulse responses to a carbon pricing shock. Solid light blue lines denote responses in the baseline model. The dark blue dashed line represents a “poor-man’s” economy, constructed as a weighted average—using the baseline model’s brown weight—of two polar cases: an economy populated entirely by green firms ($\nu = 0$) and one populated entirely by brown firms ($\nu = 1$). The shaded area illustrates attenuation arising from general-equilibrium forces that are present in the baseline but absent in the partial-equilibrium benchmark. Responses are expressed as percentage deviations from steady-state values.

Figure G.4 Drivers of Output Attenuation (ν as weight)



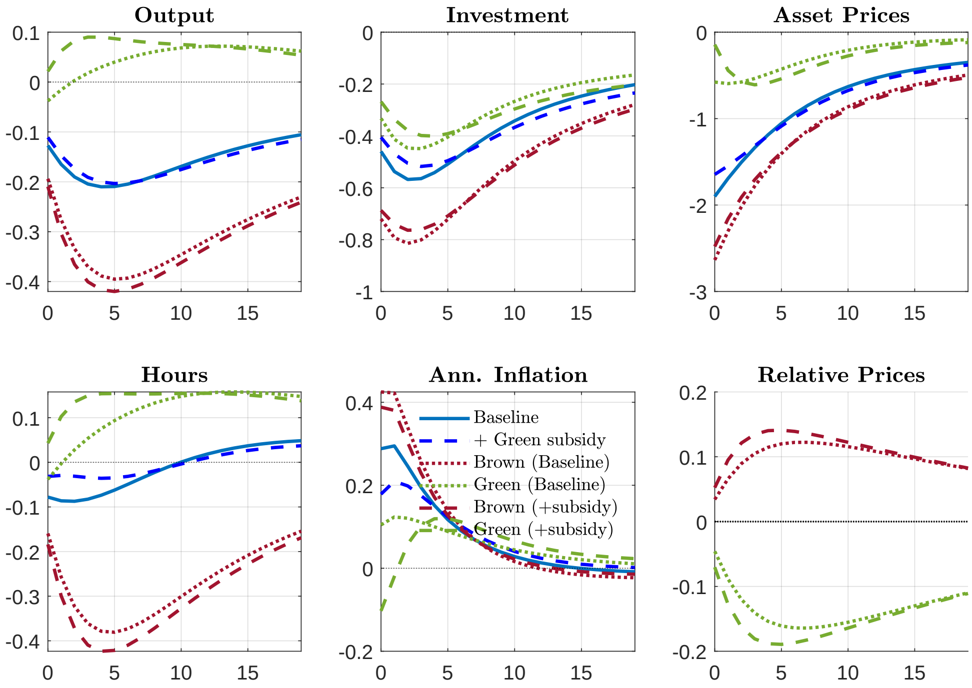
Note. The figure illustrates the degree of output attenuation resulting from alternative model parameterizations. Attenuation is defined as the difference between the responses in the poor-man economy and those in the full model. Carbon intensity is held constant at 0.22 by adjusting aggregate productivity. The solid blue line shows attenuation in the baseline calibration. The yellow dash-dotted line in panel (a) corresponds to a higher weight of brown goods ($\nu = 0.85$). The purple dashed line in panel (b) shows attenuation when the elasticity of substitution between brown and green goods is reduced ($\eta = 1.05$). The red dotted line in panel (c) illustrates the effect of reduced technological heterogeneity between brown and green firms ($\gamma_B = 0.31$, $\gamma_G = 0.12$). Responses are expressed in percentage points.

Figure G.5 Drivers of Attenuation/Amplification - Asset Prices/Inflation - ν as weight



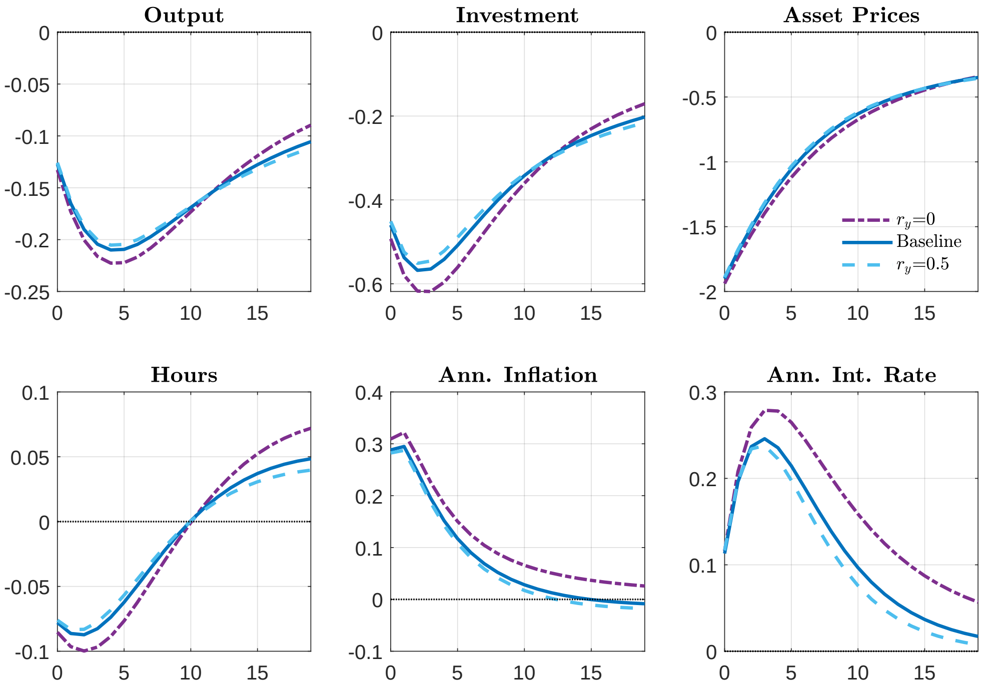
Note. The figure illustrates the degree of attenuation/amplification of asset prices/inflation resulting from alternative model parametrizations. Attenuation is defined as the difference between the responses in the baseline model and those in the corresponding poor-man (partial-equilibrium) economy. Carbon intensity is held constant at 0.22 by adjusting aggregate productivity. The solid blue line shows attenuation in the baseline calibration. Yellow dash-dotted lines correspond to a higher weight of brown goods ($\nu = 0.85$). Purple dashed lines show attenuation when the elasticity of substitution between brown and green goods is reduced ($\eta = 1.05$). Red dotted lines illustrate the effect of reduced technological heterogeneity between brown and green firms ($\gamma_B = 0.31$, $\gamma_G = 0.12$). Responses are expressed in percentage points.

Figure G.6 IMPULSE RESPONSES WITH GREEN SUBSIDIES



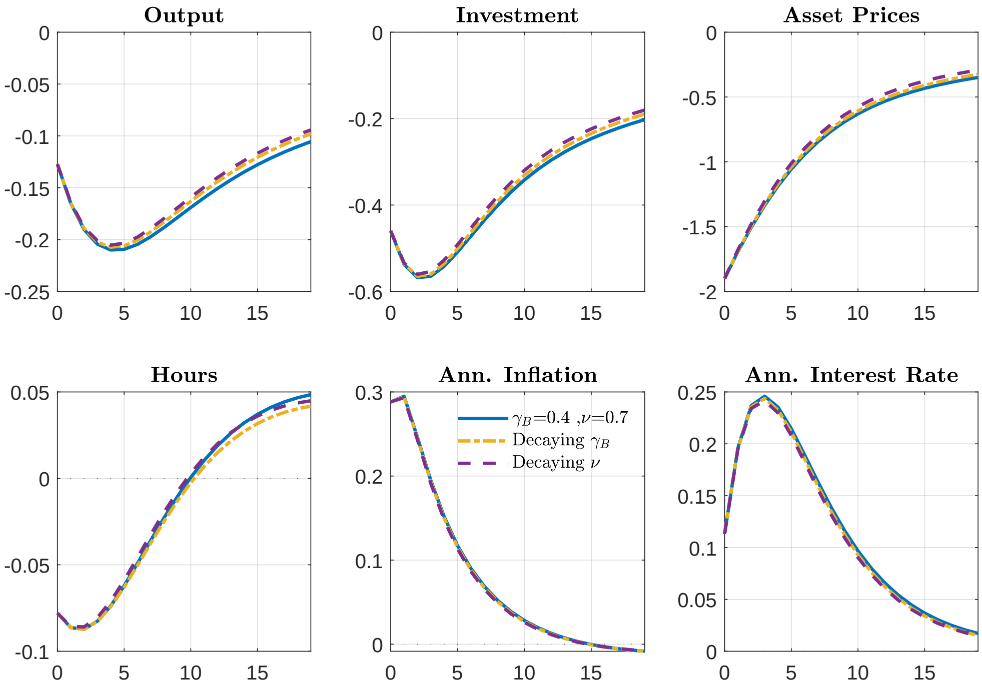
NOTE. Impulse responses to a carbon pricing shock in the baseline model and in a model where green activity is subsidized. The baseline model is represented in solid light blue, the model with green subsidies in dashed blue. Dotted green and brown denote green and brown activity in the baseline, respectively, and dashed green and brown illustrate green and brown activity in the model with green subsidies. Responses are expressed as percentage deviations from steady-state values.

Figure G.7 IMPULSE RESPONSES UNDER DIFFERENT TAYLOR RULES



NOTE. Impulse responses to a carbon pricing shock in the baseline model and models with alternative weights on output gap (r_y). The baseline model is represented in solid light blue. The dashed dotted purple lines illustrates an economy with zero weight on output gap. The dotted light blue line an economy with greater weight on the output gap. Responses are expressed as percentage deviations from steady-state values.

Figure G.8 TIME-VARYING RESPONSES - DECAYING CO_2 INTENSITY



NOTE. Impulse responses to a carbon pricing shock under a greener transition scenario. Solid light blue lines show the baseline response. Dashed purple lines illustrate the effects of a decaying value of ν, while dashed yellow lines show the impact of a decaying value of γ_B. All responses are expressed as percentage deviations from their steady-state values.