The Carbon-Adjusted Fiscal Multiplier*

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Abstract

Public spending may influence greenhouse gas emissions, thereby affecting the environment. To this end, we introduce the *carbon-adjusted* fiscal multiplier, which extends the standard concept by accounting for the carbon adjustment, defined as the dollar value of climate damages incurred per dollar of public spending. Using a climate production network that incorporates differences in carbon intensity across industries, we quantify the response of GDP and climate damages to sector-specific government spending shocks. The carbon adjustment varies inversely with sectors' carbon intensity: while negligible for most industries, it can be as low as -0.71 for public spending in cement manufacturing.

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1 Introduction

Fiscal multipliers are a critical tool for assessing the economic impact of public spending. Understanding their size and variation is essential for policymakers, which explains the considerable debate over their magnitude and the factors influencing them (Auerbach and Gorodnichenko, 2012; Ramey, 2019). Yet, the role of the environment in shaping fiscal multipliers remains largely unexplored. Insofar government demand affects firms' production, it also modulates greenhouse gas emissions, thereby influencing climate damages. This paper fills this gap by explicitly considering the environment as a novel margin through which public spending affects output.

To this end, we introduce the carbon-adjusted fiscal multiplier, extending the standard concept by incorporating the carbon adjustment, which quantifies the dollar value of climate damages incurred per dollar of public spending. To estimate it, we develop a climate sticky-price production network model featuring sectoral heterogeneity in carbon intensity—defined as the kilograms of CO_2 equivalent emissions per dollar of gross output. Our findings reveal that, while sectoral carbon adjustments are negligible for most industries, they can be as low as -0.71 for public spending in cement manufacturing, the most carbon-intensive sector.

We start by providing a simple back-of-the-envelope measure of the carbon adjustment. To derive it, we leverage greenhouse gas emissions data from the U.S. Environmental Protection Agency (EPA) at the industry level, and derive a supply-chain-adjusted carbon intensity. This measure exhibits significant heterogeneity, ranging from 0.01 for "tenant-occupied housing" to 8.84 for "cement manufacturing". How does this sectoral variation influence the output effects of public spending? To explore this, we perform a back-of-the-envelope calculation of the carbon adjustment, using the social cost of carbon (SCC) to quantify the dollar value of damages caused by CO_2 emissions associated with one dollar of public spending in a given industry. The back-of-the-envelope sectoral carbon adjustments are negative, and become more so for highly carbon-intense industries and higher SCCs. Even with the $31 SCC of Nordhaus (2017)—in the low end of the estimates in the literature—the carbon adjustments can reach -0.28.

The back-of-the-envelope calculation operates under a restrictive assumption: a one-dollar increase in public spending in one sector leads to a proportional increase in gross output across sectors as predetermined by the Input-Output matrix. This approach, being partial-equilibrium in nature, overlooks potential crowding out effects and ignores any transmission mechanisms of public spending other than sectoral differences along the supply chain. Such simplifications could lead to significant misestimations of the impact of public spending on climate damages. To address these limitations and accurately capture the variation in carbon adjustments across sectors, we develop a fully-fledged production network model.

We extend a New Keynesian production network with a climate block as in Golosov et al. (2014) and Nordhaus (2017). The economy consists of 388 industries connected by an Input-Output matrix. Firms produce using labor, capital, and intermediate inputs, setting prices subject to heterogeneous Calvo-type price rigidities across sectors. Upon production, firms emit CO_2 through an extent—determined by the carbon intensity of gross output—that varies across industries. The emission pulse accumulates into the stock of atmospheric emissions, which depletes only gradually over time. Climate damages arise because any increase in atmospheric emissions above pre-industrial levels reduces aggregate productivity. We use this model to study the effects of sector-specific public spending shocks.

In calibrating the model, we leverage the Use and Total Requirements tables of the U.S. Bureau of Economic Analysis (BEA) to discipline the Input-Output matrix and sectors' contributions to consumption, investment, and government spending. For the key dimension of sectoral heterogeneity of the model—the variation in the carbon intensities of gross output—we take the measure based on information from the EPA.[1] We set the carbon cycle to be consistent with Joos et al. (2013), so to account that although 30% of the emission pulse exits from the atmosphere after 10 years, roughly 20% of it still remains in the atmosphere after a thousand year. For the parametrization of climate damages, we make the model consistent with the implications of Barrage and Nordhaus (2024) on the GDP loss associated with one degree Celsius rise in temperatures above current levels. Finally, we set households' discount factor targeting a 1.5% annual real interest rate in steady state, in line with Giglio et al. (2015), Drupp et al. (2018), and Giglio et al. (2021).

To validate the parametrization of the damages, we compute the SCC in the model, and find a value of $77. This is a rather conservative figure, when compared to the vast dispersion of the SCC in the literature. From this perspective,

[1] Since the model explicitly considers inter-sectoral linkages, we calibrate it with the direct emission intensities, and not the supply-chain-adjusted ones.

our calibration strategy ensures that our economy is consistent with the forces shaping the transmission of public spending across industries in the short-run, as well as the medium- and long-run dynamics of emissions and climate damages. Hence, our model is an ideal laboratory to assess how public spending influences both GDP and environmental outcomes.

To illustrate how the model works, we consider a public spending shock in the most carbon-intensive sector, "cement manufacturing". The rise in the sector's gross output boosts emissions, which gradually accumulate into the atmospheric carbon stock. The stock peaks after 12 years and takes other 113 years to halve. Since climate damages are directly tied to the emission stock, also aggregate productivity slowly drops to its through, and remains negative for an extended period. Consequently, the short-run increase in GDP triggered by public spending is followed by a very persistent drop, uniquely driven by climate damages. This yields a novel channel for the long-lasting impact of public spending on GDP, complementing the results of Antolin-Diaz and Surico (2025). Although our mechanism is less quantitatively significant than theirs—which operates via changes in R&D—ours functions at even lower frequencies.

We then compute sectoral (present-value) fiscal multipliers, which measure the cumulative response of aggregate value added to an increase in public spending in a sector. In a counterfactual economy without climate damages, the multipliers range between -0.36 and 0.84. Sectoral fiscal multiplier can be negative: one dollar of public spending in a given sector has to be financed with higher taxes on households, crowding out the demand for other sectors, *other things equal*. Instead, in our baseline model, the multipliers are tilted towards more negative values, with the lowest multiplier of -0.90 being associated with spending in "cement manufacturing".

To quantify the sectoral carbon adjustments, we take the difference between the fiscal multipliers in the baseline economy and the counterfactual model without climate damages. Interestingly, while the carbon adjustments tend to be negative, this is not always the case. They are positive (although negligible) for about 146 industries, as the increase in public spending in relatively green sectors may crowd out output—and thus emissions—in polluting sectors. This stands in contrast with the back-of-the-envelope measure, which is always negative. In addition, while the carbon adjustments tend to be negligible for most industries, they are highly quantitatively relevant for around 50 industries, being as low as -0.71 for "cement manufacturing". However, the carbon adjustments become substantial for most industries if we consider higher SCCs or lower interest rates[2] which are still in line within the values employed in the literature.

Then, we compare the model implications on the carbon adjustments vis-à-vis the back-of-the-envelope measure. We find some discrepancies which are due to the fact that the back-of-the-envelope measure (i) neglects any crowding out effect, thus overestimating emissions and the carbon adjustment on average, and (ii) abstracts from any source of sectoral heterogeneity other than the Input-Output matrix. However, these differences are not quantitatively large, and tend to decrease at lower values of the SCC.

We build on the body of work that studies the propagation of public spending in production networks (Acemoglu et al., 2016; Baqaee and Farhi, 2018; Proebsting, 2022; Bouakez et al., 2023, 2024; Cardi and Restout, 2023; Flynn et al., 2024; Peri et al., 2025). These papers focus on how inter-sectoral linkages and sectoral heterogeneity are critical features to quantify the output effects of fiscal policy, and its transmission channels. We add a novel margin to this strand of the literature: the environment. Specifically, we emphasize the relevance of accounting for differences in carbon intensity across industries and explicitly considering climate damages into the measurement of fiscal multipliers.

From this perspective, we introduce emissions dynamics and climate damages as in Golosov et al. (2014), Nordhaus (2017), Barrage and Nordhaus (2024) into the analysis of public spending. A similar approach is also present in Mallucci (2022), Barrage (2024), Phan and Schwartzman (2024), which highlight that climate change affects the magnitude of government expenditures and revenues, and can even lead to sovereign defaults. We complement the approach of this body of work: in our setting, climate change does not influences the amount of public spending in the economy, but rather the environment determines the way in which public spending ultimately influences GDP.

Finally, our paper connects to the growing literature on the linkages between the business cycle and the environment, which explores the impact of monetary policy on environmental outcomes (Ferrari Minesso and Pagliari, 2023, Ferrari and Nispi Landi, 2024) and examines the effects of carbon taxation on inflation (Del Negro et al., 2023; Airaudo et al., 2024; Ferrari and Nispi Landi, 2025), and the stance of monetary policy (Nakov and Thomas, 2024; Olovsson and Vestin, 2023). Our contribution lies in analyzing how public spending influences environmental variables, by introducing the concept of carbon-adjusted fiscal multipliers.

[2]Given the strong persistence of climate damages, lower discount rates may reduce the carbon adjustment.

2 A Back-of-the-Envelope Carbon Adjustment

This section provides a simple back-of-the-envelope empirical measure of the carbon adjustment to the fiscal multiplier. To do so, we leverage information on emissions at the industry level from the EPA. Specifically, the EPA attributes U.S. greenhouse gas emissions at the five-digit NAICS code level (see Yang et al., 2020), yielding information on emissions for about 400 sectors. Since the EPA provides this emission breakdown for the years 2010-2016, we consider the last year of the sample, 2016, as our reference period.

The amount of emissions vary substantially across industries, ranging from virtually no emission for “veterinary services” up to 1,518.5 million metric tons of CO_2 equivalent emissions for “electric power generation, transmission, and distribution”. However, this measurement is plagued by two main limitations. First, the variation in the total amount of emissions could be largely explained by differences in the size of each sector in terms of the total amount of produced goods. Second, an industry that does not directly emit greenhouse gas could do it indirectly by demand intermediate inputs from highly polluting sectors.

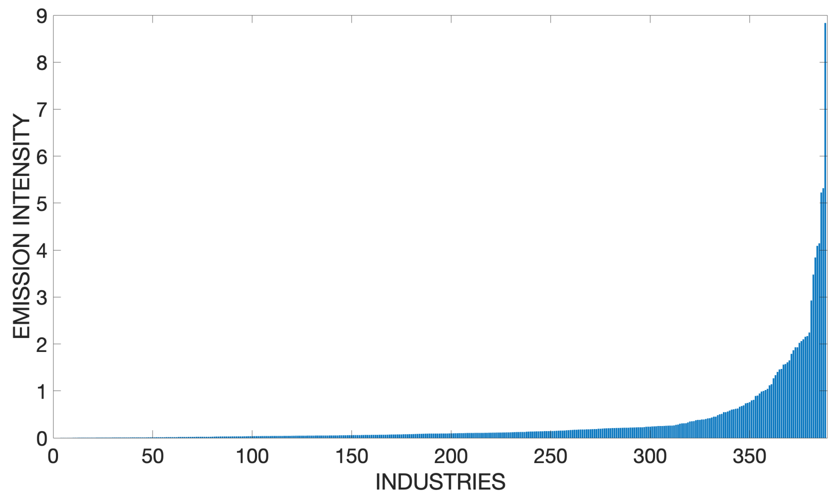
To address these issues, we proceed in two steps. We start by computing the *direct* emission intensity of gross output for each industry, defined as the amount of greenhouse emissions in kilograms of CO2 equivalent for each 2017 dollar of gross output. For the latter, we take information from the BEA on sectoral nominal gross output in the year 2017. Then, we account for input-output linkages by computing *supply-chain-adjusted* emission intensities. Let us denote by ζ_i the direct emission intensity of sector i, and stack all sectors' intensities in the vector $\mathbf{Z}$. Then, the vector of supply-chain-adjusted emission intensities $\tilde{\mathbf{Z}}$ is determined as

$$\tilde{\mathbf{Z}} = \mathbf{Z} \times (\mathbf{I} - \mathbf{R})^{-1}, \tag{1}$$

where $(\mathbf{I} - \mathbf{R})^{-1}$ is the Leontief Inverse matrix, $\mathbf{I}$ is the diagonal matrix, and $\mathbf{R}$ is the direct requirements matrix that characterizes the production network of the economy. We compute the latter using information on the Input-Output tables of the BEA in year 2017. Thus, our objects of interest are elements $\tilde{\zeta}_i$ of the supply-chain-adjusted emission intensities vector, $\tilde{\mathbf{Z}}$.

We report the range of the supply-chain-adjusted emission intensities in Figure 1, and show the list of the top 10 emitting industries in Table 1. This analysis uncovers substantial variation in the emission intensities across sectors, going from the minimum value of 0.01 for ”tenant-occupied housing” up to 8.84 for “cement manufacturing”. This means that each dollar of gross output in cement manufac-

Figure 1: Emission Intensities of Gross Output Across Industries.



Note: The figure reports the supply-chain-adjusted carbon intensities of gross output across sectors, ordered from the lowest to the highest value. This measure captures the kilograms of CO_2 equivalent emissions associated with one 2017 dollar of gross output.

turing is associated with a pulse of 8.84 kilograms of CO_2 into the atmosphere.

What are the implications of sectoral heterogeneity in carbon intensity on the output effects of public spending? To answer this question, we introduce a back-of-the-envelope measure of the carbon adjustment to the fiscal multiplier, which measures the dollar value of climate damages incurred per dollar of public spending. We quantify it as follows:

$$\text{Carbon Adjustment}_i = \frac{\text{SCC}_i \times \tilde{\zeta}_i}{1000}, \tag{2}$$

where SCC_i is the social cost of carbon, which estimates the dollar damage associated with emitting one additional ton of CO_2. Thus, the carbon adjustment multiplies the supply-chain carbon intensity with the social cost of carbon, and divides it by 1000 to adjust for the fact that our intensity is defined in terms of kilograms of CO_2, whereas the SCC is in tons of CO_2.

The implicit assumption in our back-of-the-envelope measure is that a one dollar increase in public spending in one sector raises gross output of all sectors exactly by the amount determined by the Input-Output matrix. In other words, this is a partial-equilibrium approach that abstracts from any crowding out and disregards any transmission mechanism of public spending other than sectoral heterogeneity along the supply chain.

In addition, in Equation (2), the social cost of carbon proxies the environmen-

Table 1: Carbon Intensity of Gross Output - Top 10 Industries

Cement manufacturing	8.84 kg/2017 USD
Grain farming	5.32 kg/2017 USD
Electric power generation, transmission, and distribution	5.23 kg/2017 USD
Beef cattle ranching and farming	4.14 kg/2017 USD
Fertilizer manufacturing	4.09 kg/2017 USD
Lime and gypsum product manufacturing	3.84 kg/2017 USD
Dairy cattle and milk production	3.48 kg/2017 USD
Coal mining	2.93 kg/2017 USD
Pipeline transportation	2.24 kg/2017 USD
Alumina refining and primary aluminum production	2.17 kg/2017 USD

Note: The table reports the top 10 industries in terms of their supply-chain-adjusted carbon intensity of gross output.

tal damages due to the additional emissions associated with one additional dollar of gross output triggered by a surge in public consumption in a given sector. Thus, the carbon adjustment crucially depends on the SCC such that a higher value of the social cost of carbon makes the carbon adjustment to be even more negative. In other words, a higher SCC indicates that one additional dollar of public spending in a polluting industry would generate relatively larger climate damages, and thus reduce both the response of GDP and the value of the fiscal multiplier.

We compute the carbon adjustment by considering six different values of the SCC, which span the wide range of values considered in the literature. Specifically, we consider a SCC of $31 estimated by Nordhaus (2017) with the DICE 2016 model; a SCC of $51, which is the reference value of the Biden Administration; a SCC of $66 as implied by the DICE 2023 model of Barrage and Nordhaus (2024); a SCC of $132, the truncated mean of the meta-analysis of Moore et al. (2024); and a SCC of $250 used in the Stern (2007) report. Note that while we consider a wide range of values, we still restrict the dispersion in the SCC relative to the estimates of the literature, as for instance recently Bilal and Känzig (2024) find a SCC above $1000.

Table 2 shows the back-of-the-envelope carbon adjustments associated with each of these SCCs. This analysis yields two main conclusions. First, in all cases the range of the carbon adjustment spans negative values, reaching a maximum value of zero. This is because our implicit assumptions indicate that public

Table 2: Range of Back-of-the-Envelope Carbon Adjustments

Social Cost of Carbon	\$31	\$51	\$66	\$100	\$132	\$250
	$[-0.27, 0]$	$[-0.45, 0]$	$[-0.58, 0]$	$[-0.88, 0]$	$[-1.17, 0]$	$[-2.21, 0]$

Note: The table reports the range of the back-of-the-envelope carbon adjustments to the fiscal multipliers for different values of the social cost of carbon.

spending has no crowding out. As a result, public spending can only raise emissions, unless the emission intensity is close to zero, in which case the emission pulse is negligible, leading to a null carbon adjustment. This result indicates that the carbon adjustment can be positive under two conditions: (i) public spending raises the demand from low carbon-intensity sectors, and (ii) there is a crowding out the production of highly polluting industries. In this case, emissions shrink, leading to an improvement in the environment.

The second key conclusion of the results in Table 2 is that independently on the value of the SCC, the variation in the carbon adjustment is quantitatively relevant: under a SCC of \$100, the carbon adjustment can be as large as -0.88. Assuming a fiscal multiplier of 0.8 (see Ramey, 2019), such a low carbon adjustment would imply that public spending has negative effects on GDP.[3]

This analysis highlights that the carbon adjustment to the fiscal multiplier can be substantial, at least for the industries with high carbon intensities. However, this back-of-the-envelope measurement may severely misestimate the actual carbon adjustments, as it is based on a tight partial-equilibrium assumption on the effect of public spending across industries. To relax this condition and properly quantify the variation in the carbon adjustment across sectors, we move next into building a fully-fledged climate production network model.

3 Model

The economy is a multi-sector climate production network with sticky prices. The production side consists of multiple industries that are inter-connected through an Input-Output matrix. Sectors differ in their contributions to private consumption, private investment, and public consumption, as well as in their use and supply of intermediate inputs, and degrees of price rigidity.

[3] If the fiscal multiplier is 0.8 and the carbon adjustment is -0.88, then the carbon-adjusted fiscal multiplier is 0.8-0.88=-0.08.

CO_2—emitted by firms during production—accumulates in the atmospheric carbon stock. Crucially, industries exhibit heterogeneity in their carbon intensity of gross output, determining the pulse of CO_2 emissions per dollar of gross output. Deviations in atmospheric carbon stock from pre-industrial levels impose a (productivity) damage to gross output, which is homogeneous across industries.

The economy also incorporates a representative household, a monetary authority setting nominal interest rates via a Taylor rule, and a fiscal authority purchasing goods from each sector based on sector-specific public spending shocks.

3.1 Household

The representative household chooses consumption C_t, labor N_t, investment I_t, physical capital K_{t+1}, and one-period risk-free nominal bonds B_t to maximize its life-time utility:

$$\max_{C_t,N_t,I_t,K_{t+1},B_t} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{1-\sigma}}{1-\sigma} - \theta \frac{N_t^{1+\eta}}{1+\eta} \right] \tag{3}$$

$$\text{s.t} \quad P_t C_t + P_{I,t} I_t + B_t + T_t = W_t N_t + R_{K,t} K_t + R_{t-1} B_{t-1} + \text{Profit}_t, \tag{4}$$

where β is the time discount factor, σ captures risk aversion, θ is a labor disutility shifter, and η denotes the inverse of the Frisch elasticity. The budget constraint in Equation (4) posits that every period the household purchases consumption goods at price P_t and investment goods at price $P_{I,t}$, invests in nominal bonds, and pays a nominal lump-sum tax T_t. It finances its expenditures with the proceeds of the nominal bond, whose interest rate is R_t, profits rebated from firms, Profit_t, and labor and capital income, where W_t and $R_{K,t}$ denote the nominal wage and nominal return to capital, respectively.

Physical capital evolves according to a law of motion characterized by investment adjustment costs, whose magnitude is captured by the parameter χ:

$$K_{t+1} = (1-\delta) K_t + I_t \left[1 - \chi \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \right], \tag{5}$$

where δ is the depreciation rate.

To account for the fact that labor does not perfectly move across industries at the business cycle frequency, we follow Bouakez et al. (2023, 2024) and posit that aggregate labor is a CES function of sectoral labor flows, $N_{i,t}$:

$$N_t = \left[\sum_{i=1}^{\mathcal{I}} \omega_{N,i}^{-\frac{1}{\nu_N}} N_{i,t}^{\frac{\nu_N+1}{\nu_N}} \right]^{\frac{\nu_N}{\nu_N+1}}, \tag{6}$$

where $\omega_{N,i}$ is the weight of sector i, ν_N captures the elasticity of substitution of labor across industries, and $\mathcal{I}$ is the number of industries in the model. The aggregate nominal wage can be defined as a function of nominal sectoral wages:

$$W_t = \left[\sum_{i=1}^{\mathcal{I}} \omega_{N,i} W_{i,t}^{\nu_N+1} \right]^{\frac{1}{\nu_N+1}}. \tag{7}$$

This structure implies that the optimal supply of labor to sector i equals:

$$N_{i,t} = \omega_{N,i} \left(\frac{W_{i,t}}{W_t} \right)^{\nu_N} N_t. \tag{8}$$

Similarly, we posit that aggregate physical capital is a CES function of sectoral capital flows, $K_{i,t}$:

$$K_t = \left[\sum_{i=1}^{\mathcal{I}} \omega_{K,i}^{-\frac{1}{\nu_K}} K_{i,t}^{\frac{\nu_K+1}{\nu_K}} \right]^{\frac{\nu_K}{\nu_K+1}}, \tag{9}$$

where $\omega_{K,i}$ is the weight of sector i and ν_K determines the elasticity of substitution of capital across industries. The aggregate nominal return to capital is

$$R_{K,t} = \left[\sum_{i=1}^{\mathcal{I}} \omega_{K,i} R_{K,i,t}^{\nu_K+1} \right]^{\frac{1}{\nu_K+1}}. \tag{10}$$

The optimal supply of capital to sector i can be defined as

$$K_{i,t} = \omega_{K,i} \left(\frac{R_{K,i,t}}{R_{K,t}} \right)^{\nu_K} K_t. \tag{11}$$

In this setting, when $\nu_N, \nu_K \to \infty$, labor and capital are perfectly mobile, and nominal wages and returns to capital are equalized across industries. Instead, insofar $\nu_N, \nu_K < \infty$, labor and capital are imperfectly mobile and differentials emerge across industries in the remuneration of the two factors of production. While our approach parsimoniously capture the imperfect degree of mobility of labor and capital across industries in the short run, Huffman and Wynne (1999) and Miranda-Pinto and Young (2019) show how this modeling approach yields comovement dynamics across industries remarkably in line with the data.

3.2 Firms

The production side consists of $\mathcal{I}$ industries. In each sector, denoted by $i \in [1, \ldots, \mathcal{I}]$, there is a continuum of producers that combine labor, capital, and a bundle of intermediate inputs to produce differentiated varieties of goods. These varieties are aggregated into a single good in each sector by a representative wholesaler. Wholesalers' goods are then purchased by retailers, who assemble them into consumption and investment bundles sold to households, intermediate-input bundles sold to producers, and public-consumption goods sold to the fiscal authority.

3.2.1 Producers

Within each sector, a continuum of monopolistically competitive firms indexed by $j \in [0,1]$ produce differentiated varieties. These firms produce with a Cobb-Douglas technology using labor, capital, and a composite of intermediate inputs:

$$Z_{i,t}^{j} = (1 - D_t)\, {N_{i,t}^{j}}^{\alpha_{N,i}} {K_{i,t}^{j}}^{\alpha_{K,i}} {H_{i,t}^{j}}^{\alpha_{H,i}}, \tag{12}$$

where $Z_{i,t}^{j}$ is gross output of producer j in industry i at time t, while $N_{i,t}^{j}$, $K_{i,t}^{j}$, and $H_{i,t}^{j}$ are labor, capital, and intermediates. The labor, capital, and intermediate-input gross-output intensities, $\alpha_{N,i}$, $\alpha_{K,i}$, and $\alpha_{H,i}$, are sector-specific.

Importantly, gross output is also affected by the environment through climate damages D_t. As we describe in detail in Section 3.7, these damages depend on the current atmospheric carbon stock: when the stock rises, it yields to a productivity loss that is homogeneous across industries.

Producers purchase labor services and capital services from workers at price $W_{i,t}$ and $R_{K,i,t}$, and intermediate inputs from retailers at price $P_{H,i,t}$. Then, they sold their output to wholesalers at price $P_{i,t}^{j}$. Producers face a price-setting friction, so that they can update their prices with the sector-specific Calvo (1983) probability $1 - \phi_i$. Accordingly, producers set optimal reset prices to maximize the expected discounted stream of profits.

3.2.2 Wholesalers

In each sector, the perfectly competitive representative wholesaler purchases the different varieties assembled by producers, $Z_{i,t}^{j}$, and bundles them into the final sectoral good $Z_{i,t}$ with the CES technology

$$Z_{i,t} = \left[\int_0^1 {Z_{i,t}^{j}}^{\frac{\mu-1}{\mu}} \mathrm{dj} \right]^{\frac{\mu}{\mu-1}}, \tag{13}$$

where μ denotes the elasticity of substitution across varieties within each sector. Equation (13) implies that the price of the sectoral good of sector i is

$$P_{i,t} = \left[\int_0^1 {P_{i,t}^{j}}^{1-\mu} \mathrm{dj} \right]^{\frac{1}{1-\mu}}. \tag{14}$$

The goods produced by the wholesalers are destined for consumption, investment, government consumption, and intermediate-input use. Accordingly, the resource constraint at the sectoral level reads

$$Z_{i,t} = C_{i,t} + I_{i,t} + G_{i,t} + \sum_{x=1}^{\mathcal{I}} H_{i,x,t}, \tag{15}$$

where $C_{i,t}$ and $I_{i,t}$ denote the demand of sector i goods from consumption and investment retailers, $G_{i,t}$ is the demand from the fiscal authority, and $H_{i,x,t}$ corresponds to the demand of sector i goods from the retailer that assembles the intermediate inputs destined to producers in sector x.

3.3 Consumption Retailer

A perfectly competitive representative consumption retailer assembles sectoral consumption flows, $C_{i,t}$, into the final consumption good, C_t, with the technology

$$C_t = \left[\sum_{i=1}^{\mathcal{I}} \omega_{C,i}^{\frac{1}{\nu_C}} C_{i,t}^{\frac{\nu_C - 1}{\nu_C}} \right]^{\frac{\nu_C}{\nu_C - 1}}, \tag{16}$$

where $\omega_{C,i}$ is the contribution of sector i to private consumption, and ν_C denotes the elasticity of substitution of sectoral consumption flows. It follows that the consumption price, P_t, is a function of sectoral prices, and it equals

$$P_t = \left[\sum_{i=1}^{\mathcal{I}} \omega_{C,i} P_{i,t}^{1-\nu_C} \right]^{\frac{1}{1-\nu_C}}. \tag{17}$$

As a result, the retailer's optimal demand of goods from sector i is

$$C_{i,t} = \omega_{C,i} \left(\frac{P_{i,t}}{P_t} \right)^{-\nu_C} C_t. \tag{18}$$

Similar equations hold for the investment retailer, though with different weights, $\omega_{I,i}$, and elasticity of substitution, ν_I.

3.4 Intermediate-Input Retailers

For each sector, there is a perfectly competitive representative intermediate-input retailer assembles sectoral goods, $H_{x,i,t}$, into the bundle of intermediate inputs used by sector i producers, $H_{i,t}$, with the technology

$$H_{i,t} = \left[\sum_{x=1}^{\mathcal{I}} \omega_{H,x,i}^{\frac{1}{\nu_H}} H_{x,i,t}^{\frac{\nu_H - 1}{\nu_H}} \right]^{\frac{\nu_H}{\nu_H - 1}} \tag{19}$$

where $\omega_{H,x,i}$ is the contribution of sector x to the bundle of intermediate inputs used by producers in sector i, and ν_H denotes the elasticity of substitution of intermediate inputs across industries. The price of the bundle of intermediate inputs demanded by sector i producers, $P_{H,i,t}$, equals

$$P_{H,i,t} = \left[\sum_{x=1}^{\mathcal{I}} \omega_{H,x,i} P_{x,t}^{1-\nu_H} \right]^{\frac{1}{1-\nu_H}}. \tag{20}$$

Finally, the optimal demand of sector x goods from the retailer that assembles the intermediate inputs used by producers in sector i reads

$$H_{x,i,t} = \omega_{H,x,i} \left(\frac{P_{x,t}}{P_{H,i,t}} \right)^{-\nu_H} H_{i,t}. \tag{21}$$

3.5 Monetary Authority

The monetary authority sets the nominal interest rate with a standard Taylor which reacts to aggregate CPI inflation, $\Pi_t = P_t/P_{t-1}$, and the output gap, Y_t/Y_t^f, defined as the ratio between aggregate GDP, Y_t, and that in a counterfactual version of the model with flexible prices, Y_t^f:

$$\frac{R_t}{\bar{R}} = \left(\frac{R_{t-1}}{\bar{R}} \right)^{\phi_r} \left[\Pi_t^{\phi_\pi} \left(\frac{Y_t}{Y_t^f} \right)^{\phi_y} \right]^{1-\phi_r}, \tag{22}$$

where $\bar{R}$ is the steady-state interest rate,[4] and ϕ_r, ϕ_π, and ϕ_y denote the degree of inertia and responsiveness to inflation and the output gap, respectively.

3.6 Fiscal Authority

The fiscal authority purchases goods from wholesalers. The flow of sectoral public consumption is determined by a sequence of auto-regressive processes

$$\log G_{i,t} = (1-\rho) \log \bar{G}_i + \rho \log G_{i,t-1} + \varepsilon_{i,t}, \tag{23}$$

where ρ is the degree of persistence, and $\varepsilon_{i,t}$ is a sector-specific public consumption shock. The fiscal authority runs a balanced budget and finances its expenditures with a lump-sum tax levied on the household:

$$\sum_{i=1}^{\mathcal{I}} P_{i,t} G_{i,t} = T_t. \tag{24}$$

3.7 Environmental Block

When assembling sectoral gross output, wholesalers release CO_2 emissions. Specifically, the emissions of sector i, $E_{i,t}$, are defined as

$$E_{i,t} = \zeta_i \bar{P}_i Z_{i,t}, \tag{25}$$

[4] Throughout the text, $\bar{A}$ denotes the steady-state value of variable A_t.

which depends on the amount of gross output of sector i, $Z_{i,t}$, valued at its steady-state price, $\bar{P}_i$.[5] The parameter ζ_i captures the emission intensity of gross output of sector i, denoting the kilograms of CO_2 associated to each dollar of sectoral gross output. Crucially, this parameter varies across sectors and is the key dimension of sectoral heterogeneity in the model, which allows us to account for the vast differences in emissions observed across industries.

The aggregate flow of CO_2 emissions, E_t, sums over sectoral emissions:

$$E_t = \sum_{i=1}^{\mathcal{I}} E_{i,t}. \tag{26}$$

For the carbon cycle, we follow the logic in Golosov et al. (2014) and posit that the emission accumulates in the stock of carbon in the atmosphere according to a mixture of two different law of motions. In this way, we can account for the fact that while a large fraction of new emissions quickly fades out, a fraction of it remains in the atmosphere almost permanently (Joos et al., 2013; Folini et al., 2025). In particular, we consider that a share ι of the emission pulse accumulates into the atmosphere according to the law of motion

$$S_{1,t} = (1 - \varphi_1) S_{1,t-1} + \iota E_t, \tag{27}$$

where $S_{1,t}$ is the corresponding stock of carbon in the atmosphere, and φ_1 is its abatement rate. The remaining fraction of emissions accumulate into the atmosphere according to a second law of motion:

$$S_{2,t} = (1 - \varphi_2) S_{2,t-1} + (1 - \iota) E_t, \tag{28}$$

with a distinct abatement rate, φ_2. The total amount of atmospheric carbon, S_t, is then determined as the sum of the two stocks

$$S_t = S_{1,t} + S_{2,t}. \tag{29}$$

Given the stock of atmospheric carbon, environmental damages equal to

$$1 - D_t = \exp\left\{-\gamma\left(S_t - \tilde{S}\right)\right\}, \tag{30}$$

which depend on the difference in current stock of emissions, S_t, from its pre-industrial levels, $\tilde{S}$. The parameter γ captures how the magnitude of climate damages varies with changes in atmospheric carbon. When $\gamma = 0$, there are no climate damages, and emissions have no effect on output.

[5] Since in the data the emission intensities are defined in terms of real gross output, we posit that sectoral emissions depend on sectoral gross output valued at steady-state prices to ensure a one-to-one mapping between changes in emissions and changes in sectoral quantities.

3.8 Market Clearing and Aggregation

The labor market clears when the labor supplied by households to each sector equals labor demand across all producers within the sector, such that $N_{i,t} = \int_0^1 N_{i,t}^j \, \text{dj}$. Similarly, the market clearing of physical capital implies that $K_{i,t} = \int_0^1 K_{i,t}^j \, \text{dj}$. Bonds are in zero net supply, i.e. $B_t = 0$.

Producers' profits equal the value of gross output net of production costs, $\text{Profit}_{i,t}^j = P_{i,t}^j Z_{i,t}^j - W_{i,t} N_{i,t}^j - R_{K,i,t} K_{i,t}^j - P_{H,i,t} H_{i,t}^j$. Summing the profits across all producers and all sector yields aggregate profits: $\text{Profit}_t = \sum_{i=1}^{\mathcal{I}} \int_0^1 \text{Profit}_{i,t}^j \text{dj}$.

From producers' technology of Equation (12) and aggregating within each sector yields nominal value added at the industry level $\mathcal{Y}_{i,t}$,

$$\mathcal{Y}_{i,t} = P_{i,t} Z_{i,t} - P_{H,i,t} H_{i,t}, \tag{31}$$

which equals the difference between the value of sectoral gross output and the value of intermediate inputs used by all producers in sector i.

Summing up the nominal value added across all industries yields the aggregate nominal GDP of the economy, $\mathcal{Y}_t$:

$$\mathcal{Y}_t = \sum_{i=1}^{\mathcal{I}} \mathcal{Y}_{i,t}. \tag{32}$$

Real GDP—the ratio between nominal GDP and the consumption price, P_t—is the sum of the real values of consumption, investment, and public spending:

$$Y_t = \frac{\mathcal{Y}_t}{P_t} = C_t + \frac{P_{I,t}}{P_t} I_t + \sum_{i=1}^{\mathcal{I}} \frac{P_{i,t}}{P_t} G_{i,t}. \tag{33}$$

4 Calibration

We consider our economy as consisting of $\mathcal{I} = 388$ industries, corresponding to the five-digit level of NAICS codes.[6] A period in the model equals to a month, so to account for the short price duration of some sectors.

We start by setting the time discount factor to $\beta = 0.9988$ targeting a 1.5% annual real interest rate. Although this choice is well below the 4% considered in DICE models (see Nordhaus, 2013), it is in line with the estimates of Giglio et al. (2015) and Giglio et al. (2021), who find long-run discount rates of 2.6% for risky real estate that provide an upper bound on the risk-free rate. Our choice is also

[6] We consider all the industries reported in the detailed sectors tables, excluding "custom duties" (as it just consists of import taxes), "private households", and all the industries related to the government (since the model considers public spending as an exogenous stream of purchases).

in line with the evidence in Drupp et al. (2018), in which 92 percent of surveyed experts supports a discount rate between 1% and 3%. However, since the choice of the discount rate is very controversial and important in determining the magnitude of both fiscal multipliers and the social cost of carbon, we also ascertain the robustness of our results to different values for the annual real interest rate at steady state, going from 0.5% up to 4%.

We then fix the risk aversion parameter to the standard value of $\sigma = 2$, and set $\eta = 0.5$ so that the Frisch elasticity is 2. While this choice is much larger than the elasticity of labor supply estimated at the individual level (see Chetty et al., 2013), Erosa et al. (2016) shows that an aggregate labour supply elasticity of 1.75 is consistent with individual-level micro-evidence. This choice allows the model to generate levels of the fiscal multipliers more in line with the literature.[7] Then, we calibrate the labor disutility shifter to $\theta = 3.59$ to target a value of labor at steady state of $\bar{N} = 0.33$.

We use BEA data to set the capital depreciation rate: we compute the ratio of current cost depreciation of fixed assets in 2022 to the stock of fixed assets at the end of 2021. We find a value of $\delta = 0.0048$, implying an annual rate of 5.61%. The investment adjustment cost is $\chi = 6.5$ to ensure that the volatility of investment relative to GDP—upon aggregate productivity shocks—is in line with the data.

The elasticity of substitution of labor across industries is set to $\nu_N = 1$, in line with the estimate of Horvath (2000). Following Bouakez et al. (2023, 2024), we set the elasticity of capital across industries so that it coincides with that of labor, so that $\nu_K = 1$. The sectoral labor weights and the sectoral capital weights are set to ensures that at steady state there are no differences in the wage rate and the return to capital across industries, implying that $\omega_{N,i} = \bar{N}_i/\bar{N}$ and $\omega_{K,i} = \bar{K}_i/\bar{K}$.

The elasticity of substitution across varieties is set to $\mu = 11$, so that markups equal 10 percent. Conditional on markups, we calibrate the factor intensities $\alpha_{N,s}$, $\alpha_{K,s}$, and $\alpha_{H,s}$ to match the shares of labor, capital, and intermediate input in gross output, by imposing that $\alpha_{N,s} + \alpha_{K,s} + \alpha_{H,s} = 1$.

We fix the elasticity of substitution of consumption to the value of $\nu_C = 0.8$, in line with the estimate of Herrendorf et al. (2013). We set analogously the elasticity of substitution of investment across industries, so that $\nu_I = 0.8$. The elasticity of substitution of intermediate inputs is $\nu_H = 0.1$ to imply a strong degree of complementarity of materials across industries, as suggested by the

[7] We also consider alternative calibration values, showing that if anything the relevance of the carbon adjustment slightly increases at lower values of the Frisch elasticity.

estimates of Atalay (2017) and Boehm et al. (2019).

Conditional on the elasticities of substitution, the sectoral weights $\omega_{C,i}$ and $\omega_{I,i}$ can be set to target the contribution of each industry to private consumption and private investment. Similarly, the steady-state values of sectoral public consumption. $\bar{G}_i$ discipline the sectoral contribution to public spending. To do so, we leverage the information of the Use table of the BEA for the year 2017. The parameters $\omega_{H,i,x}$ determine the Input-Output matrix and are set according to the 2017 Total Domestic Requirements table of the BEA.

Government spending at steady state, $\sum_{i=1}^{\mathcal{I}} \bar{P}_i \bar{G}_i$, is set at 6 percent of GDP, as in the data.[8] The autocorrelation of the autoregressive process determining sectoral public spending is $\rho = 0.983$, to imply a persistence of 0.95 at the quarterly frequency as estimated by Leeper et al. (2010). The Calvo probabilities are calibrated with the information on price duration across industries of Pasten et al. (2020). Regarding the monetary authority, we calibrate the parameters of the Taylor rule following Clarida et al. (2000): the responsiveness to inflation is $\phi_\pi = 1.5$, the responsiveness to the output gap is 0.0417 (to imply a responsiveness to the annualized gap of 0.5), and the degree of inertia is $\phi_r = 0.9300$ (to imply an inertia of 0.8 at quarterly frequency).

Finally, we calibrate the parameters disciplining the climate side of the model. We start by setting the emission intensities of gross output, ζ_i, to match the information computed in Section 2 using data from the EPA. Importantly, we use the direct emission intensities, and not the supply-chain-adjusted ones, as our model implicitly takes into account how the production in a given industry generates emissions through its demand of intermediate inputs from all other sectors. We calibrate the carbon cycle so to make it consistent with Joos et al. (2013), so that although 30% of the emission pulse dissipates from the atmosphere after 10 years, roughly 20% of it still remains in the atmosphere after a thousand year. To do so, we set that 41% of any emission pulse accumulates into a first law of motion of atmospheric carbon, with a very low abatement rate: $\varphi_1 = 0.000054$, which implies a half-life of atmospheric carbon of a thousand years. Then, the remaining fraction of the emission pulse accumulates into a second law of motion characterized by a much higher abatement rate: $\varphi_2 = 0.0038$, which implies a half-life of atmospheric carbon of 15 years.

[8]Moro and Rachedi (2022) shows that while total public spending is slightly below 20 percent, the bulk of it consists of the compensation of public employees. Instead, the purchases of goods and services from private firms—which is the counterpart of public spending in our model—amounts to 6 percent (and thus account for 35 percent of total public expenditures) in 2023.

The crucial parameter of the model is the one modulating the magnitude of climate damages, γ, which governs how changes in the current stock of atmospheric carbon relative to its pre-industrial levels affects productivity. We discipline climate damages in three steps. First, we consider each unit of emissions as representing a gigaton of carbon, and set the stock of emissions at steady state to $\bar{S} = 900$, consistently with the observed carbon in atmosphere in 2023.[9] Second, the pre-industrial stock of emissions equals $\tilde{S} = 581$ as in Golosov et al. (2014). Third, we set climate damages such that the model can replicate the GDP loss associated with a one degree Celsius rise in temperatures—above current levels—implied by the 2023 DICE model of Barrage and Nordhaus (2024). The 2023 DICE models predicts that one additional degree Celsius would reduce GDP by 1.66%. This impact of warming on GDP is within the estimates of the literature (Newell et al., 2021; Burke et al., 2023; Nath et al., 2024). We shock our model with the amount of emissions that raise temperatures by one degree Celsius,[10] and compute the associated GDP drop. Our model matches the same GDP drop implied by the 2023 DICE model with a damage parameter of $\gamma = 6.935 \times 10^{-5}$.

To validate the selection of the climate damage parameter, we compute the SCC of our calibrated model. We consider a shock to emissions in the model, back out the response of all variables, and compute the SCC on impact (i.e., at time 0) as in Golosov et al. (2014):

$$SCC = \mathbb{E}_0 \sum_{j=0}^{\infty} \beta^j \frac{U'(C_j)}{U'(C_0)} \frac{\partial Y_j}{\partial S_j} \frac{\partial S_j}{\partial E_0}, \tag{34}$$

where $U'(C_t)$ denotes the marginal utility of consumption. We find a SCC of \$77, a conservative value when compared to those considered in the literature, as discussed in Section 2.

5 Quantitative Analysis

This section evaluates the quantitative predictions of the model and quantifies the relevance of the carbon adjustment to the fiscal multiplier. We start with

[9]Since we calibrate the model to the information on carbon intensities from the EPA, making the model to be consistent with the magnitude of the stock of emissions requires it to be consistent also with the magnitude of GDP in trillion of dollars. To do so, we set aggregate productivity in steady state to target an annualized GDP of 20 trillions in 2017 dollars, in line with the data over the last decade.

[10]Since the damage function in Barrage and Nordhaus (2024) is in terms of temperatures whereas our model features the stock of emissions, we map these two concepts by positing that temperatures are a logarithmic function of the stock of atmospheric carbon as in Golosov et al. (2014): $T_t = \left(\frac{3}{\log 2}\right) \log\left(\frac{S_t}{\tilde{S}}\right)$. Specifically, an increase by one degree Celsius requires 233.95 gigaton of emissions above current levels.

Section 5.1, by describing how GDP, emissions, and climate damages react to public spending shocks, and then measure sectoral fiscal multipliers in Section 5.2, and the carbon adjustments in Section 5.3. Section 5.5 ascertains the robustness of our results, and Section 5.4 studies the mechanisms through which public spending yields a variation in the carbon adjustments above and beyond to the predictions of our back-of-the-envelope measure.

5.1 Public Spending, Emissions, and Climate Damages

We start by studying the dynamics triggered by a sectoral public spending shock in our model featuring the climate block. To do so, we consider a shock to public spending in the industry with the highest emission intensity of gross output: cement manufacturing. Then, we take the responses of aggregate GDP, the flow and stock of emissions, and climate damages. We replicate the same analysis in a counterfactual economy in which there is no climate block, and thus with no implications for either emissions or environmental damages.

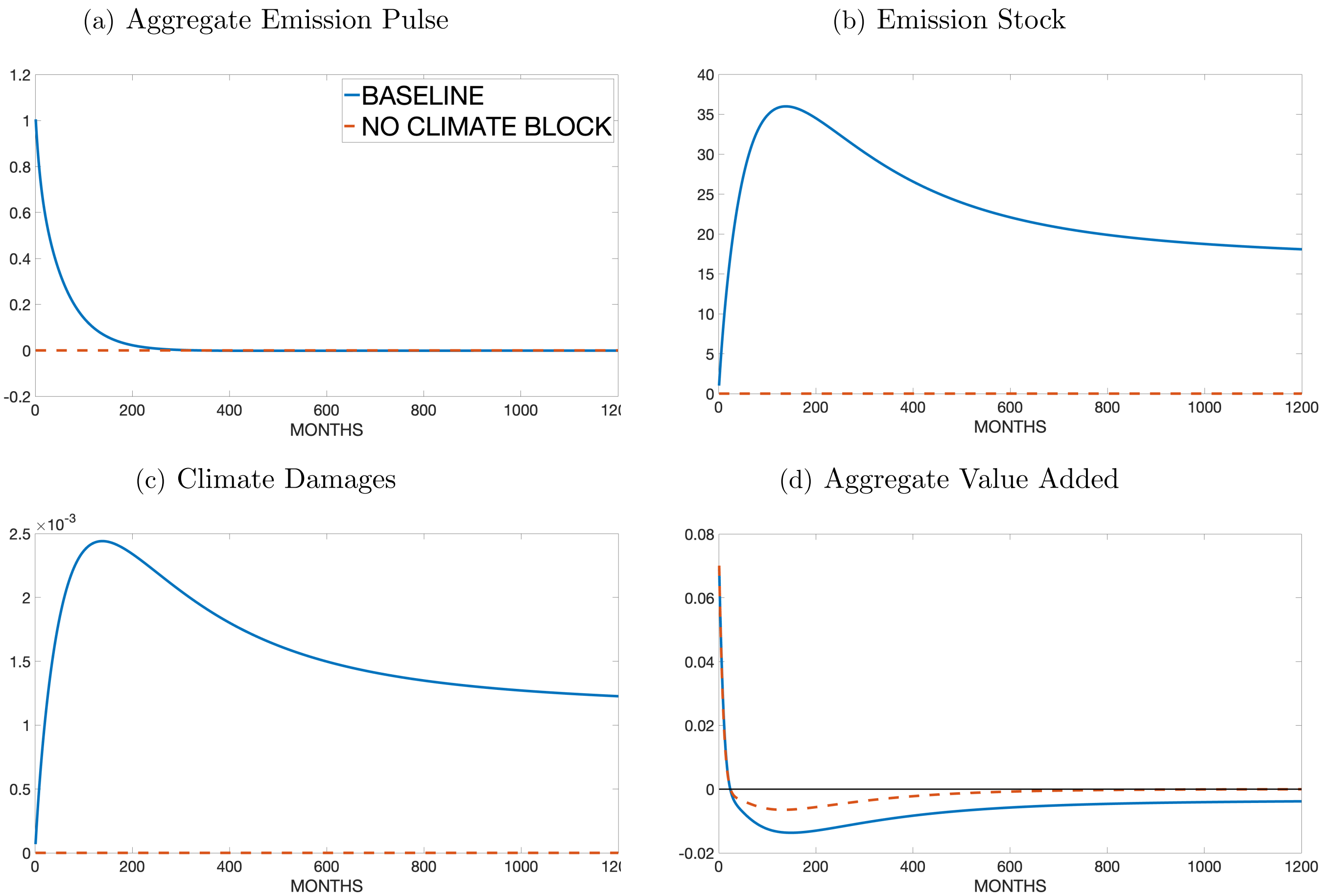
We report the results of this exercise in Figure 2. Panel (a) shows the responses of the aggregate emission pulse. While there is no emission whatsoever in the counterfactual economy with no environmental block, in the baseline model a public spending shock to cement manufacturing—that increases aggregate public spending by 1%—leads to a surge of the flow emissions on impact which equals 8.4% of the aggregate emission flow at steady state. Then, the emission pulse dies out with the same autocorrelation of public spending, since this is what drives the surge in output, and thus greenhouse gas pollutants.

Panel (b) indicates that the surge in the emission pulse leads to a rise in the stock of atmospheric carbon. Importantly, the very low depreciation rate of emissions imply that the magnitude of the flow is negligible with respect to the size of the stock of atmospheric carbon. As such, atmospheric carbon reacts very slowly with barely any change on impact. Indeed, it takes almost 12 years for the emission stock to reach its peak. After than, the reduction in the emission stock proceeds sluggishly: after reaching its peak, the stock takes 113 years to halve.

The response of climate damages is reported in Panel (c), and mirrors the behavior of the stock of emissions, as determined by Equation (30). Thus, also climate damages are slow-moving upon a public spending shock: aggregate productivity slowly drops to its through, remaining negative for an extended period.

What are the implications of these dynamics for aggregate GDP? Panel (d) shows that—absent the climate block—the bulk of the GDP response to public

Figure 2: Public Spending and the Environment



Note: The figures show the responses (in percentage deviations from steady state) of the aggregate emission pulse (Panel a), the emission stock (panel b), climate damages (Panel c), and aggregate value added (Panel d), to a public spending shocks in cement manufacturing, the industry with the highest emission intensity of gross output. The continuous line indicates the dynamics implied by the baseline model with a climate block, whereas the dashed line indicates the predictions of a counterfactual economy with no climate block.

spending is in the very short run. Since environmental damages barely move on impact, in our model the short-run response of GDP closely follows that of the counterfactual version without climate damages. However, a gap between the two emerges after 4 years, and strongly persists over time: the 50-year cumulative response of GDP accounts for just 70% of its total cumulative response (in absolute values). In other words, the GDP response to public spending is tilted towards very low frequencies. Thus, accounting for environmental dynamics provides a novel channel through which public spending can generate long-lasting effect on GDP. From this perspective, we complement the evidence of Antolin-Diaz and Surico (2025) on the long-run effects of government spending, showing that even though the role of the environment is not as quantitatively relevant as that of

R&D, its effects on GDP work at relatively lower frequencies.

5.2 Sectoral Fiscal Multipliers

To measure the effects of sectoral government spending on aggregate GDP, we use the present-value fiscal multiplier:

$$\mathcal{M}_i = \frac{\sum_{j=0}^{\infty} \beta^j \mathbb{E}_t \left(Y_{t+j} - \bar{Y} \right)}{\sum_{j=0}^{\infty} \beta^j \mathbb{E}_t \left(\frac{P_{i,t+j}}{P_{t+j}} G_{i,t+j} - \frac{\bar{P}_i}{\bar{P}} \bar{G}_i \right)}, \tag{35}$$

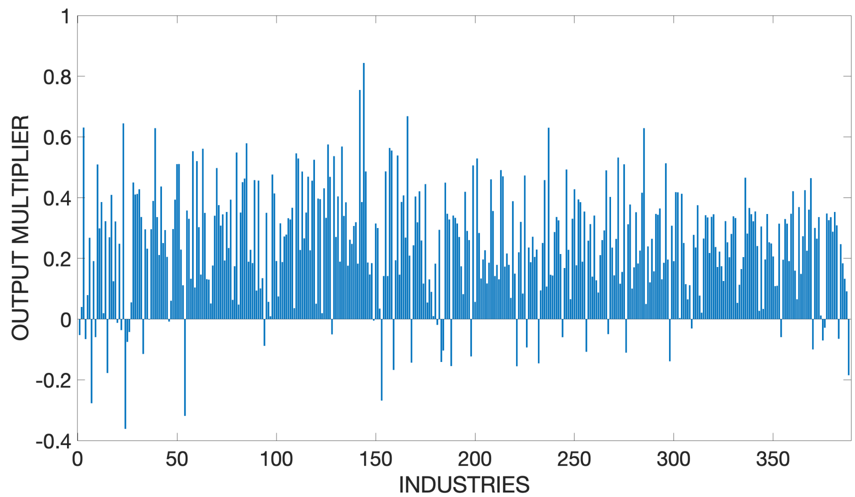
which computes the dollar change in aggregate value added associated with a temporary shock that raises public spending in sector i by one dollar.[11] Equation (35) indicates that the sectoral fiscal multipliers discount the entire path of the GDP response to a sectoral government spending shock. This discounting implies that although public spending may lead to climate damages, since they are very slow-moving and materialize only in the long run, they may not contribute at all into the measurement of the fiscal multiplier. Thus, the choice of the discounting discussed in the calibration of Section 4 is crucial not only for measuring the SCC, but also for the role of climate damages in the fiscal multipliers.

Figure 3 reports the sectoral fiscal multipliers in a version of the model without climate damages, when $\gamma = 0$, with industries arranged from the least to the most polluting. The sectoral multipliers range from a value of -0.36 associated to the case in which public spending is directed to "lessors of nonfinancial intangible assets", up to 0.84 for the case of spending in "guided missile and space vehicle manufacturing". In total, there are 40 industries with negative multipliers, and two with multipliers above 0.7 (the second one is "electric lamp bulb and part manufacturing").

What drives this variation in the sectoral fiscal multipliers? Bouakez et al. (2024) shows that the response of aggregate GDP to public spending is relatively larger when it happens in industries with (i) higher labor intensities, (ii) stickier prices, (iii) lower contribution to final private demand, and (iv) in downstream industries. For instance, negative multipliers arise when public spending originates in industries with a high share of capital in gross output. In this case, the sector cannot promptly expand its production, and thus public spending only produces crowding-out effects. These dynamics justify why taking seriously all the dimensions of sectoral heterogeneity in our calibration of Section 4 is essential for generating empirically relevant dispersion in the size of the sectoral fiscal multipliers.

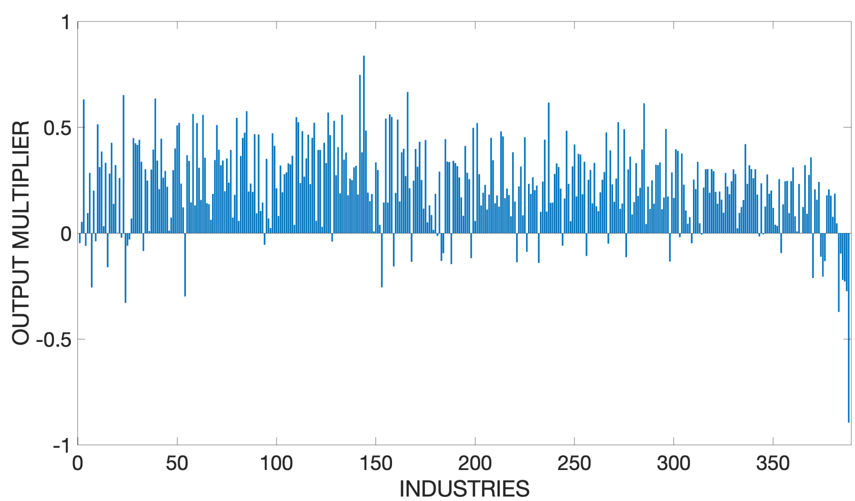
[11] The value of sectoral public spending is defined in real terms with respect to the numeraire of the economy, the aggregate consumption price, P_t.

Figure 3: Sectoral Fiscal Multipliers - Economy Without Climate Damages.



Note: The figure reports the sectoral fiscal multipliers (i.e., the discounted sum of the response of aggregate GDP to changes in public spending in each of the 388 industries of the model) in the counterfactual economy without climate damages (i.e., $\gamma = 0$). The multipliers are sorted by the carbon intensity of gross output, from the industry with the lowest value to the highest one.

Figure 4: Sectoral Fiscal Multipliers - Economy With Climate Damages.



Note: The figure reports the sectoral fiscal multipliers (i.e., the discounted sum of the response of aggregate GDP to changes in public spending in each of the 388 industries of the model) in the baseline economy with climate damages. The multipliers are sorted by the carbon intensity of gross output, from the industry with the lowest value to the highest one.

What happens when we activate the role of climate damages in the model? The sectoral fiscal multipliers of the baseline economy are shown in Figure 4. In this case, the range of multipliers is tilted towards higher negative values, going from -0.90 to 0.84. As in the previous case, there are only two industries with multipliers above 0.7, but the number of industries with negative multipliers is now 45. The industry with the lowest multiplier becomes "cement manufacturing", that is, the sector with the highest carbon intensity. This simple observations already suggests that accounting for climate damages is important to understand the output effects of public spending.

5.3 Sectoral Carbon Adjustments

Given the sectoral fiscal multipliers, the sectoral carbon adjustments equal to:

$$\text{Carbon Adjustment}_i = \mathcal{M}_i - \mathcal{M}_i|_{\gamma=0} \ . \tag{36}$$

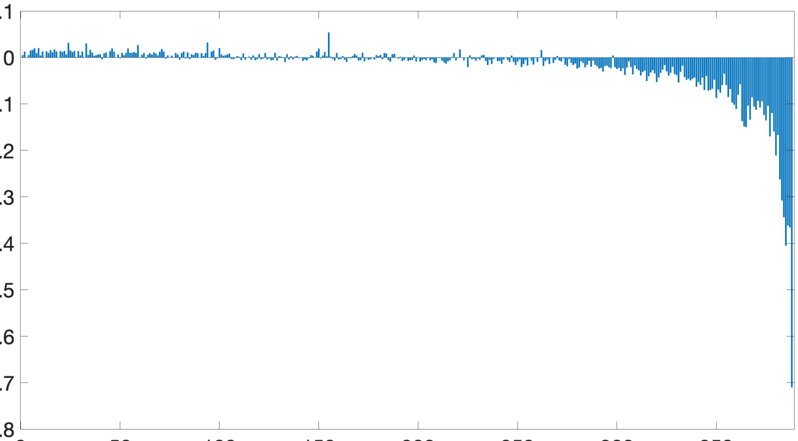
Hence, the sectoral carbon adjustments are computed as the difference between the sectoral fiscal multipliers in the baseline model, $\mathcal{M}_i$, and those of the counterfactual economy without climate damages, $\mathcal{M}_i|_{\gamma=0}$.

The carbon adjustments in Figure 5—again with industries arranged from the least to the most polluting—uncover three main findings. First, while the carbon adjustment tends to be negative, this is not always the case. The adjustment is positive (although negligible) for about 146 industries. This stands in contrast with the implications of the back-of-the-envelope measure, for which the highest possible value for the carbon adjustment is zero. In other words, Figure 5 suggests that shocks to relatively green industries (i.e., industries with low carbon intensities) crowd out brown industries (i.e., industries with high carbon intensities), pushing the stock of emissions slightly below its steady-state level, thus turning climate damages into climate gains.[12] Second, the carbon adjustment tends to be negligible for most industries. We find it to be above 5 cents in absolute value for about 50 industries. However, and this is the third main finding, the carbon adjustment is highly quantitatively relevant for those 50 industries, and can be as low as -0.71 for the most carbon-intense sector, "cement manufacturing".

These results indicate that the output effects of any public spending in infrastructure project that involves a relevant contribution from "cement manufacturing" should be severely scaled down, as it leads to a substantial boost in emissions, and thus climate damages. The same argument applies to any public spending that demands significant production from "electric power generation,

[12] To be more precise, when the stock of emissions goes below its steady-state level, also climate damages drop below steady state. Thus, while climate damages are still a negative drag for aggregate productivity, the public spending shock has resulted into an improvement in the environment, leading to a climate gain.

Figure 5: Sectoral Carbon Adjustments.



Note: The figure reports the sectoral carbon adjustments, measured as the difference between the sectoral fiscal multipliers in the baseline economy with climate damages and the sectoral fiscal multipliers in the counterfactual economy without climate damages. The carbon adjustments are sorted by the carbon intensity of gross output, from the industry with the lowest value to the highest one.

transmission, and distribution", the industry with the third-most negative carbon adjustment, with a value of -0.37.

We disentangle the contribution of consumption and investment to the sectoral carbon adjustments in Appendix A.1. Specifically, we replicate the calculation of the adjustments based on the fiscal multipliers of Equation (35), but replace aggregate GDP in the numerator with either aggregate consumption, or aggregate investment. We find that the sectoral carbon adjustments to the consumption multiplier range between -0.51 and 0.04, while for the investment multiplier the range is between -0.22 and 0.02. Consequently, climate damages dampen relatively more consumption, and through that end up affecting GDP.

Importantly, as pointed out in Section 2, the relevance of the sectoral carbon adjustments increases at higher values of the SCC (i.e., higher values of the climate damage parameter, γ) and lower interest rates (i.e., higher values of the time discount factor, β). We quantify these effects in Appendix A.2.1. For instance, if we calibrate the damage parameter to target a SCC of \$250 as in Stern (2007), the sectoral carbon adjustments range between -2.29 and 0.17. In this case, there are 75 industries with a carbon adjustment above 0.1 (in absolute terms), and 130 industries with a value above 0.05. Similarly, if we set the interest rate to 0.5% (the long-run value implied by the dot plot of the Federal Open Market

Committee of the Federal Reserve System), then even with the same damage parameter of the baseline economy, the carbon adjustments range between -1.55 and 0.12. In other words, there are empirically relevant cases in which accounting for the effect of public spending on the environment can be highly relevant, and first order for the computation of the fiscal multipliers for most industries.

Interestingly, Appendix A.2.1 shows that the difference between the model-implied carbon adjustments relate to the back-of-the-envelope measure increase with the value of the SCC. These results provide two main conclusions. First, while the back-of-the-envelope measure does not exactly matches the actual sector carbon adjustments, it provides a very good approximation at relatively low values of the SCC. Second, the approximation deteriorates at high SCC, and thus a policy maker that intends to compute the carbon adjustments and believes that the SCC is substantial should be cautious when using the back-of-the-envelope measure.

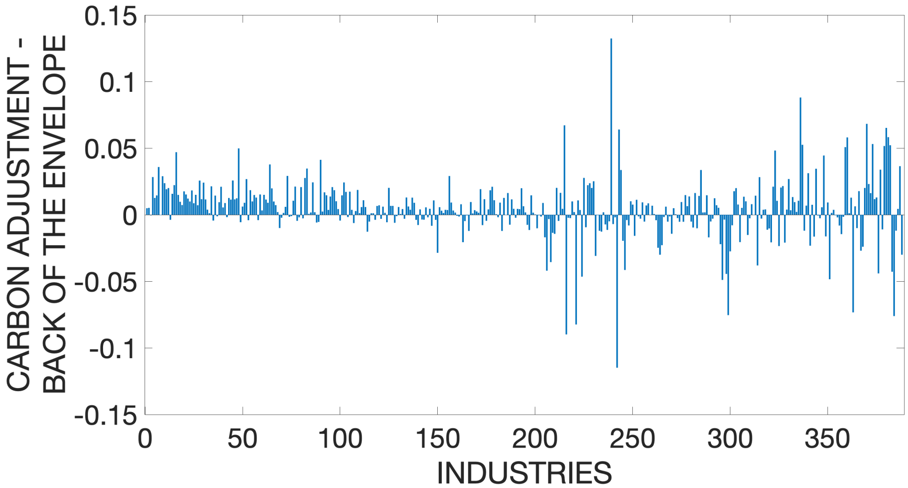
5.4 Model vs. Back-of-the-Envelope Measurement

How does the model-implied carbon adjustments relate to the back-of-the-envelope measure? We address this question by reporting the difference between these two measures in Figure 6.

We find that there are the two measures are not highly far off, as their difference ranges between -0.11 and 0.13. Actually, if we average the differences across the two measures across all industries we get a value of virtually zero. What is the rationale behind the discrepancies between the two measurements? Thee differences arise due to the stringent assumptions behind the back-of-the-envelope approach: a one-dollar increase in public spending in one sector leads to a proportional increase in gross output across sectors as predetermined by the Input-Output matrix. In doing that, it overlooks potential crowding out effects and ignores any transmission mechanisms of public spending other than sectoral differences along the supply chain. Consequently, this approach completely abstract from any general-equilibrium consideration.

These results highlight the relevance of using a model-based analysis in the measurement of the carbon adjustment. Interestingly, Appendix A.2 shows that the differences in the adjustments between the model and the back-of-the-envelope approach increase in the size of climate damages. Consequently, the bias of the simple measurement becomes limited at low values of the SCC, and can thus be used as a prima-facie estimate of the carbon adjustments.

Figure 6: Comparison with Back-of-the-Envelope Measure.



Note: The figure reports the difference between the sectoral carbon adjustments and the back-of-the-envelope measure. These differences are sorted by the carbon intensity of gross output, from the industry with the lowest value to the highest one.

5.5 Robustness Checks

We ascertain the robustness of our findings in an extensive battery of robustness checks, reported in Appendix A.2.

We first start by evaluating the role of the climate damage parameter, γ, and set different calibration that targets the same values of the SCC considered in Section 2. While the sectoral carbon adjustments become highly relevant at high values of the SCC, we find that the carbon adjustment of cement manufacturing is still about 30 cents even in case the SCC is \$31 as in Nordhaus (2017).

Then, we look into the choice of the interest rate, conditional on the baseline value of the climate damage parameter. Analogously to the previous case, we find that although the magnitude of the carbon adjustments increase at lower interest rates, they range between -0.32 and 0.03 even at a 4% rate.

Next, we evaluate the implications of different parametrization of the carbon cycle. We consider two cases which are disciplined by the predictions of the models MESMO and LOVECLIM in Joos et al. (2013). First, we set a relatively more persistent stock of atmospheric carbon so that 55% of an emission pulse is still in the atmosphere after 100 years. We then consider a carbon cycle in which 30% of an emission pulse is still in the atmosphere after 100 years. Notice that in the baseline model the fraction of an emission pulse still in the atmosphere after a century is 39%. We find that the carbon adjustments widens when considering the more persistent stock of atmospheric carbon, since its range now goes from -0.90 to 0.07, whereas the faster carbon cycle economy implies a carbon adjustment between -0.64 and 0.05. Since these two alternative specifications of the carbon cycle restrict the empirically relevant variation in carbon cycle, these results suggest that our calibration of the law of motion of atmospheric carbon is relatively conservative.

Finally, we study the role of the Frisch elasticity, price rigidity, and the imperfect mobility of labor and capital across industries. However, altering the calibration of the model along all these dimensions also modifies the magnitude of the associated climate damages. Thus, to compare economies which have the same quantitative implications on climate damages, we re-calibrate every time each economy to target the same SCC of $77 as in the baseline model. We start by looking into the value of the Frisch elasticity, and show that a low value of this parameter which is consistent with the micro-evidence on the labor supply elasticity yields if anything a slightly larger carbon adjustment. Similarly, we find that the carbon adjustment is slightly larger when we abstract from price stickiness, by considering a flexible-price economy, or when we allow labor and capital to perfectly reallocate across industries upon a shock.

6 Conclusion

This paper has introduced a novel concept in the context of fiscal policy: the carbon-adjusted fiscal multiplier. The carbon adjustment measures the dollar amount of climate damages per dollar of public spending. This concept builds on the premise that insofar public spending leads to changes in output, then it also alters emission patterns, and ultimately the magnitude of climate damages.

We build a climate production network model to quantify the carbon adjustment by focusing on sectoral fiscal multipliers, that is, the response of aggregate GDP to sector-specific public spending shocks. Crucially, the model features also sectoral heterogeneity in the carbon intensity of gross output, thus allowing us to study the implications of changes in public demand towards highly polluting sectors. In the baseline model, although the carbon adjustments are negligible for most industries, they can be as low as -0.71 for public spending in the most carbon-intensive sector, “cement manufacturing”. The magnitude of the carbon adjustments can be substantially larger if we consider either settings with (empirically relevant) higher social cost of carbons or lower interest rates.

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A Appendix

A.1 Additional Results: Consumption and Investment

This section provides additional quantitative results of our baseline model by measuring the carbon adjustment for both the consumption and investment fiscal multipliers. We start by an exercise similar to that of Section 5.1, and show the responses of aggregate consumption and aggregate investment to a public spending shock in cement manufacturing.

Figure A.1 reports the response of aggregate consumption (in Panel a) and investment (in Panel b) in the first 120 years in the aftermath of the public spending shock to cement manufacturing. The continuous lines indicate the dynamics implied by the baseline model with a climate block, whereas the dashed lines indicate the predictions of a counterfactual economy with no climate block.

The presence of the investment adjustment costs make the two responses to be negative and hump-shaped, and especially so for the case of investment. Independently on these dynamics, we find in either case that the responses in the baseline economy and the counterfactual model without climate damages coincide in the short run. As for the case of the GDP response of Figure 2, this has to do with the fact that atmospheric carbon—and thus climate damages—are very slow-moving, and barely adjust in the short run.

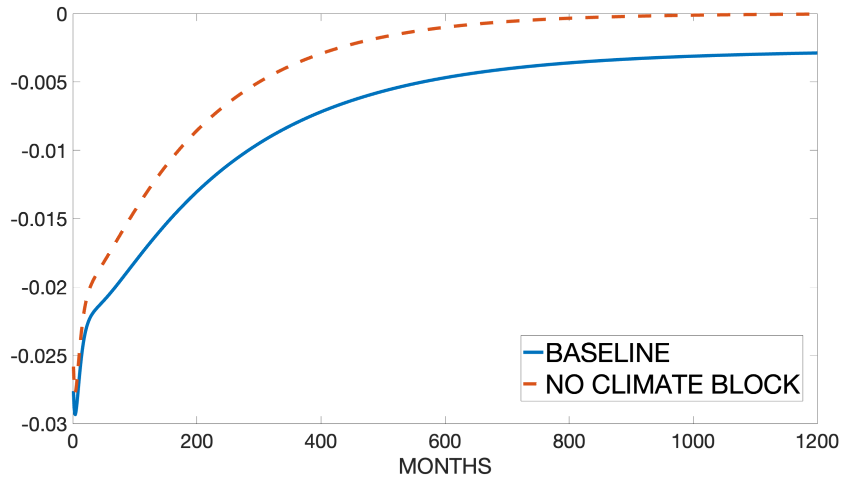
However, we find that the wedge in the responses of investment across the two model economies is quite limited. Instead, the response of consumption in the baseline economy is highly persistently negative, and the wedge with respect to the version without climate damages shows up already after 2 years. In other words, climate damages end up influencing much more the response of consumption than that of investment. From this perspective, Figure A.1 shows that the additional drop in GDP to public spending due to climate damages is mainly driven by a drop in consumption, with a much lower contribution coming from investment.

Starting from this observation, we proceed in computing also the sectoral fiscal multipliers for consumption and investment. We do so by modifying the computation of the multipliers in Equation (35) as follows. The present-value consumption fiscal multipliers, $\mathcal{M}_{C,i}$, are defined as

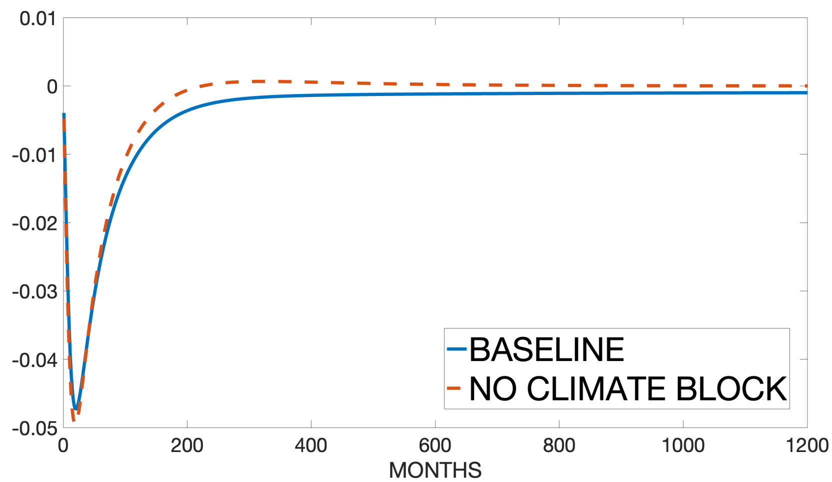
$$\mathcal{M}_{C,i} = \frac{\sum_{j=0}^{\infty} \beta^j \mathbb{E}_t \left(C_{t+j} - \bar{C}\right)}{\sum_{j=0}^{\infty} \beta^j \mathbb{E}_t \left(\frac{P_{i,t+j}}{P_{t+j}} G_{i,t+j} - \frac{\bar{P}_i}{\bar{P}} \bar{G}_i\right)}, \tag{A.1}$$

Figure A.1: Responses of Aggregate Consumption and Investment.

(a) Aggregate Consumption



(b) Aggregate Investment

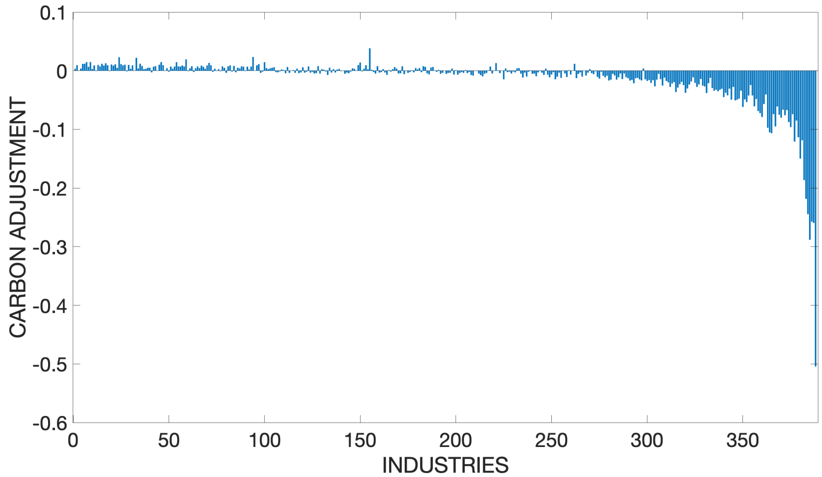


Note: The figures show the responses (in percentage deviations from steady state) of aggregate consumption (Panel a) and aggregate investment (Panel b) to a public spending shocks in cement manufacturing, the most carbon-intense industry. The continuous lines indicate the dynamics implied by the baseline model with a climate block, whereas the dashed lines indicate the predictions of a counterfactual economy with no climate block.

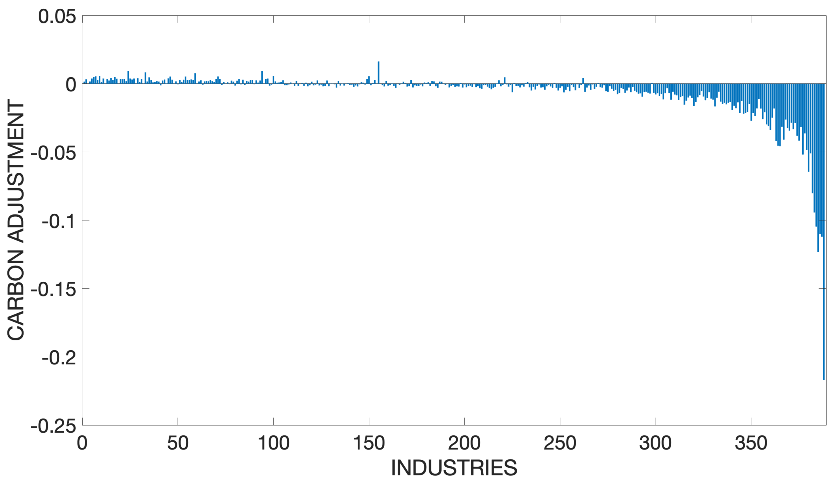
which modifies Equation (35) by substituting the change in GDP throughout the response to public spending from its steady-state level, $Y_{t+j} - \bar{Y}$, with the equivalent object but computed for aggregate consumption $C_{t+j} - \bar{C}$. Similarly,

Figure A.2: Carbon Adjustment.

(a) Consumption



(b) Investment



Note: The figure reports the sectoral carbon adjustments, measured as the difference between the sectoral fiscal multipliers in the baseline economy with climate damages and the sectoral fiscal multipliers in the counterfactual economy without climate damages, for consumption in Panel (a) and for investment in Panel (b). The carbon adjustments are sorted by the carbon intensity of gross output, from the industry with the lowest value to the highest one.

the present-value investment fiscal multipliers, $\mathcal{M}_{I,i}$, are defined as

$$\mathcal{M}_{I,i} = \frac{\sum_{j=0}^{\infty} \beta^j \mathbb{E}_t \left(\frac{P_{I,t+j}}{P_{t+j}} I_{t+j} - \frac{P_I}{P} \bar{I} \right)}{\sum_{j=0}^{\infty} \beta^j \mathbb{E}_t \left(\frac{P_{i,t+j}}{P_{t+j}} G_{i,t+j} - \frac{\bar{P}_i}{P} \bar{G}_i \right)}, \tag{A.2}$$

which differ from the GDP and consumption multiplier only to the extent that in this case we need also to take into account changes in the relative price of investment goods, $P_{I,t}/P_t$, to properly measure the variation in the value of investment upon public spending shocks.

We then replicate the measurement of the fiscal multipliers in the counterfactual economies without climate damages, and recover $\mathcal{M}_{C,i}|_{\gamma=0}$ and $\mathcal{M}_{I,i}|_{\gamma=0}$ for consumption and investment, respectively. In this case, the consumption multipliers range between -0.84 and -0.09, whereas the investment multipliers go from -0.63 and -0.07.

With these measurements, we can quantify the carbon adjustment for consumption

$$\text{Carbon Adjustment}_{C,i} = \mathcal{M}_{C,i} - \mathcal{M}_{C,i}|_{\gamma=0} \tag{A.3}$$

and the carbon adjustment for investment

$$\text{Carbon Adjustment}_{I,i} = \mathcal{M}_{I,i} - \mathcal{M}_{I,i}|_{\gamma=0} \ . \tag{A.4}$$

Figure A.2 reports the carbon adjustment for consumption in Panel (a) and that of investment in Panel (b). For the case of consumption, the carbon adjustment ranges between -0.51 and 0.04. Instead, the carbon adjustment of investment is much more limited, going from -0.22 to 0.02. In either case, the lowest value is attained when public spending originates in cement manufacturing.

These results indicate that climate damages dampen relatively more consumption, and through that end up affecting GDP. Thus, incorporating emission dynamics and climate damages in the measurement of the effect of public spending is more relevant for policy-makers interested in understanding the response of aggregate consumption.

A.2 Robustness Checks

This section evaluates the robustness of our findings on the carbon adjustments in an extensive battery of robustness checks. Section A.2.1 studies the role of different parameterizations of the climate damage parameter, γ, which is displined by targeting the range of SCCs considered in the literature. Section A.2.2 shows how the model implications vary across different values of the interest rate, implied by different calibrations of households' time discount rate, β. Finally, Section A.2.3 considers alternative calibrations of the carbon cycle, and Section A.2.4 looks into different Frisch elasticities, η.

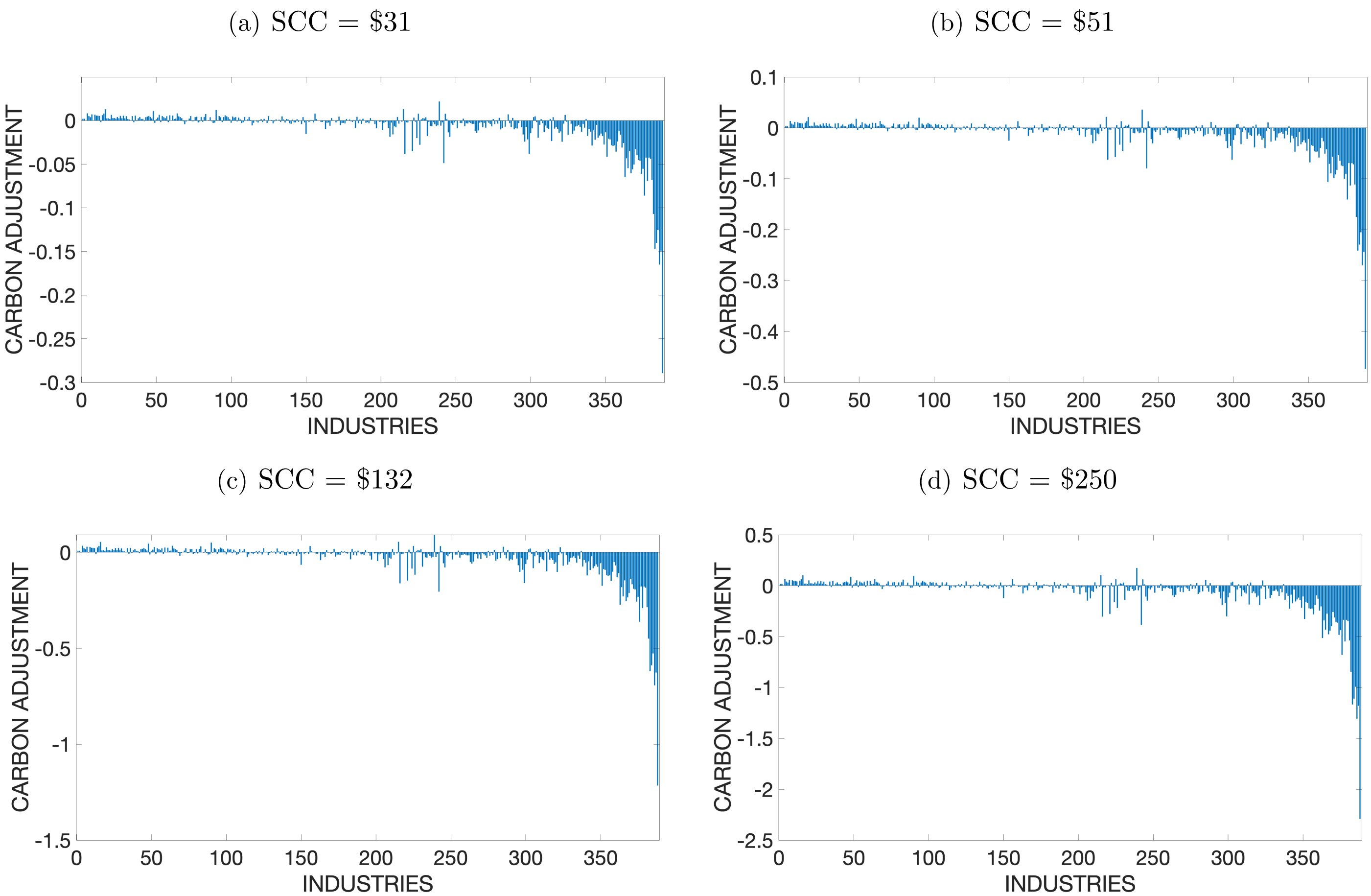
A.2.1 Role of Climate Damages

We ascertain the robustness of our findings to different calibrations of the climate damages. We discipline this exercise as follows: we select the value of climate damages, γ, such that the model yields values of the SCC—measured as in Equation (34)—which span the range considered in the literature. Specifically, we consider a SCC of \$31 estimated by Nordhaus (2017) with the DICE 2016 model; a SCC of \$51, which is the reference value of the Biden Administration; a SCC of \$132, the truncated mean of the meta-analysis of Moore et al. (2024); and a SCC of \$250 used in the Stern (2007) report. To attain these values, we need to set the climate damage parameter to $\gamma = 2.8 \times 10^{-5}$, $\gamma = 4.6 \times 10^{-5}$, $\gamma = 1.2 \times 10^{-4}$, and $\gamma = 2.3175 \times 10^{-4}$, respectively.

We then report in Figure A.3 the carbon adjustments for these different economies. The carbon adjustments range between -0.29 and 0.02 for the economy with a SCC of \$31, between -0.47 and 0.04 for the economy with a SCC of \$51, between -1.22 and 0.09 for the economy with a SCC of \$132, and between -2.29 and 0.17 for the economy with a SCC of \$250. Thus, the relevance of the range in the sectoral carbon adjustments increases directly with the value of climate damages and the SCC. In the case of a SCC of \$250, the carbon adjustment becomes quantitatively relevant for a very large number of industries. For instance, the number of sectors whose adjustment is larger than 5 cents (in absolute value) is 130, and the number of sectors with an adjustment larger than 30 cents is 28.

For each economy, we also compute the difference in the carbon adjustments comparing the model measurement and that implied by the back-of-the-envelope approach. We show the results in Figure A.4. In all cases, we keep observing discrepancies that arise from the fact that the simple approach only considers heterogeneity in the production network as the transmission channel of public spending, whereas the model encompasses additional empirically relevant sources of sectoral heterogeneity. Interestingly, the magnitude in the difference between the model and the back-of-the-envelope approach also increases in the size of the SCC. With a \$31 SCC, the differences between the carbon adjustments of the model and the simple approach range between -0.05 and 0.05. Instead, at a \$250 SCC, the range becomes much wider, going from -0.37 to 0.43. Thus, the bias in the carbon adjustment derived with simple approach becomes negligible at low values of the SCC.

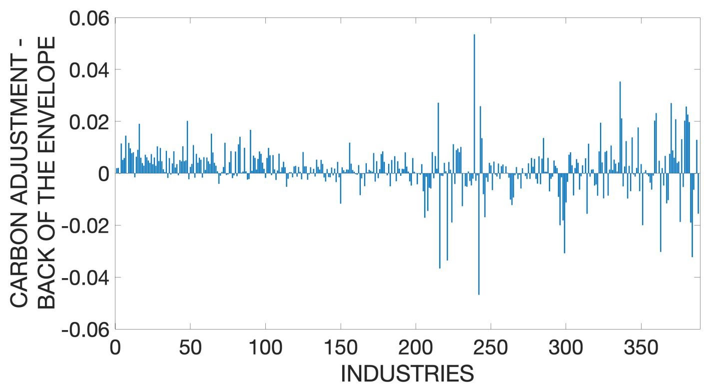
Figure A.3: Carbon Adjustments with Different Climate Damages.



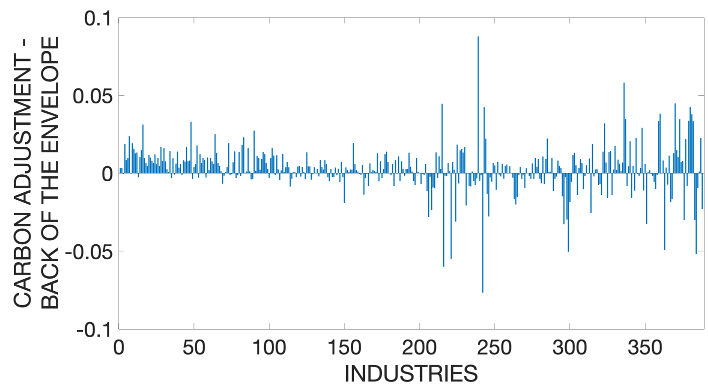
Note: The figure reports the sectoral carbon adjustments, measured as the difference between the sectoral fiscal multipliers in the baseline economy with climate damages and the sectoral fiscal multipliers in the counterfactual economy without climate damages for different specifications of climate damages. Panel (a) features $\gamma = 2.8 \times 10^{-5}$ and a SCC of \$31, Panel (b) features $\gamma = 4.6 \times 10^{-5}$ and a SCC of \$51, Panel (c) features $\gamma = 1.2 \times 10^{-4}$ and a SCC of \$132, and Panel (d) features $\gamma = 2.3175 \times 10^{-4}$ and a SCC of \$250. The carbon adjustments are sorted by the carbon intensity of gross output, from the industry with the lowest value to the highest one.

Figure A.4: Comparison with Back-of-the-Envelope Measure with Different Climate Damages.

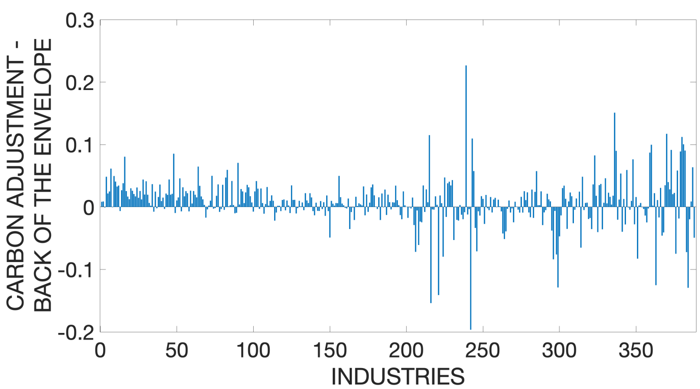
(a) SCC = \$31



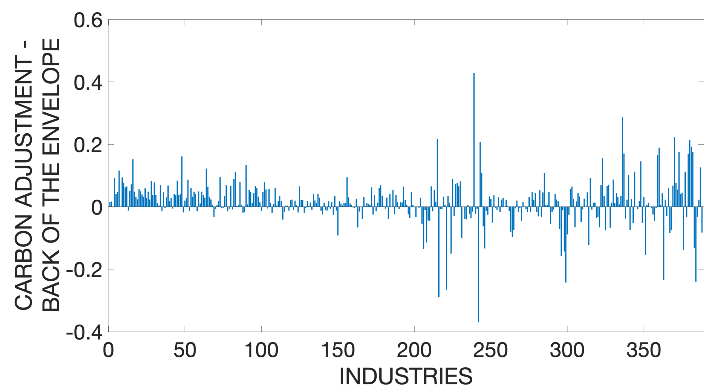
(b) SCC = \$51



(c) SCC = \$132



(d) SCC = \$250



Note: The figure reports the difference between the sectoral carbon adjustments and the back-of-the-envelope measure for different specifications of climate damages. Panel (a) features $\gamma = 2.8 \times 10^{-5}$ and a SCC of \$31, Panel (b) features $\gamma = 4.6 \times 10^{-5}$ and a SCC of \$51, Panel (c) features $\gamma = 1.2 \times 10^{-4}$ and a SCC of \$132, and Panel (d) features $\gamma = 2.3175 \times 10^{-4}$ and a SCC of \$250. The differences are sorted by the carbon intensity of gross output, from the industry with the lowest value to the highest one.

A.2.2 Role of the Interest Rates

We then evaluate the implications of different interest rates. This choice is critical for two reasons. First, the computation of the SCC crucially depends on the discounting of future climate damages, and thus increases at lower values of the interest rate. Two, the same happens when incorporating climate damages into the measurement of the fiscal multiplier. Since we consider a present-value multiplier and climate damages only emerge in the long-run, lower discounting values imply a stronger role of the environment in determining the response of output to public spending.

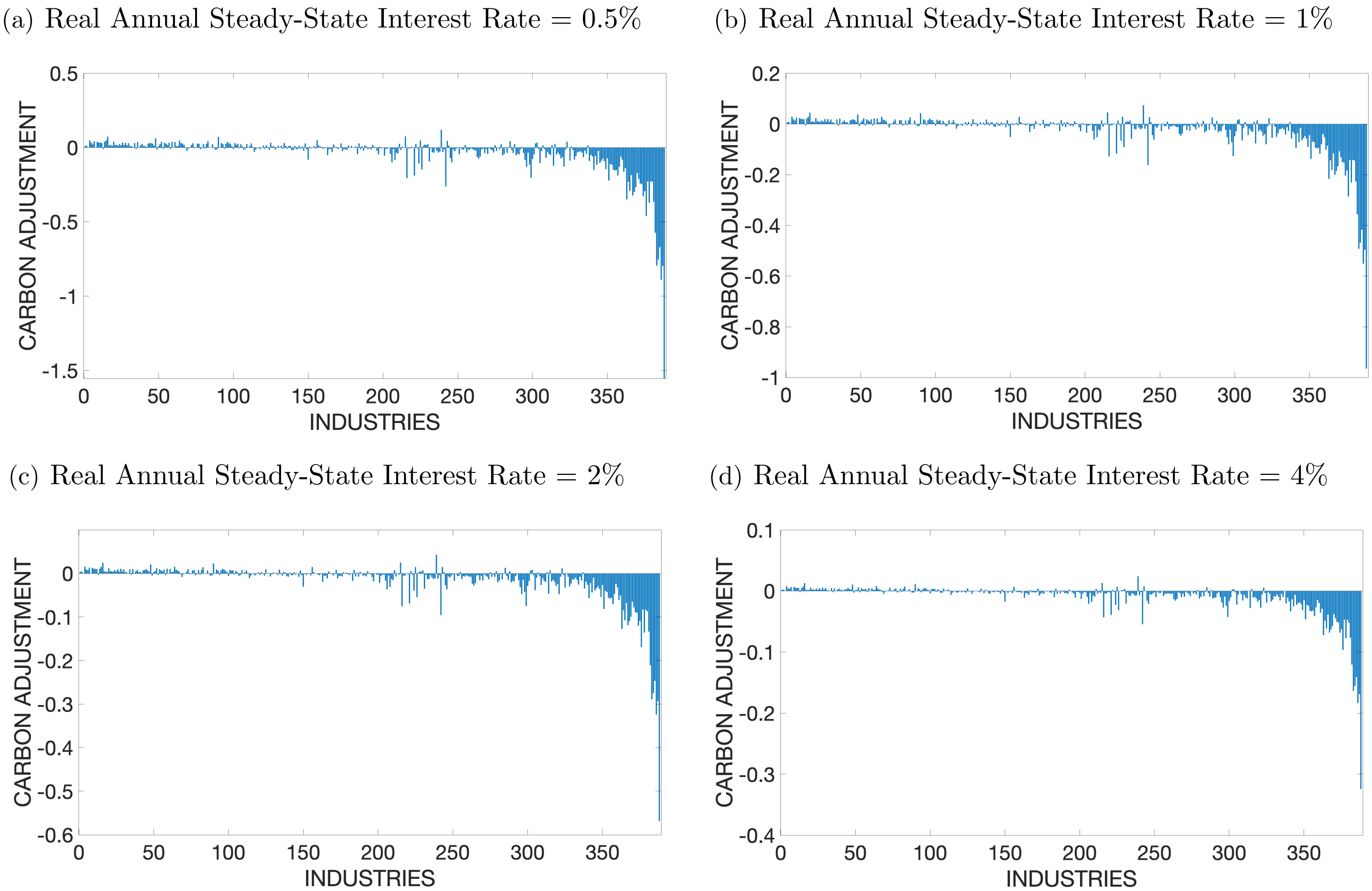
In the baseline model, we have set the real interest rate at steady state to 1.5%, in order to be consistent with the evidence of Giglio et al. (2015), Drupp et al. (2018), and Giglio et al. (2021). However, in this section we consider additional four values, ranging from the 0.5% implied by the dot plot of the Federal Open Market Committee of the Federal Reserve System (i.e., the average long-run nominal interest rate is at 2.5% and the inflation target is 2%, thus implying a 0.5% long-run real rate) up to the 4% considered in DICE models (see Nordhaus, 2013). In doing that, we also consider a value of 1% and 2%.

Different discounting implies the measurement of both the SCC and the fiscal multiplier. For instance, in the economy with a 0.5% interest rate, although we use the same climate damage parameter of the baseline, we now find a SCC of \$128. Instead, in the 4% interest rate case, the SCC equals to \$42. From this perspective, the fact that an interest rate in line with Nordhaus (2013) yields a low SCC in the line of those produced by DICE models give further validity to the calibration of climate damages in our model.

With respect to the sectoral fiscal multipliers, let us start by considering a version of the model without climate damages. In this setting, a 0.5% rate implies a range between -0.40 and 0.83, whereas a model with a 4% rate yields values between -0.30 and 0.87. These values indicate that the interest rate does not substantially alter the quantification of the multipliers. This is because the bulk of the response of GDP to public spending is in the short run, and thus different discounting choices barely alter the measurement of the fiscal multiplier.

This is not the case in the baseline economy with climate damages. Since the latter materialize in the long run, discount does matter. Indeed, a 0.5% rate implies sectoral fiscal multipliers between -1.79 and 0.82. The 4% rate economy yields a range between -0.42 and 0.86. Consequently, the different choices of the real interest rate ultimately impacts the measurement of the carbon adjustments.

Figure A.5: Carbon Adjustments with Different Interest Rates.



Note: The figure reports the sectoral carbon adjustments, measured as the difference between the sectoral fiscal multipliers in the baseline economy with climate damages and the sectoral fiscal multipliers in the counterfactual economy without climate damages for different specifications of the time discount factor, and thus the annual real interest rate at steady state. Panel (a) features $\beta = 0.9996$ and a real interest rate of 0.5%, Panel (b) features $\beta = 0.9992$ and a real interest rate of 1%, Panel (c) features $\beta = 0.9984$ and a real interest rate of 2%, and Panel (d) features $\beta = 0.9967$ and a real interest rate of 4%. The carbon adjustments are sorted by the carbon intensity of gross output, from the industry with the lowest value to the highest one.

Figure A.5 reports the carbon adjustments implied by the four calibration of the time discount parameter: Panel (a) refers to the case of a 0.5% interest rate, Panel (b) is the economy with a 1% interest rates, Panel (c) considers a 2% rate, and Panel (d) a 4% one. The range of the carbon adjustments is $[-1.55, 0.12]$ with a 0.5% interest rate, $[-0.97, 0.07]$ with a 1% interest rate, $[-0.57, 0.04]$ with a 2% interest rate, and $[-0.32, 0.03]$ with a 4% interest rate. These findings give you two main conclusions. First, even with the 4% interest rate of DICE models—and thus with a marked discounting of long-run climate damages—the lower end of the carbon adjustments are highly economically significant. Second, low interest rates consistent with empirical evidence amplify the relevance of taking into accounting environmental dynamics in the output effects of climate damages. For instance, an interest rate of 1%—which is still in the bound of discount factors considered valid by the experts surveyed in Drupp et al. (2018)—implies carbon adjustments that are larger (in absolute value) than 10 cents for 33 industries.

A.2.3 Role of the Emission Depreciation Rate

The carbon cycle of the model is calibrated in line with Joos et al. (2013), so that although 30% of the emission pulse dissipates from the atmosphere after 10 years, roughly 20% of it still remains in the atmosphere after a thousand year. As a result, the model implies that 39% of an emission pulse is still in the atmosphere after 100 years.

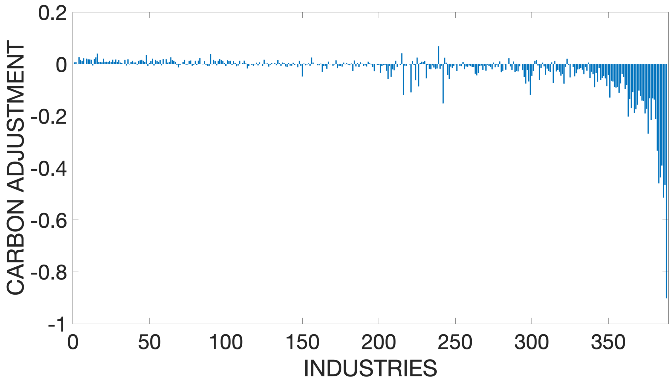
In this section, we ascertain the robustness of our results to different calibrations of the carbon cycle. To discipline this analysis, we refer again to Joos et al. (2013) and parametrize the law of motion of atmospheric carbon in line with the prediction of the models MESMO and LOVECLIM, which define the empirically relevant band on the speed of depreciation of emissions. Specifically, we consider a first economy in which carbon emissions stay longer in the atmosphere, such that 55% of an emission pulse is still in the atmosphere after 100 years. Vice versa, in the second economy the decay of emissions is relatively faster, so that after a century we have just 30% of the original emission pulse.

To match these targets, we find the following values for the parameters of the carbon cycle: $\varphi_1 = 0.000054$, $\varphi_2 = 0.001059$, and $\iota = 0.41$ for the persistent carbon-cycle case, and $\varphi_1 = 0.000054$, $\varphi_2 = 0.003843$, and $\iota = 0.313$ for the more transitory carbon-cycle economy.

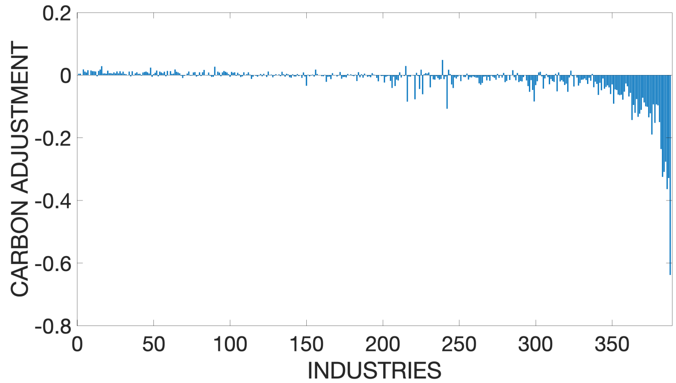
Panel (a) and (b) of Figure A.6 report the sectoral carbon adjustments implied by these two economies. We find that, in either case, there is no much variation in the carbon adjustments with respect to our baseline model, and if

Figure A.6: Carbon Adjustments - Robustness Checks.

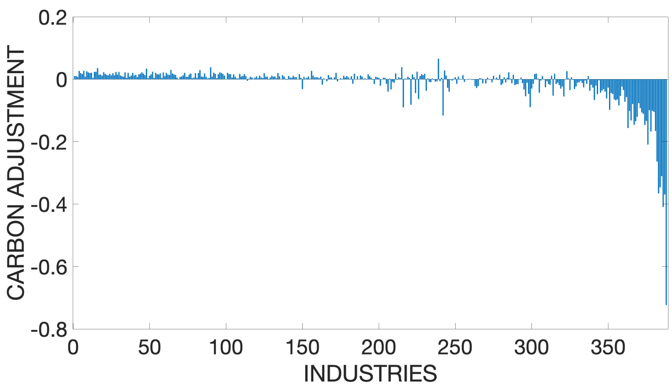
(a) Low Emission Depreciation Rate



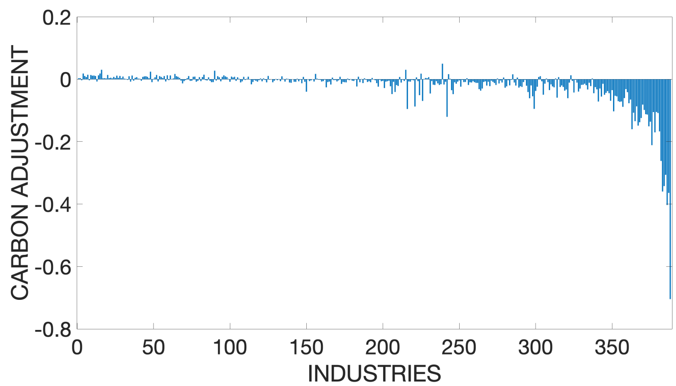
(b) High Emission Depreciation Rate



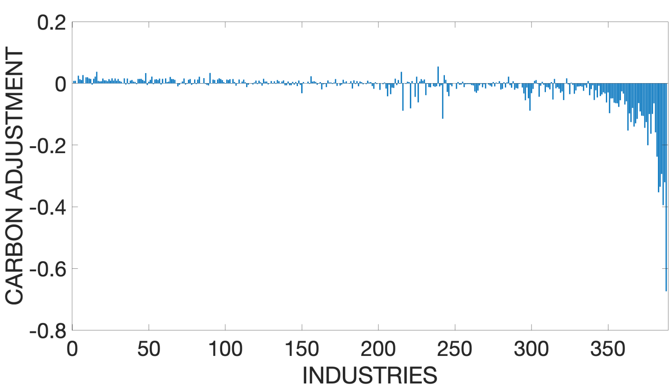
(c) Low Frisch Elasticity



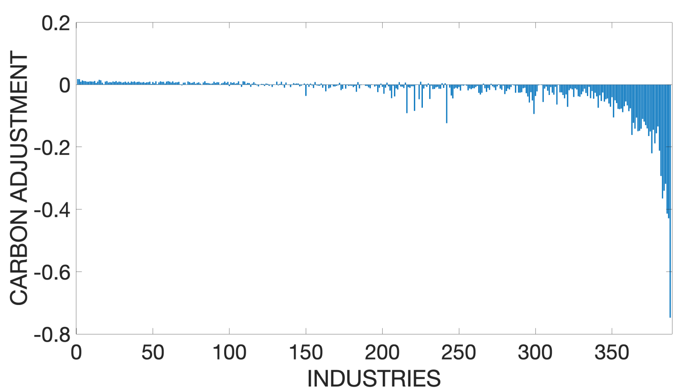
(d) High Frisch Elasticity



(e) Flexible Prices



(f) Perfect Mobility of Labor and Capital



Note: The figure reports the sectoral carbon adjustments, measured as the difference between the sectoral fiscal multipliers in the baseline economy with climate damages and the sectoral fiscal multipliers in the counterfactual economy without climate damages for different model economies. Panel (a) features a persistent carbon cycle ($\varphi_1 = 0.000054$, $\varphi_2 = 0.001059$, and $\iota = 0.41$), Panel (b) features a relatively more transitory carbon cycle ($\varphi_1 = 0.000054$, $\varphi_2 = 0.003843$, and $\iota = 0.313$), Panel (c) considers a low Frisch elasticity (i.e., $\eta = 1/0.5$), Panel (d) considers a high Frisch elasticity (i.e., $\eta = 1/4$), Panel (e) abstracts from price stickiness and considers flexible prices $\phi_i = 0$, $\forall i$, and Panel (f) considers perfect mobility of labor and capital across industries ($\nu_N, \nu_K \to \infty$). The carbon adjustments are sorted by the carbon intensity of gross output, from the industry with the lowest value to the highest one.

anything there is more margin for relatively wider ranges for the carbon adjustments. For instance, the range of sectoral carbon adjustments is $[-0.90, 0.06]$ in the low emission depreciation case, and $[-0.64, 0.05]$ in the high emission depreciation case. Since these two alternative specifications of the carbon cycle restrict the empirically relevant variation in carbon cycle, these results suggest that our calibration of the law of motion of atmospheric carbon is relatively conservative.

A.2.4 Role of the Frisch Elasticity, Price Flexibility and Factor Mobility

The last set of robustness checks focus on three main dimensions: the Frisch elasticity of labor supply, the degree of price rigidity, and the degree of mobility of labor and capital across industries. However, altering the calibration of the model along all these dimensions also modifies the magnitude of the associated climate damages. Thus, to compare economies which have the same quantitative implications on climate damages, we re-calibrate every time each economy to target the same SCC of \$77 as in the baseline model. In this way, we ensure that we can perform the right comparison with the baseline model and identify the effect of changes in the three dimensions of the robustness check by keeping constant climate damages across the different specifications.

We start with the Frisch elasticity. In the baseline calibration, we set it to 2, so that $\eta = 0.5$. This value is larger than the labor supply elasticity estimated at the individual level, which tends to be well below 1 (see Chetty et al., 2013). However, our choice is motivated by two facts. First, Erosa et al. (2016) shows that an aggregate labour supply elasticity of 1.75 is still consistent with the micro-evidence on the low labor supply elasticity at the individual level. Second, our choice allows the model to generate levels of the fiscal multipliers more in line with the literature. Indeed, the level of multipliers increases with the labor supply elasticity (Hall, 2009).

To ascertain the robustness of our findings to the calibration of the Frisch elasticity, we consider two cases. In the first one, we set the elasticity to 0.5, so that $\eta = 2$, in line with the lower end of the estimates in Chetty et al. (2013). In the second one, we consider a much higher value by setting the elasticity to 4, so that $\eta = 0.25$, in line with the value used by Ramey (2021). Importantly, reducing the labor supply elasticity also exacerbates climate damages, as households rely less on additional hours worked to reduce the negative effects of a higher amount of carbon in the atmosphere. Thus, we recalibrate the low elasticity economy by setting the climate damage parameter to $\gamma = 5.725 * 10^-5$. In other words, reducing the Frisch elasticity gets the same SCC of the baseline economy with a lower climate damage parameter. Vice versa, the economy with the higher labor supply elasticity requires a climate damage parameter of $\gamma = 7.4 * 10^-5$ to target the SCC of $77.

We then report in Panel (c) and (d) of Figure A.6 the implications of these two economies for the sectoral carbon adjustments, which hardly change relative to the baseline. They range between $[-0.72, 0.07]$ with the low elasticity, and between $[-0.71, 0.05]$ with the high elasticity. Thus, if anything, reducing the Frisch elasticity to a value consistent with the evidence at the individual level slightly increases the dispersion in the carbon adjustments. However, this economy implies substantially lower fiscal multipliers, with a maximum level of 0.22 in the case without climate damages, way below the 0.84 of the baseline economy. Instead, the high Frisch elasticity case yields to multipliers than even exceed one.

Next, we look into the role of price stickiness by setting the Calvo probabilities to zero, $\phi_i = 0 \ \forall i$, and study an economy with fully flexible prices. In this case, the SCC of the economy is very similar to the baseline case: we just need a minimal reduction in the climate damage parameter with $\gamma = 6.93 * 10^-5$ to get the same SCC of $77 of the baseline economy. Panel (e) of Figure A.6 shows that in this case the range of the carbon adjustments shrinks slightly to $[-0.67, 0.06]$.

Finally, we study an economy with perfectly mobile labor and capital across sectors, by setting $\nu_N, \nu_K \to \infty$. Also in this case we need a low reduction in the climate damage parameter to target the same SCC of the economy, with $\gamma = 6.75 * 10^-5$. In this case, Panel (f) of Figure A.6 indicates that the range of the carbon adjustments actually widens to $[-0.77, 0.02]$.

All in all, these robustness checks corroborate that our main findings on the dispersion in the carbon adjustments towards highly relevant values holds across an extensive battery of alternative parametrizations of the model or specifications of our economy.