GREEN TRANSITION IN THE EURO AREA: DOMESTIC AND GLOBAL FACTORS

2025

BANCO DE ESPAÑA
Eurosistema

Documentos de Trabajo
N.º 2537

Pablo Garcia, Pascal Jacquinot, Črt Lenarčič,
Kostas Mavromatis, Niki Papadopoulou and
Edgar Silgado-Gómez

GREEN TRANSITION IN THE EURO AREA: DOMESTIC AND GLOBAL FACTORS (*)

Pablo Garcia (**)

BANQUE CENTRALE DU LUXEMBOURG

Pascal Jacquinot (***)

EUROPEAN CENTRAL BANK

Črt Lenarčič (****)

BANKA SLOVENIJE

Kostas Mavromatis (*****)

DE NEDERLANDSCHE BANK

Niki Papadopoulou (******)

EUROPEAN CENTRAL BANK

Edgar Silgado-Gómez (*******)

BANCO DE ESPAÑA

We would like to thank Maurice Bun, Marco Del Negro, Matteo Ciccarelli, Eva Ortega, Günter Coenen, Paolo Guarda, Massimiliano Pisani, Pablo Burriel, the members of the WGEM and participants at the 7th Annual Research Conference of Banco de España, XXIX Meeting of the Central Bank Researchers' Network (CEMLA) and IAAE Annual Conference 2025 for useful comments. We are extremely grateful to Matija Lozej and Romanos Priftis for the very useful comments and discussions at various stages of this project. Last, we are grateful to Giosué Cavagna and Anna Matzner for excellent research assistance. The views expressed do not reflect those of Banque Centrale du Luxembourg, Banka Slovenije, De Nederlandsche Bank, Central Bank of Cyprus, Banco de España, or the European Central Bank. Any remaining errors are the sole responsibility of the authors.
** pablo.garciasanchez@bcl.lu
*** pascal.jacquinot@ecb.europa.eu
**** crt.lenarcic@bsi.si
***** k.mavromatis@dnb.nl
****** niki.papadopoulou@ecb.europa.eu
******* edgar.silgado@bde.es

Documentos de Trabajo. N.º 2537

October 2025

https://doi.org/10.53479/40866

The Working Paper Series seeks to disseminate original research in economics and finance. All papers have been anonymously refereed. By publishing these papers, the Banco de España aims to contribute to economic analysis and, in particular, to knowledge of the Spanish economy and its international environment.

The opinions and analyses in the Working Paper Series are the responsibility of the authors and, therefore, do not necessarily coincide with those of the Banco de España or the Eurosystem.

The Banco de España disseminates its main reports and most of its publications via the Internet at the following website: http://www.bde.es.

Reproduction for educational and non-commercial purposes is permitted provided that the source is acknowledged.

© BANCO DE ESPAÑA, Madrid, 2025

ISSN: 1579-8666 (edición electrónica)

Abstract

We explore the macroeconomic effects of climate policies promoting the green energy transition in the euro area using an extended version of the Euro Area and Global Economy (EAGLE) model. The model differentiates between brown and green energy sectors and incorporates carbon taxes and brown capital income taxes. We analyze scenarios with unilateral and globally coordinated carbon taxes, with and without revenue redistribution to green firms and financially constrained households. Carbon taxes act as negative supply shocks, raising inflation and lowering output, while subsidies to green energy firms reduce green energy prices, supporting the transition and easing recessions. Redistribution to constrained households boosts consumption but does not accelerate the green transition. Taxes on brown capital income lower both inflation and output by acting as demand shocks. Recycling revenue from this tax to subsidize green capital investment strengthens the shift to green energy and moderates economic contractions. Global coordination of carbon taxes delivers only modest additional macroeconomic effects compared with unilateral action, as substitution in energy use outweighs international spillovers. Sensitivity analyses confirm the robustness of these findings under alternative assumptions about price rigidity, substitution elasticities and monetary policy.

Keywords: climate policy, carbon taxation, fiscal policy, monetary policy, euro area, DSGE modeling.

JEL classification: C53, E32, E52, F45, H30, Q48.

Resumen

Exploramos los efectos macroeconómicos de las políticas climáticas que impulsan la transición energética en la zona del euro mediante una versión ampliada del modelo Euro Area and Global Economy (EAGLE). El modelo distingue entre sectores de energía intensiva en carbono y energía limpia, e incorpora impuestos al carbono y gravámenes sobre la renta del capital en los sectores contaminantes. Analizamos escenarios con impuestos al carbono unilaterales y coordinados a escala global, con y sin redistribución de la recaudación hacia las empresas no contaminantes y los hogares con restricciones de liquidez. Los impuestos al carbono operan como perturbaciones de oferta negativos, elevando la inflación y reduciendo la producción, mientras que las subvenciones a las empresas de energía limpia abaratan los precios de su energía, favorecen la transición y amortiguan las recesiones. La redistribución hacia los hogares financieramente restringidos impulsa el consumo, pero no acelera la transición energética. Los impuestos sobre la renta del capital contaminante reducen tanto la inflación como la producción, al operar como perturbaciones de demanda. El reciclaje de la recaudación de este impuesto para subvencionar la inversión en capital de energía limpia refuerza el desplazamiento hacia esta y modera las contracciones económicas. Los efectos macroeconómicos adicionales de la coordinación global son modestos en comparación con la acción unilateral, ya que la sustitución en el uso de la energía prevalece sobre los *spillovers* internacionales. Varios análisis de sensibilidad confirman la solidez de estos resultados bajo supuestos alternativos sobre las rigideces de los precios, las elasticidades de sustitución y la orientación de la política monetaria.

Palabras clave: política climática, impuestos al carbono, política fiscal, política monetaria, zona del euro, modelos DSGE.

Códigos JEL: C53, E32, E52, F45, H30, Q48.

1 Introduction

Following the 2015 Paris Agreement, the EU set ambitious targets to reduce greenhouse gas emissions by 55% by 2030 and 90% by 2040, aiming for carbon neutrality by 2050. Although Avgousti et al. (2023) report that the EU met its 2020 emissions reduction target early, the European Environment Agency in its latest Trends and projections in Europe 2024 projects that, without further policy action, reductions will fall short, reaching 51% by 2030 and only 62% by 2040.

Fiscal policy can play a crucial role in achieving these goals, influencing labor and capital allocation, inflation, output, and wealth distribution. Across the EU, environmental taxes serve as important tools, with carbon taxation recognized as particularly effective. In addition, the EU Emissions Trading System functions as an implicit carbon tax to limit emissions. On the expenditure side, transfers and subsidies support emission reductions and green technology adoption. Policymakers must also consider the general equilibrium effects of climate policy, carefully designing measures to manage macroeconomic impacts on key variables like output and inflation, alongside more detailed effects such as income distribution. They should also remain mindful of coordination to reduce potential distributional challenges, trade distortions, and competitiveness losses.

Against this backdrop, we use a large-scale micro-founded model to analyze the macroeconomic effects of climate policies promoting the switch to green energy, focusing on taxes and subsidies. We extend the Euro Area and Global Economy (EAGLE) dynamic stochastic general equilibrium (DSGE) model (Gomes et al., 2012), which represents the euro area within the global economy. Following prior studies such as Golosov et al. (2014), Känzig (2023), and Coenen et al. (2024), we incorporate an environmental dimension into the baseline EAGLE model. Its detailed trade matrix and distinction between tradable and non-tradable sectors provide a comprehensive framework to assess domestic environmental policies and their spillovers across the EA, US, and the rest of the world.

On the supply side, monopolistically competitive brown energy firms combine brown capital and labor to produce a brown energy good, which generates carbon emissions. In contrast, green energy firms combine green capital and labor to produce a green energy good, which is emission-free.[1] Both types of energy goods are then sold to domestic households for final consumption or to domestic intermediate tradable and non-tradable firms for use as inputs. On the demand side, households consume energy and non-energy goods using a constant elasticity of substitution (CES) aggregator. In addition, households with full access to asset markets can accumulate three types of physical capital: brown (fossil fuel-intensive), green (clean-energy intensive) and non-energy-related. Importantly, accumulating new brown and green capital requires importing tradable goods, creating a direct channel through which foreign environmental policy affects domestic outcomes. Regarding environmental policies, the government in each region (i) imposes a carbon tax as a surcharge on the price of the brown energy; (ii) taxes households' brown capital income; and (iii) redistributes a share of these revenues to green energy producers and households.

Our first exercise assesses the macroeconomic effects of a carbon tax imposed as a surcharge on brown energy, targeting both consumers and intermediate producers. We examine the impact of introducing this carbon tax solely within the EA, without redistribution of its revenue, as well as scenarios where carbon tax revenues are redistributed to green energy firms and financially constrained households. In addition, we explore the effects of a globally coordinated increase in carbon taxes.

Without redistribution and with a domestic carbon tax, our results align with those of Coenen et al. (2024). The tax acts as a negative supply shock, reducing output and raising inflation. In response, the monetary authority increases the policy rate, causing the euro to appreciate against its trading partners' currencies and shrinking the trade balance. Regarding energy use and production, the carbon tax raises the price of brown energy, reducing demand from firms and households, leading to lower brown production, while green energy production rises.

Redirecting a third of the carbon tax revenues to green energy firms (with the remaining two-thirds allocated to government debt or regular expenditures) strengthens the transition and moderates the recessionary effects. Green energy inflation declines as producer subsidies lower marginal costs, amplifying substitution away from brown energy. Extending redistribution to financially constrained households boosts their consumption through higher disposable income

[1] Hence, our setup captures the idea that producing green and brown energy requires different stocks of capital. For example, brown capital could include coal plants or oil refineries, while green capital could involve wind turbines, solar panels, or hydroelectric plants.

but does little to accelerate the green transition. The effects of a fully revenue-neutral policy, in which all carbon tax proceeds are redistributed equally between green firms and constrained households, are a scaled-up version of the partial redistribution case: a stronger green transition and a smaller contraction in output.

Importantly, carbon taxes are disinflationary in the brown energy market: higher taxes reduce brown energy inflation before tax, even as output declines. This indicates that demand effects dominate supply-side pressures in the short- to medium run. Redistributive policies further strengthen this demand channel, slightly amplifying the decline in brown energy inflation before tax. In the medium- to longer-run however the supply channel dominates due to the strong decline in brown energy output, leading to an overshooting of brown energy inflation before tax. In the green energy market, by contrast, the absence of redistribution leads to an increase in inflation. This effect substantially weakens or even reverses when redistribution is introduced, highlighting the role of supply-side support in easing price pressures during the transition.

We also examine a globally coordinated increase in carbon taxes. While the contraction in EA output is larger and inflation rises somewhat more than under a unilateral tax, the differences remain modest. Substitution effects in energy use continue to dominate over international spillovers. A key distinction is that the euro appreciates far less than in the unilateral scenario, leading to higher non-energy inflation and a larger decline in household purchasing power, both of which contribute to the sharper fall in aggregate consumption.

Next, we study taxes on brown capital rental income. These measures shift incentives away from brown investment by reducing after-tax returns. Unlike carbon taxes, they generate both lower output and lower inflation, acting as a negative demand shock. The transition to green energy proceeds through the same substitution mechanisms, but without the inflation-output tradeoff associated with carbon taxes. When the tax revenues are used to subsidize green capital income, the shift toward green energy strengthens, while the contraction in GDP and consumption becomes more moderate.

Finally, we undertake a detailed sensitivity analysis to assess the robustness of our baseline findings. We re-run the core experiments under five alternative specifications: (i) a gradual, permanent increase in the carbon tax consistent with long-term climate targets; (ii) greater price rigidity in energy sectors; (iii) higher elasticity of substitution between brown and green energy in household and firm energy composites; (iv) higher substitutability between tradable and non-tradable inputs in the production of brown energy investment goods; and (v) a Taylor rule that targets headline rather than core inflation. The qualitative implications remain unchanged—carbon taxation entails an inflation–output trade-off, and taxes on brown capital lower both output and inflation—while the magnitude and persistence of effects vary in a manner consistent with economic theory. Permanent tax paths generate more persistent macroeconomic adjustments, greater substitutability accelerates the shift to green energy, and higher price stickiness in the brown energy sector amplifies the adverse effects on both real GDP and inflation.

Literature review. Our work contributes to the literature that uses dynamic general equilibrium models to explore environmental policies. Due to the breadth of this field, we only reference a few key contributions. Golosov et al. (2014) derive an analytical expression for the optimal carbon tax in a closed-economy real model, showing how it depends on factors such as the discount rate and economic damages from carbon emissions. Känzig (2023) incorporates nominal rigidities and household heterogeneity, emphasizing that the economic burden of climate policy is unevenly distributed. Lanteri and Rampini (2025) shift the focus to firm heterogeneity, showing that financially constrained, smaller firms are more likely to invest in older, more polluting capital than their unconstrained, larger counterparts. In turn, Acemoglu et al. (2012) and Acemoglu et al. (2016) study optimal climate policy in an endogenous growth framework with clean and dirty technologies, while Baldwin et al. (2020) highlight the role of investment frictions, studying how brown capital irreversibility and learning-by-doing in green technologies shape policy effectiveness.

The closest paper to ours is Coenen et al. (2024), which extends the ECB's New Area-Wide Model (NAWM) by incorporating disaggregated energy production, distinguishing between dirty and clean energy. However, there are key distinctions between our approach and Coenen et al. (2024)—some related to the NAWM and EAGLE models themselves, and others stemming from the specific energy-related features we introduce. First, the EAGLE model with its detailed trade matrix and inclusion of tradable and non-tradable sectors allows us to emphasize the open economy dimension of environmental policy. Second, we analyze different types of capital with varying environmental impacts: fossil fuel-intensive, clean energy-intensive, and non-energy-related. Third, unlike Coenen et al. (2024), where a competitive firm combines brown and green energy into a single final energy good for production and consumption, we treat brown and green energy as distinct commodities, each subject to its own market-clearing condition.

Other papers that explore the impact of carbon taxes on the economy using large-scale DSGE models for quantitative analysis include Varga et al. (2022), Del Negro et al. (2023), and Bartocci et al. (2024). However, these models differ from ours in terms of formulation or research questions.[2] Bartocci et al. (2024) examine the macroeconomic effects of carbon taxes using a two-country model of the euro area and the rest of the world. They find that carbon taxes push down aggregate inflation because the negative impact on aggregate demand outweighs the direct inflationary effect. We find these strong negative demand pressures in the market for brown energy only in the short- to medium-run, where brown energy inflation before carbon tax declines. However, this strong negative demand effect in the market for brown energy is not enough to impede the rise in headline inflation.

Lastly, our paper contributes to the literature using Integrated Assessment Models (IAMs) or Computable General Equilibrium frameworks to assess the impacts of carbon taxes. Among the earliest IAMs is the DICE/RICE family of models, which was recently reviewed by Nordhaus (2017). Other notable examples include the GCAM model of Calvin et al. (2019) and the MAgPIE model in Dietrich et al. (2019). In contrast to these studies, we employ a large-scale micro-founded model, enabling us to investigate the transmission channels of climate change on the macroeconomy over the short to medium term. The aforementioned models, on the other hand, are better suited for examining the interactions between climate and the economy over longer time horizons.

Organization of the paper. The paper is structured as follows. Section 2 presents the theoretical extension of the EAGLE model. Section 3 discusses the calibration of the key structural

[2]For instance, Varga et al. (2022) use a DSGE model of the European Union and the rest of the world with a detailed disaggregation of energy for production and consumption to analyze the impact of carbon policies on real activity. Similar to our results, they find that carbon taxes reduce GDP, but this negative effect can be mitigated if fiscal revenues are recycled to reduce other distortionary taxes or subsidize clean energy production. However, their analysis does not address the effects on nominal variables, such as inflation. Del Negro et al. (2023) develop a multi-sector New Keynesian model and, in line with our results, they find that carbon taxes create an inflation-output tradeoff.

parameters, with a focus on the energy sector. Section 4 reports our quantitative results for the carbon tax, global coordination on carbon pricing, and taxes on brown capital investment. Section 5 tests the sensitivity of our findings to alternative parameter values and modeling assumptions. Section 6 concludes.

2 Modeling Environment

2.1 A sketch of the original EAGLE model

The Euro Area and Global Economy (EAGLE) model is a multi-country DSGE model that represents the euro area within a global framework, capturing the interactions between four regions—two within the euro area and two outside. The model treats all regions symmetrically, except for monetary policy, which is unified across the euro area but region-specific elsewhere. Below, we outline the model's structure and refer readers to Gomes et al. (2010, 2012) for a detailed exposition.

Each region consists of infinitely-lived households that consume final goods, accumulate capital, and supply labor to firms. Households are divided into two categories based on their access to financial markets: unconstrained households (also known as Ricardian) can trade assets—holding money, bonds, and capital—while constrained households (also known as non-Ricardian) lack market access and rely solely on money to smooth consumption over time. Physical capital is domestically owned, but unconstrained households in each region participate in international financial markets, trading riskless bonds denominated in US dollars. For these households, an uncovered interest parity condition links the interest rate differential to the expected change in the exchange rate between the domestic currency and the global core currency, the US dollar. The presence of constrained households allows the model to incorporate Keynesian effects of public expenditure. Labor markets are characterized by monopolistic competition, introducing wage rigidity. Following Calvo (1983), only a fraction of wages can be renegotiated each period, while the rest adjust according to a weighted average of past and steady-state inflation.

The production side of the model involves several layers. An intermediate sector produces both tradable and non-tradable goods using capital and labor services, employing Cobb-Douglas technologies. These intermediate firms set prices according to a Calvo pricing mechanism, introducing price rigidity into the model. Tradable goods are sold both domestically and internationally, while non-tradable goods are restricted to the domestic market. Export prices are set in the currency of the destination country, meaning the pass-through of exchange rate fluctuations into import prices is incomplete in the short run. Competitive firms then aggregate domestic non-tradables, domestic tradables, and imported tradables into final goods for private consumption and investment, using constant-elasticity-of-substitution production functions. Public consumption, however, is entirely focused on domestic non-tradable goods.

Each country has both a monetary authority and a fiscal authority (with a shared monetary authority in the case of the euro area). The monetary authority sets the nominal interest rate using a standard Taylor rule, responding to the domestic inflation rate and output growth rate. The fiscal authority determines public expenditure and sets lump-sum transfers. Public expenditure is financed through taxes or public debt issued on domestic financial markets. Taxes may be lump-sum or distortionary, with the latter applied to labor income, capital income, and consumption. A fiscal rule ensures the stability of public debt. In the case of the two regions within the monetary union, monetary and nominal exchange rate policies are coordinated at the union level, while fiscal policies remain region-specific.[3]

2.2 From EAGLE to C-EAGLE

We extend the EAGLE model to include energy sectors, drawing on the works of Känzig (2023) and Coenen et al. (2024). Our model departs from Coenen et al. (2024) in several key areas. Households consume final goods, including non-energy, brown energy, and green energy, with the shares of energy goods in the consumption bundle treated as preference parameters. Although this setup allows for different energy shares between Ricardian and non-Ricardian households (as in Känzig, 2023), we assume equal weights for simplicity. Furthermore, Ricardian households accumulate both brown and green capital alongside regular capital, enabling us to differentiate between taxes on brown capital and subsidies for green investments.

On the supply side, we distinguish between monopolistically competitive brown and green

[3]To complement this brief description, Figure 1 illustrates the production structure of the extended EAGLE model, incorporating the energy sector, which we will explore in more detail next.

energy producers. The former use brown capital and labor to produce brown energy, which generates carbon emissions. Green energy producers, in turn, use green capital and labor to produce green energy, which is emission-free. These energy firms sell their output exclusively within the domestic economy, either directly to households for final consumption or to domestic intermediate tradable and non-tradable goods firms that use energy as an input. These intermediate firms operate under monopolistic competition and use a CES production function with a non-unit elasticity between energy and non-energy inputs.

The government in each region imposes carbon taxes as a surcharge on the price of brown energy, as well as taxes on the returns from brown capital investment. We investigate various redistribution schemes, which can target green energy firms, financially constrained households, or both.

Although the original EAGLE analyzes four different regions, in C-EAGLE the focus narrows down to three regions, namely the EA, the US and the rest of the world. The structure of the economy is symmetric across all three regions of the model. For brevity, we focus on the home region, as the same framework applies to other regions, with particular emphasis on the energy sector (the rest follows the structure of the original EAGLE model).[4] The size of the world economy is normalized to one. The size of each region measures the share of resident households and domestic sector-specific firms, both defined on a continuum of mass s. In what follows, the focus is on the Home economy (H) of size s^H.

2.3 Final goods firms

On the production side, we assume the following structure. In the final goods market, there is a continuum of perfectly competitive producers who combine tradable and non-tradable intermediate goods to produce a final non-energy consumption good (see A.3 in the online Appendix). Similarly, a continuum of perfectly competitive producers creates final investment goods. Our model distinguishes between three types of capital, which leads to three categories of final investment goods producers: general investment goods producers (see A.4 in the online Appendix), brown investment goods producers, and green investment goods producers. The energy sector

[4]Market clearing conditions are detailed in the online Appendix C.

is monopolistically competitive and produces both brown and green energy. Energy goods are sold to consumers for final consumption and to intermediate goods producers as inputs. Brown energy is produced using brown capital and labor through Cobb-Douglas technology, while green energy is produced similarly using green capital and labor. All final goods are non-tradable.

2.3.1 Brown and green energy investment goods

Firms producing brown and green energy investment goods are symmetric, act under perfect competition and use non-tradable, domestic and imported tradable intermediate goods as inputs. The intermediate goods are assembled according to a constant elasticity of substitution (CES) technology.

Brown energy investment good. Each firm $x \in \left[0, s^H\right]$ produces a brown energy investment good $\mathcal{Q}^{IB}(x)$ with the following CES technology:[5]

$$\mathcal{Q}^{IB}(x) = \left[v_{IB}^{\frac{1}{\mu_{IB}}} TT_t^{IB}(x)^{\frac{\mu_{IB}-1}{\mu_{IB}}} + (1 - v_{IB})^{\frac{1}{\mu_{IB}}} NT_t^{IB}(x)^{\frac{\mu_{IB}-1}{\mu_{IB}}} \right]^{\frac{\mu_{IB}}{\mu_{IB}-1}} \tag{1}$$

where:

$$TT_t^{IB}(x) = \left[v_{TIB}^{\frac{1}{\mu_{TIB}}} HT_t^{IB}(x)^{\frac{\mu_{TIB}-1}{\mu_{TIB}}} + (1 - v_{TIB})^{\frac{1}{\mu_{TIB}}} IM_t^{IB}(x)^{\frac{\mu_{TIB}-1}{\mu_{TIB}}} \right]^{\frac{\mu_{TIB}}{\mu_{TIB}-1}} \tag{2}$$

Two intermediate inputs are used in the production of the brown investment good. A basket NT_t^{IB} of non-tradable intermediate goods and a composite bundle TT_t^{IB} of domestic (HT_t^{IB}) and imported (IM_t^{IB}) tradable goods. The parameter $\mu_{IB} > 0$ denotes the intra-temporal elasticity of substitution between tradable and non-tradable goods, while $v_{IB} \in [0, 1]$ measures the weight of the tradable bundle in the production of the brown investment good. For the bundle of tradable goods, the parameter $\mu_{TIB} > 0$ denotes the intra-temporal elasticity of substitution between the bundles of domestic and foreign tradable intermediate goods, while $v_{TIB} \in [0, 1]$ measures the weight of domestic tradable intermediate goods. Imports $IM_t^{IB}(x)$ are a CES

[5]The IB superscript in $\mathcal{Q}^{IB}(x)$ stands for brown investment.

function of basket of goods imported from other countries:

$$IM_t^{IB}(x) = \left[\sum_{CO \neq H} \left(\upsilon_{IMIB}^{H,CO} \right)^{\frac{1}{\mu_{IMIB}}} \left(IM_{IB,t}^{H,CO}(x) \left(1 - \Gamma_{IM^{IB},t}^{H,CO}(x) \right) \right)^{\frac{\mu_{IMIB}-1}{\mu_{IMIB}}} \right]^{\frac{\mu_{IMIB}}{\mu_{IMIB}-1}} \tag{3}$$

where $\mu_{IMIB} > 0$ and the coefficients $\upsilon_{IMIB}^{H,CO}$ are such that $0 \leq \upsilon_{IMIB}^{H,CO} \leq 1$, $\sum_{CO \neq H} \upsilon_{IMIB}^{H,CO} = 1$.[6] The term $\Gamma_{IM^{IB},t}^{H,CO}(x)$ represents adjustment costs on bilateral investment imports of country H from country CO:

$$\Gamma_{IM^{IB},t}^{H,CO}(x) \equiv \frac{\gamma_{IMIB}}{2} \left(\frac{IM_{IB,t}^{H,CO}(x) / \mathcal{Q}_t^{IB}(x)}{IM_{IB,t-1}^{H,CO} / \mathcal{Q}_{t-1}^{IB}} - 1 \right)^2, \quad \gamma_{IMIB} \geq 0 \tag{4}$$

We assume that each firm x takes the previous period (sector-wide) import share of brown investment good, $IM_{IB,t-1}^{H,CO}/\mathcal{Q}_{t-1}^{IB}$, and the current demand for its brown investment good, $\mathcal{Q}_t^{IB}(x)$, as given. On one hand, the adjustment costs lower the short-run price elasticity of imports of brown investment good, while on the other hand, the level of imports of brown investment good is permitted to jump in response to changes in brown investment good demand.

Green energy investment good. The production structure for green energy investment goods mirrors that of brown investment goods, with the same nested CES framework and analogous parameters specific to the green sector. Each firm $x \in [0, s^H]$ produces a green energy investment good $\mathcal{Q}^{IG}(x)$ with the following CES technology:[7]

$$\mathcal{Q}_t^{IG}(x) = \left[\upsilon_{IG}^{\frac{1}{\mu_{IG}}} TT_t^{IG}(x)^{\frac{\mu_{IG}-1}{\mu_{IG}}} + (1 - \upsilon_{IG})^{\frac{1}{\mu_{IG}}} NT_t^{IG}(x)^{\frac{\mu_{IG}-1}{\mu_{IG}}} \right]^{\frac{\mu_{IG}}{\mu_{IG}-1}} \tag{5}$$

where the composite tradable input $TT_t^{IG}(x)$ is itself a CES aggregate of domestic and imported tradables:

$$TT_t^{IG}(x) = \left[\upsilon_{TIG}^{\frac{1}{\mu_{TIG}}} HT_t^{IG}(x)^{\frac{\mu_{TIG}-1}{\mu_{TIG}}} + (1 - \upsilon_{TIG})^{\frac{1}{\mu_{TIG}}} IM_t^{IG}(x)^{\frac{\mu_{TIG}-1}{\mu_{TIG}}} \right]^{\frac{\mu_{TIG}}{\mu_{TIG}-1}} \tag{6}$$

[6] The subscript letters $IMIB$ refer to imports of tradable goods to produce a brown investment good x.

[7] The IG superscript in $\mathcal{Q}^{IG}(x)$ stands for green investment.

Production requires two intermediate inputs: a non-tradable basket $NT_t^{IG}(x)$ and a tradable bundle $TT_t^{IG}(x)$. The parameter $\mu_{IG} > 0$ is the elasticity of substitution between tradable and non-tradable components, and $v_{IG} \in [0,1]$ determines the share of tradables in green investment production. Within the tradable input, the elasticity of substitution between domestic and imported inputs is $\mu_{TIG} > 0$, with $v_{TIG} \in [0,1]$ denoting the weight of domestic sources. Imports $IM_t^{IG}(x)$ are constructed as a CES aggregate over country-level imports:

$$IM_t^{IG}(x) = \left[\sum_{CO \neq H} \left(v_{IMIG}^{H,CO} \right)^{\frac{1}{\mu_{IMIG}}} \left(IM_{IG,t}^{H,CO}(x) \left(1 - \Gamma_{IM^{IG},t}^{H,CO}(x) \right) \right)^{\frac{\mu_{IMIG}-1}{\mu_{IMIG}}} \right]^{\frac{\mu_{IMIG}}{\mu_{IMIG}-1}} \tag{7}$$

where $\mu_{IMIG} > 0$ and the weights $v_{IMIG}^{H,CO}$ satisfy $0 \leq v_{IMIG}^{H,CO} \leq 1$, $\sum_{CO \neq H} v_{IMIG}^{H,CO} = 1$. The adjustment cost function $\Gamma_{IM^{IG}}^{H,CO}(x)$ applies to bilateral green investment imports from each source country:

$$\Gamma_{IM^{IG},t}^{H,CO}(x) \equiv \frac{\gamma_{IMIG}}{2} \left(\frac{IM_{IG,t}^{H,CO}(x) / \mathcal{Q}_t^{IG}(x)}{IM_{IG,t-1}^{H,CO} / \mathcal{Q}_{t-1}^{IG}} - 1 \right)^2, \quad \gamma_{IMIG} \geq 0 \tag{8}$$

Firms treat the lagged sector-wide import share $IM_{IG,t-1}^{H,CO}/\mathcal{Q}_{t-1}^{IG}$ and the current demand for $\mathcal{Q}_t^{IG}(x)$ as given. The adjustment cost mechanism dampens the short-term responsiveness of import flows to price signals but still allows for discrete jumps in import levels in response to shifts in demand for green investment goods.

2.3.2 Energy sector: Brown and green energy producers

Consistent with the data (see Dhyne et al., 2006) and following Känzig (2023), we assume that final good firms in the energy sectors are monopolistically competitive and use a technology similar to that in Golosov et al. (2014). As in Coenen et al. (2024), brown and green energy firms set prices infrequently in the spirit of Calvo (1983). Each brown energy variety is produced by a firm b in a continuum of mass s^H ($b \in [0, s^H]$). Similarly, each green energy variety is produced by a firm g in a continuum of the same mass s^H ($g \in [0, s^H]$).

Technology. Each brown and green good, respectively b and g, is produced using a Cobb-Douglas technology:

$$
\begin{aligned}
Y_{B,t}(b) &= z_{B,t} K_{B,t}^{D}(b)^{\gamma_B} N_t^{D}(b)^{1-\gamma_B} - \psi_B & (9)\\
Y_{G,t}(g) &= z_{G,t} K_{G,t}^{D}(g)^{\gamma_G} N_t^{D}(g)^{1-\gamma_G} - \psi_G & (10)
\end{aligned}
$$

where ψ_B and ψ_G are fixed costs taking the same values across firms belonging to the same sector. The inputs are homogeneous capital services, $K_{B,t}^{D}(b)$ and $K_{G,t}^{D}(g)$, and an index of differentiated labor services, $N_t^{D}(b)$ and $N_t^{D}(g)$. Capital and labor services are supplied by domestic households under perfect competition and monopolistic competition, respectively. In addition, $z_{B,t}$ and $z_{G,t}$ are sector-specific productivity shocks. The profits of the brown energy firm receive the following form:

$$
P_{B,t} Y_{B,t}(b) - \left(1+\tau_t^{W_F}\right) W_t N_t^{D}(b) - R_{B,t}^{K} K_{B,t}(b) \tag{11}
$$

To support the green transition, firms in the green energy sector receive a subsidy, $\tau_t^{E_G}$, proportional to their revenues. The total amount of subsidy that they receive constitutes a fraction, ς_E^{Y}, of the government's carbon tax revenues. The variable $\tau_t^{W_F}$ is a payroll tax rate levied by the domestic government on wage payments. We assume it is the same across firms. The profits of the green energy firm receive the following form:

$$
\left(1+\tau_t^{E_G}\right) P_{G,t} Y_{G,t}(g) - \left(1+\tau_t^{W_F}\right) W_t N_t^{D}(g) - R_{G,t}^{K} K_{G,t}(g) \tag{12}
$$

Cost minimization. Firms belonging to the brown (green) sector take the rental cost of capital $R_{B,t}^{K}$ ($R_{G,t}^{K}$) and the aggregate wage index W_t as given. Firms belonging to the brown sector demand capital and labor services to minimize total input cost, $R_{B,t}^{K} K_{B,t}^{D}(b) + \left(1+\tau_t^{W_F}\right) W_t N_t^{D}(b)$, subject to the production function (9). Similarly, firms in the green sector minimize the cost $R_{G,t}^{K} K_{G,t}^{D}(g) + \left(1+\tau_t^{W_F}\right) W_t N_t^{D}(g)$ subject to the production function (10).

The first-order conditions of the firms' cost minimization problem with respect to capital and labor inputs—respectively $K_{B,t}^{D}(b)$ and $N_t^{D}(b)$ for the brown sector, $K_{G,t}^{D}(g)$ and $N_t^{D}(g)$ for the green sector—are sector-specific. Given that all firms face the same factor prices and all firms use the same technology, the nominal marginal cost is identical across firms within each sector (i.e. $MC_{B,t} = MC_t\,(b)$ and $MC_{G,t} = MC_t\,(g)$):

$$MC_{B,t} = \frac{1}{z_{B,t}\,(\gamma_B)^{\gamma_B}\,(1-\gamma_B)^{1-\gamma_B}}\left(R^K_{B,t}\right)^{\gamma_B}\left(\left(1+\tau_t^{W_F}\right)W_t\right)^{1-\gamma_B} \tag{13}$$

$$MC_{G,t} = \frac{1}{z_{G,t}\,(\gamma_G)^{\gamma_G}\,(1-\gamma_G)^{1-\gamma_G}}\left(R^K_{G,t}\right)^{\gamma_G}\left(\left(1+\tau_t^{W_F}\right)W_t\right)^{1-\gamma_G} \tag{14}$$

Price setting. Each firm in the energy goods sector sells its differentiated output under monopolistic competition. Brown and green energy-producing firms set their prices infrequently *à la* Calvo (1983). Specifically, brown energy-producing firms reset their price with probability $(1-\xi_B)$. When instead they do not reset their price, they index the prevailing price of the previous period, $P_{B,t-1}$, to the previous period's brown energy price inflation, $\pi_{B,t}$, and its steady state counterpart, π_B, with indexation parameter, χ_B. Brown energy firms maximize the discounted sum of their current and expected future nominal profits:

$$E_t\sum_{k=0}^{\infty}\Lambda_{I,t,t+k}\,\xi_B^k\left[\prod_{s=1}^{k}\pi_{B,t+s-1}^{\chi_B}\pi_B^{(1-\chi_B)}\widetilde{P}_{B,t}(b)Y_{B,t+k}(b) - MC_{B,t+k}\left(Y_{B,t+k}(b)+\psi_B\right)\right] \tag{15}$$

subject to the total demand for energy brand b of firms in the intermediate goods sectors and households, each specified in detail below. In the expression above $\Lambda_{I,t,t+k}$ is the stochastic discount factor of the financially unconstrained households to be specified in section 2.5.1 and who are assumed to own brown energy producing firms. The first-order condition reads as follows:[8]

$$\frac{\widetilde{P}_{B,t}}{P_{B,t}} = \frac{\theta_B}{\theta_B-1}\,\frac{F_{B,t}}{G_{B,t}} \tag{16}$$

[8]Since we assume that all brown energy-producing firms that reset their price choose the same price ($\widetilde{P}_{B,t}$), we drop index b in what follows.

where θ_B is the elasticity of substitution across brown energy good varieties. Furthermore, $F_{B,t}$ and $G_{B,t}$ are specified as follows:

$$F_{B,t} = \frac{MC_{B,t}}{P_{B,t}} Y_{B,t} + \xi_B \beta E_t \left[\frac{\Lambda_{I,t+1}}{\Lambda_{I,t}} \left(\frac{\pi_{B,t+1}}{\pi_{B,t}^{\chi_B} \pi_B^{1-\chi_B}} \right)^{1-\theta_B} F_{B,t+1} \right] \tag{17}$$

$$G_{B,t} = Y_{B,t} + \xi_B \beta E_t \left[\frac{\Lambda_{I,t+1}}{\Lambda_{I,t}} \left(\frac{\pi_{B,t+1}}{\pi_{B,t}^{\chi_B} \pi_B^{1-\chi_B}} \right)^{\theta_B - 1} G_{B,t+1} \right] \tag{18}$$

The aggregate brown energy price index is a weighted average of the price that is reset in a generic period t and the past price indexed to past and steady-state brown energy price inflation:

$$P_{B,t} = \left[\xi_B \left(P_{B,t-1} \pi_{B,t-1}^{\chi_B} \pi_B^{1-\chi_B} \right)^{1-\theta_B} + (1-\xi_B) \left(\widetilde{P}_{B,t} \right)^{1-\theta_B} \right]^{\frac{1}{1-\theta_B}} \tag{19}$$

Turning now to green energy-producing firms, as explained above, they receive a subsidy that is a fraction ς_E^Y of the government's carbon tax revenues (specified in section 2.6.2) and reset their price with probability $(1-\xi_G)$. When instead they do not reset their price, they index the prevailing price of the previous period, $P_{G,t-1}$, to the previous period's green energy price inflation, $\pi_{G,t}$, and its steady state counterpart, π_G. Once re-setting the price, the energy good firm of brand g maximizes the expected discounted sum of its future nominal profits:

$$E_t \sum_{k=0}^{\infty} \Lambda_{I,t,t+k}\, \xi_G^k \left[\left(1 + \tau_{t+k}^{E_G}\right) \prod_{s=1}^{k} \pi_{G,t+s-1}^{\chi_G} \pi_G^{(1-\chi_G)} \widetilde{P}_{G,t}(g) Y_{G,t+k}(g) - MC_{G,t+k} \left(Y_{G,t+k}(g) + \psi_G \right) \right] \tag{20}$$

subject to the total demand for energy brand g of firms in the intermediate goods sectors and households, each specified in detail below. In the expression above, $\Lambda_{I,t,t+k}$ is again the stochastic discount factor of type I households (to be specified below) who are assumed to own green energy firms. The first order condition reads as follows:

$$\frac{\widetilde{P}_{G,t}}{P_{G,t}} = \frac{\theta_G}{\theta_G - 1} \frac{F_{G,t}}{G_{G,t}} \tag{21}$$

where θ_G is the elasticity of substitution across green energy good varieties. Furthermore, $F_{G,t}$ and $G_{G,t}$ are specified as follows:

$$F_{G,t} = \frac{MC_{G,t}}{P_{G,t}} Y_{G,t} + \xi_G \beta E_t \left[\frac{\Lambda_{I,t+1}}{\Lambda_{I,t}} \left(\frac{\pi_{G,t+1}}{\pi_{G,t}^{\chi_G} \pi_G^{1-\chi_G}} \right)^{1-\theta_G} F_{G,t+1} \right] \tag{22}$$

$$G_{G,t} = \left(1+\tau_t^{E_G}\right) Y_{G,t} + \xi_G \beta E_t \left[\frac{\Lambda_{I,t+1}}{\Lambda_{I,t}} \left(\frac{\pi_{G,t+1}}{\pi_{G,t}^{\chi_G} \pi_G^{1-\chi_G}} \right)^{\theta_G-1} G_{G,t+1} \right] \tag{23}$$

where parameter χ_G determines the degree of indexation to past green energy price inflation. Since we assume that all the green energy-producing firms that reset their prices choose the same price, we have dropped index g in the expressions above. The aggregate green energy price index is a weighted average of the price that is reset in a generic period t ($\widetilde{P}_{G,t}$) and the past price indexed to past and steady-state green energy price inflation:

$$P_{G,t} = \left[\xi_G \left(P_{G,t-1} \pi_{G,t-1}^{\chi_G} \pi_G^{1-\chi_G} \right)^{1-\theta_G} + (1-\xi_G) \left(\widetilde{P}_{G,t} \right)^{1-\theta_G} \right]^{\frac{1}{1-\theta_G}} \tag{24}$$

2.4 Intermediate goods firms

Firms produce tradable and non-tradable intermediate goods under monopolistic competition. Each tradable brand is produced by a firm h in a continuum of mass s^H ($h \in [0, s^H]$). Tradable goods firms sell domestically and abroad, setting prices in local currency. Each non-tradable brand is produced by a firm n in a continuum of the same mass s^H ($n \in [0, s^H]$). Both sectors use brown and green energy goods.

Technology. Each tradable and non-tradable intermediate good, respectively h and n, is produced according to:

$$Y_{T,t}^S(h) = z_{T,t} \left[\nu_{YT}^{\frac{1}{\varepsilon_T}} \left(K_t^D(h)^{\alpha_T} N_t^D(h)^{1-\alpha_T} \right)^{\frac{\varepsilon_T-1}{\varepsilon_T}} + (1-\nu_{YT})^{\frac{1}{\varepsilon_T}} \left(E_t^D(h) \right)^{\frac{\varepsilon_T-1}{\varepsilon_T}} \right]^{\frac{\varepsilon_T}{\varepsilon_T-1}} - \psi_T \tag{25}$$

$$Y_{N,t}^S(n) = z_{N,t} \left[\nu_{YN}^{\frac{1}{\varepsilon_N}} \left(K_t^D(n)^{\alpha_N} N_t^D(n)^{1-\alpha_N} \right)^{\frac{\varepsilon_N-1}{\varepsilon_N}} + (1-\nu_{YN})^{\frac{1}{\varepsilon_N}} \left(E_t^D(n) \right)^{\frac{\varepsilon_N-1}{\varepsilon_N}} \right]^{\frac{\varepsilon_N}{\varepsilon_N-1}} - \psi_N \tag{26}$$

where $\nu_{YT} \in (0,1)$ and $\nu_{YN} \in (0,1)$ denote the shares of non-energy inputs in the production of tradable and non-tradable intermediate goods, respectively. The parameters $\epsilon_T > 0$ and $\epsilon_N > 0$ represent the elasticity of substitution between non-energy and energy inputs. Here ψ_T and ψ_N are fixed costs, assumed to be identical across firms within each sector. Non-energy inputs consist of homogeneous capital services, $K_t^D(h)$ and $K_t^D(n)$, and an index of differentiated labor services, $N_t^D(h)$ and $N_t^D(n)$. Capital is supplied under perfect competition, while labor services are provided under monopolistic competition by domestic households. The variables $z_{T,t}$ and $z_{N,t}$ represent sector-specific productivity shocks. Total energy input, denoted $E_t^D(\cdot)$, is further decomposed as follows:

$$E_t^D(h) = \left(\nu_{ET}^{\frac{1}{\epsilon_E}} \left(E_{B,t}(h)\right)^{\frac{\epsilon_E - 1}{\epsilon_E}} + (1 - \nu_{ET})^{\frac{1}{\epsilon_E}} \left(E_{G,t}(h)\right)^{\frac{\epsilon_E - 1}{\epsilon_E}}\right)^{\frac{\epsilon_E}{\epsilon_E - 1}} \tag{27}$$

$$E_t^D(n) = \left(\nu_{EN}^{\frac{1}{\epsilon_E}} \left(E_{B,t}(n)\right)^{\frac{\epsilon_E - 1}{\epsilon_E}} + (1 - \nu_{EN})^{\frac{1}{\epsilon_E}} \left(E_{G,t}(n)\right)^{\frac{\epsilon_E - 1}{\epsilon_E}}\right)^{\frac{\epsilon_E}{\epsilon_E - 1}} \tag{28}$$

where $\nu_{ET} \in (0,1)$ and $\nu_{EN} \in (0,1)$ denote the shares of brown energy, $E_{B,t}(\cdot)$, in the energy composite used for producing tradable and non-tradable goods, respectively. The parameter $\epsilon_E > 0$ represents the elasticity of substitution between brown and green energy, $E_{G,t}(\cdot)$, assumed identical across tradable and non-tradable sectors for simplicity. Tradable and non-tradable goods producers face a carbon tax, $\tau_t^{E_B}$, levied as a surcharge on the price of brown energy. As a result, the energy price index for intermediate goods producers is defined as:

$$\mathcal{P}_{ET,t} = \left(\nu_{ET} \left((1 + \tau_t^{E_B}) P_{B,t}\right)^{1-\epsilon_E} + (1 - \nu_{ET}) P_{G,t}^{1-\epsilon_E}\right)^{\frac{1}{1-\epsilon_E}} \tag{29}$$

$$\mathcal{P}_{EN,t} = \left(\nu_{EN} \left((1 + \tau_t^{E_B}) P_{B,t}\right)^{1-\epsilon_E} + (1 - \nu_{EN}) P_{G,t}^{1-\epsilon_E}\right)^{\frac{1}{1-\epsilon_E}} \tag{30}$$

where $P_{B,t}$ and $P_{G,t}$ denote the prices of brown and green energy goods, respectively. Expenditure minimization yields the following standard demands for brown and green energy:

$$E_{B,t}(z) = \left(\frac{(1+\tau_t^{E_B})P_{B,t}}{\mathcal{P}_{E,t}}\right)^{-\epsilon_E} \nu E_t(z) \tag{31}$$

$$E_{G,t}(z) = \left(\frac{P_{G,t}}{\mathcal{P}_{E,t}}\right)^{-\epsilon_E} (1-\nu)E_t(z), \qquad \text{for } z = h, n \tag{32}$$

where $\mathcal{P}_{E,t}$ and ν correspond to $\mathcal{P}_{EN,t}$ and ν_{EN} for non-tradable firms, and to $\mathcal{P}_{ET,t}$ and ν_{ET} for tradable firms.

Cost minimization. Firms belonging to the intermediate sectors take the rental cost of capital R_t^K, the aggregate wage index W_t and the price of energy as given. Firms belonging to the tradables sector demand capital and labor services to minimize total input cost $R_t^K K_t^D(h) + \mathcal{P}_{ET,t} E_{E,t}^D(h) + \left(1+\tau_t^{W_F}\right) W_t N_t^D(h)$ subject to the production function, (25). Similarly, firms in the non-tradables intermediate sector minimize the cost $R_t^K K_t^D(n) + \mathcal{P}_{EN,t} E_t^D(n) + \left(1+\tau_t^{W_F}\right) W_t N_t^D(n)$ subject to the production function (26). Given that all firms face the same factor prices and all firms use the same technology, the nominal marginal cost is identical across firms within each sector (i.e. $MC_{N,t} = MC_t(n)$ and $MC_{T,t} = MC_t(h)$):

$$MC_{T,t} = z_{T,t}^{-1}\left[\nu_{YT}\left(\frac{\left(R_t^K\right)^{\alpha_T}(\Omega_t)^{1-\alpha_T}}{(\alpha_T)^{\alpha_T}(1-\alpha_T)^{1-\alpha_T}}\right)^{1-\varepsilon_T} + (1-\nu_{YT})\,\mathcal{P}_{ET,t}^{1-\varepsilon_T}\right]^{\frac{1}{1-\varepsilon_T}} \tag{33}$$

$$MC_{N,t} = z_{N,t}^{-1}\left[\nu_{YN}\left(\frac{\left(R_t^K\right)^{\alpha_N}(\Omega_t)^{1-\alpha_N}}{(\alpha_N)^{\alpha_N}(1-\alpha_N)^{1-\alpha_N}}\right)^{1-\varepsilon_N} + (1-\nu_{YN})\,\mathcal{P}_{EN,t}^{1-\varepsilon_N}\right]^{\frac{1}{1-\varepsilon_N}} \tag{34}$$

where $\Omega_t = \left(1+\tau_t^{W_F}\right) W_t$.

Price setting. Firms in the tradable and non-tradable goods sectors operate under monopolistic competition setting their prices infrequently *à la* Calvo (1983). As mentioned above, tradable goods firms sell their goods domestically and abroad, opting for local currency pricing, meaning that they set a different price for their good according to the destination market. Firms in the non-tradable sector sell their goods domestically only. The full description of the maximization problem of tradable and non-tradable goods firms is identical to that in the original model of Gomes et al. (2012) and in order to save space we do not report them here, directing thus the reader to the relevant section of their paper.

Carbon emissions. Following Coenen et al. (2024), we assume that CO_2 emissions, $\mathcal{E}_t$, arise from the production of brown energy, as well as from the production of tradable and non-tradable goods:

$$\mathcal{E}_t = \phi_0 Y_{B,t} + \phi_1 Y_{T,t}^S + \phi_2 Y_{N,t}^S \tag{35}$$

where the parameters ϕ_0, ϕ_1, $\phi_2 \geq 1$ measure the emissions per unit of output of brown energy, tradable goods, and non-tradable goods, respectively (see e.g. Heutel, 2012).

2.5 Households

There are two types of households, Ricardian and non-Ricardian. Ricardian households are indexed by $i \in [0, s^H(1-\omega)]$. They have access to financial markets, where they buy and sell domestic government bonds and internationally traded bonds, accumulate physical capital (regular, brown or green), rent their services to firms and hold money for transaction purposes. We refer to those as financially unconstrained households. Non-Ricardian households are indexed by $j \in (s^H(1-\omega), s^H]$. They cannot trade in financial and physical assets but they can intertemporally smooth consumption by adjusting their holdings of money. We refer to those as financially constrained households. Both types of households supply differentiated labor services and act as wage setters in monopolistically competitive markets.

Both types of households consume energy and non-energy goods using a CES aggregator:

$$\mathbb{C}_t(z) = \left(\nu_{C,z}^{\frac{1}{\epsilon_C}} \quad C_t(z)^{\frac{\epsilon_C - 1}{\epsilon_C}} + (1-\nu_{C,z})^{\frac{1}{\epsilon_C}} \quad C_{E,t}(z)^{\frac{\epsilon_C-1}{\epsilon_C}} \right)^{\frac{\epsilon_C}{\epsilon_C - 1}}, \quad \text{for} \quad z = i, j \tag{36}$$

where ϵ_C is the intra-temporal elasticity between non-energy and energy consumption goods, $\nu_{C,z}$ is the share of non-energy consumption goods in the consumption bundle of type $z = i$ (financially unconstrained) or type $z = j$ (financially constrained) household. For simplicity, we assume that both types of households have the same shares of non-energy and energy goods in their baskets, so that $\nu_{C,I} = \nu_{C,J}$.[9] The consumption of energy goods is further decomposed into:

$$C_{E,t}(z) = \left(\nu_{B,z}^{\frac{1}{\epsilon_{BG}}} \left(C_{B,t}(z)\right)^{\frac{\epsilon_{BG}-1}{\epsilon_{BG}}} + (1-\nu_{B,z})^{\frac{1}{\epsilon_{BG}}} \left(C_{G,t}(z)\right)^{\frac{\epsilon_{BG}-1}{\epsilon_{BG}}} \right)^{\frac{\epsilon_{BG}}{\epsilon_{BG}-1}}, \quad \text{for} \quad z = i, j \quad (37)$$

where $C_{B,t}$ and $C_{G,t}$ represent consumption in brown and green energy goods while $\nu_{B,z}$ is the share of brown energy goods in the energy bundle of household I and J, respectively. For simplicity, we assume that both household types have the same shares of brown and green energy goods in their baskets, so that $\nu_{B,I} = \nu_{B,J}$. ϵ_{BG} is the intra-temporal elasticity of substitution between brown and green energy goods.

Given that household types have the same shares of non-energy and energy goods in their consumption bundles, the aggregate price index is defined as:[10]

$$\mathcal{P}_{\mathbb{C},t} = \left(\nu_C P_{C,t}^{1-\epsilon_C} + (1-\nu_C)\, P_{C_E,t}^{1-\epsilon_C} \right)^{\frac{1}{1-\epsilon_C}} \quad (38)$$

where $\nu_C = \nu_{C,I} = \nu_{C,J}$. $P_{C,t}$ is the price of non-energy consumption goods and $P_{C_E,t}$ is the aggregate price index of energy goods. Consumers face a tax, $\tau_t^{E_B}$, which is levied as a surcharge on the price of the brown energy good.[11] Hence, the aggregate price index of energy goods is defined as:

$$P_{C_E,t} = \left(\nu_B \left((1+\tau_t^{E_B}) P_{B,t} \right)^{1-\epsilon_{BG}} + (1-\nu_B) \left(P_{G,t}\right)^{1-\epsilon_{BG}} \right)^{\frac{1}{1-\epsilon_{BG}}} \quad (39)$$

where $\nu_B = \nu_{B,I} = \nu_{B,J}$. Since we restrict ourselves to identical shares of energy and non-energy goods and identical shares of brown and green energy goods in the consumption bundles across households, the energy price indices in (38) and (39) are common for Ricardian and non-Ricardian

[9] As explained below, this assumption ensures a single aggregate price index for the composite final consumption good, which we use as the numeraire. This significantly simplifies the analysis, as, for instance, there is a single consumer price index inflation tracked by the monetary authority. Please note that Coenen et al. (2024) makes the same assumption.

[10] Notice that the reference price (*numéraire*) set to unity in the model is now the total consumption deflator including energy goods ($\mathcal{P}_{\mathbb{C},t} = 1$), implying $P_{C,t} = \left[\upsilon_C \left(P_{TT^C,t}\right)^{1-\mu_C} + (1-\upsilon_C) \left(P_{NT,t}\right)^{1-\mu_C} \right]^{\frac{1}{1-\mu_C}}$ where $P_{TT^C,t}$ and $P_{NT,t}$ represent the price of total tradable consumption goods and the price of non-tradable consumption goods respectively, as defined in the original EAGLE model.

[11] For simplicity, we assume that the carbon tax rate imposed on consumers is equal to that on tradable and non-tradable goods firms.

ones. Expenditure minimization yields the demand schedules for non-energy consumption and energy goods:

$$C_{B,t}(z) = \left(\frac{\left(1+\tau_t^{E_B}\right)P_{B,t}}{P_{C_E,t}}\right)^{-\epsilon_{BG}} \left(\frac{P_{C_E,t}}{\mathcal{P}_{\mathbb{C},t}}\right)^{-\epsilon_C} \nu_{B,z}\left(1-\nu_{C,z}\right)\mathbb{C}_t(z) \tag{40}$$

$$C_{G,t}(z) = \left(\frac{P_{G,t}}{P_{C_E,t}}\right)^{-\epsilon_{BG}} \left(\frac{P_{C_E,t}}{\mathcal{P}_{\mathbb{C},t}}\right)^{-\epsilon_C} \left(1-\nu_{B,z}\right)\left(1-\nu_{C,z}\right)\mathbb{C}_t(z) \tag{41}$$

$$C_t(z) = \left(\frac{P_{C,t}}{\mathcal{P}_{\mathbb{C},t}}\right)^{-\epsilon_C} \nu_{C,z}\mathbb{C}_t(z), \qquad \text{for} \quad z=i,j \tag{42}$$

2.5.1 Financially unconstrained households

The representative financially unconstrained household (or Ricardian) i gains utility from consumption $\mathbb{C}_t(i)$ and disutility from working $N_t(i)$. In particular, there is external habit formation in consumption, which means that its utility depends positively on the difference between the current level of individual consumption, $\mathbb{C}_t(i)$, and the lagged average consumption level of financially unconstrained households, $\mathbb{C}_{I,t-1}$.

Each household i maximizes its lifetime utility by choosing the consumption and investment goods, $\mathbb{C}_t(i)$ and $I_t(i)$ respectively, the level of the general physical capital stock, $K_{t+1}(i)$ and its utilization rate $u_t(i)$, the level of the brown capital stock, $K_{B,t+1}(i)$ and its utilization rate $u_{B,t}(i)$, the level of the green capital stock, $K_{G,t+1}(i)$ and its utilization rate $u_{G,t}(i)$, holdings of domestic government bonds and internationally traded bonds, $B_{t+1}(i)$ and $B^*_{t+1}(i)$, respectively, and holdings of money, $M_t(i)$. Household i lifetime utility function is then:

$$E_t\left[\sum_{k=0}^{\infty}\beta^k\left(\frac{1-\kappa}{1-\sigma}\left(\frac{\mathbb{C}_{t+k}(i)-\kappa\mathbb{C}_{I,t+k-1}}{1-\kappa}\right)^{1-\sigma} - \frac{1}{1+\zeta}N_{t+k}(i)^{1+\zeta}\right)\right] \tag{43}$$

where $\beta \in (0,1)$ is the discount rate, $\sigma > 0$ denotes the inverse of the intertemporal elasticity of substitution and $\zeta > 0$ is the inverse of the elasticity of work effort with respect to the real wage (Frisch elasticity). The parameter $\kappa \in (0,1)$ measures the degree of external habit formation in consumption. The individual budget constraint for household i is:

$$
\begin{aligned}
& \left(1+\tau_t^C+\Gamma_{v_I,t}(i)\right)\mathcal{P}_{\mathbb{C},t}\mathbb{C}_t\left(i\right)+P_{I,t}I_t\left(i\right)+P_{IB,t}I_{B,t}\left(i\right)+P_{IG,t}I_{G,t}\left(i\right)+R_t^{-1}B_{t+1}\left(i\right) \\
& +\left(\left(1-\Gamma_{B_t^*}(i)\right)R_t^*\right)^{-1}S_t^{H,US}B_{t+1}^*\left(i\right)+M_t\left(i\right)+\Phi_t\left(i\right)+\Xi_t \\
= & \left(1-\tau_t^N-\tau_t^{W_H}\right)W_t\left(i\right)N_t\left(i\right)+\left(1-\tau_t^D\right)\left(D_t\left(i\right)+D_t^B\left(i\right)+D_t^G\left(i\right)\right)+TR_t\left(i\right)-T_t\left(i\right) \\
& +\left(1-\tau_t^K\right)\left(R_t^K u_t\left(i\right)-\Gamma_{u,t}\left(i\right)P_{I,t}\right)K_t\left(i\right)+\tau_t^K\delta P_{I,t}K_t\left(i\right) \qquad (44) \\
& +\left(1-\tau_t^{K_B}\right)\left(R_{B,t}^K u_{B,t}\left(i\right)-\Gamma_{u_B,t}\left(i\right)P_{IB,t}\right)K_{B,t}\left(i\right)+\tau_t^{K_B}\delta_B P_{IB,t}K_{B,t}\left(i\right) \\
& +\left(1+\tau_t^{K_G}\right)\left(R_{G,t}^K u_{G,t}\left(i\right)-\Gamma_{u_G,t}\left(i\right)P_{IG,t}\right)K_{G,t}\left(i\right)+\tau_t^{K_G}\delta_G P_{IG,t}K_{G,t}\left(i\right) \\
& +B_t\left(i\right)+S_t^{H,US}B_t^*\left(i\right)+M_{t-1}\left(i\right)
\end{aligned}
$$

where $\mathcal{P}_{\mathbb{C},t}$ and $P_{I,t}$ are the prices of a unit of the private consumption good and the (non-energy) investment good, respectively. $P_{IB,t}$ and $P_{IG,t}$ are brown and green investment deflators. R_t and R_t^* denote, respectively, the risk-less returns on domestic government bonds, $B_{t+1}\left(i\right)$, and internationally traded bonds, $B_{t+1}^*\left(i\right)$. Domestically traded bonds are denominated in domestic currency (euro). Internationally traded bonds are denominated in US dollars. $S_t^{H,US}$ is the nominal exchange rate, expressed in terms of units of Home currency per unit of the US dollar. The term $\Gamma_{B^*,t}$ represents a financial intermediation premium that the household must pay when taking a position in the international bond market. The incurred premium is rebated in a lump-sum manner (see variable Ξ_t in the budget constraint) to domestic Ricardian households that own firms. The term $M_t\left(i\right)$ represents domestic money holdings.

The fiscal authority levies taxes on the household's gross income and spending. In particular, τ_t^C denotes the consumption tax rate levied on consumption purchases, τ_t^N, τ_t^K (respectively $\tau_t^{K_B}$) and τ_t^D represent tax rates levied respectively on wage income, rental capital income (respectively brown) and dividends from firms ownership, while $\tau_t^{W_H}$ is an additional pay-roll tax rate levied on household wage income that represents the household contribution to social security. Following Coenen et al. (2008) we assume that the utilization cost of physical capital and physical capital depreciation are exempted from taxation. Notice that green investment is subsidized at τ^{K_G}. The variable $TR_t\left(i\right)$ represents lump-sum transfers received from the government and $T_t\left(i\right)$ lump-sum taxes. The generic household i holds state-contingent securities, $\Phi_t\left(i\right)$, which are traded among Ricardian households and provide insurance against individual income risk.

The household provides labor services, $N_t(i)$, at wage rate $W_t(i)$ and rents general capital services $u_t(i) K_t(i)$, at the rental rate R_t^K, to domestic firms, brown capital services $u_{B,t}(i) K_{B,t}(i)$, at the rental rate $R_{B,t}^K$, to domestic firms and green capital services $u_{G,t}(i) K_{G,t}(i)$, at the rental rate $R_{G,t}^K$, to domestic firms. Varying the intensity of capital utilization is subject to a proportional cost Γ_u, Γ_{u_B} and Γ_{u_G}, respectively. The law of motion for the three types of capital stock (owned by household i) is:

$$K_{t+1}(i) = (1-\delta) K_t(i) + (1 - \Gamma_{I,t}(i)) I_t(i) \tag{45}$$

$$K_{B,t+1}(i) = (1-\delta_B) K_{B,t}(i) + (1 - \Gamma_{IB,t}(i)) I_{B,t}(i) \tag{46}$$

$$K_{G,t+1}(i) = (1-\delta_G) K_{G,t}(i) + (1 - \Gamma_{IG,t}(i)) I_{G,t}(i) \tag{47}$$

where δ, δ_B and δ_G are the depreciation rates, and $\Gamma_{I,t}$, $\Gamma_{IB,t}$ and $\Gamma_{IG,t}$ represent adjustment costs. The purchases of the consumption good are subject to a proportional transaction cost, $\Gamma_{v_I,t}$. The variables $D_t(i)$, $D_t^B(i)$ and $D_t^G(i)$ in the budget constraint represent the dividends paid by intermediate good firms and brown and green energy-producing firms to Ricardian households.

Each household i acts as wage setter for its differentiated labor services $N_t(i)$ in monopolistically competitive markets. It is assumed that wages are determined by staggered nominal contracts *à la* Calvo (1983).

2.5.2 Financially constrained households

In each country there is a continuum of financially constrained (or non-Ricardian) households indexed by $j \epsilon [s^H(1-\omega), s^H]$. Even though non-Ricardian households do not have access to capital and bond markets, they can intertemporally smooth consumption by adjusting their holdings of money. The household j chooses purchases of the consumption good $\mathbb{C}_t(j)$ and holdings of money $M_t(j)$ that maximize its lifetime utility function (that is assumed to be similar to that of Ricardian households), subject to its budget constraint:

$$
\begin{aligned}
& \left(1+\tau_t^C+\Gamma_{v,t}\right) \mathcal{P}_{\mathbb{C},t} \mathbb{C}_t(j)+M_t(j)+\Phi_t(j) \\
= & \left(1-\tau_t^N-\tau_t^{W_H}\right) W_t(j) N_t(j)+T R_t(j)+T R_t^{E_G}(j)-T_t(j)+M_{t-1}(j)
\end{aligned} \tag{48}
$$

where the transaction cost, $\Gamma_{v,t}$, depends on consumption-based velocity. The terms $TR_t(j)$ and $TR_t^{E_G}(j)$ correspond to general transfers and transfers from redistribution of carbon taxes by the government, respectively, all lump-sum. Similarly to Ricardian households, non-Ricardian households act as wage setters for their differentiated labor services.

2.6 Monetary and fiscal authorities

2.6.1 Monetary policy

The monetary authority faces a Taylor-type interest rate rule specified in terms of annual CPI inflation excluding energy, $\Pi_{C,t}^4 \equiv P_{C,t}/P_{C,t-4}$ and quarterly output growth, $\tilde{Y}_t \equiv Y_t/Y_{t-1}$:

$$
R_t^4 = \phi_R R_{t-1}^4+\left(1-\phi_R\right)\left[\overline{R}^4+\phi_\Pi\left(\Pi_{C,t}^4-\overline{\Pi}^4\right)\right]+\phi_{g_Y}\left(\tilde{Y}_t-1\right)+\varepsilon_{R,t} \tag{49}
$$

where $\overline{R}^4 = \beta^{-4}\ \overline{\Pi}$ is the equilibrium nominal interest rate, $\overline{\Pi}$ is the monetary authority's inflation target and the term $\varepsilon_{R,t}$ is a serially uncorrelated monetary policy shock.

2.6.2 Fiscal policy

Fiscal instruments for climate policy. The government in each region imposes a carbon tax, $\tau_t^{E_B}$, as a surcharge on the price of the brown energy input/good on tradable and non-tradable goods firms as well as on households, provides subsidies to the revenues of the green energy sector, $\tau_t^{E_G}$, as well as lump-sum transfers, $TR_t^{E_G}$, to financially constrained households. The subsidy that the green energy firms receive represents a fraction, ς_E^Y, of the government's carbon tax revenues such that:

$$\varsigma_E^Y \left[\tau_t^{E_B} \frac{1}{s^H} \left(\int_0^{s^H} P_{B,t} E_{B,t}(h)\, dh + \int_0^{s^H} P_{B,t} E_{B,t}(n)\, dn \right) + \tau_t^{E_B} P_{B,t} \left(C_{B,t}(I) + C_{B,t}(J) \right) \right]$$
$$= \tau_t^{E_G} \frac{1}{s^H} \int_0^{s^H} P_{G,t} Y_{G,t}(g)\, dg \tag{50}$$

where $\varsigma_E^Y \in [0,1]$ and $\int_0^{s^H} P_{B,t} E_{B,t}(h)\, dh$ and $\int_0^{s^H} P_{B,t} E_{B,t}(n)\, dn$ represent the aggregate expenditure of domestic tradable goods firms and non-tradable goods firms on brown energy. $\int_0^{s^H} P_{G,t} Y_{G,t}(g) dg$ represents the aggregate revenues, net of subsidies, of green energy producers residing in the domestic economy. $C_{B,t}(I) = \frac{1}{s^H(1-\omega)} \int_0^{s^H(1-\omega)} C_{B,t}(i)\, di$ and $C_{B,t}(J) = \frac{1}{s^H\omega} \int_{s^H(1-\omega)}^{s^H} C_{B,t}(j)\, dj$ are the total demand for brown energy by the financially constrained and financially unconstrained households, respectively. The lump-sum transfers to financially constrained households represent a fraction, ς_E^C, of the government's carbon tax revenues such that:

$$\varsigma_E^C \left[\tau_t^{E_B} \frac{1}{s^H} \left(\int_0^{s^H} P_{B,t} E_{B,t}(h)\, dh + \int_0^{s^H} P_{B,t} E_{B,t}(n)\, dn \right) + \tau_t^{E_B} P_{B,t} \left(C_{B,t}(I) + C_{B,t}(J) \right) \right]$$
$$= TR_t^{E_G} \tag{51}$$

where $\varsigma_E^C \in [0,1]$. We assume that $0 \leq \varsigma_E^Y + \varsigma_E^C \leq 1$. As in Känzig (2023), we assume that carbon taxes are set according to the following rule $\tau_t^{E_B} = (1 - \rho_{\tau^{E_B}})\tau^{E_B} + \rho_{\tau^{E_B}} \tau_{t-1}^{E_B} + \varepsilon_{\tau^{E_B},t}$, with $\rho_{\tau^{E_B}} \in (0,1)$. The government also imposes taxes on financially unconstrained households' brown capital income, $\tau_t^{K_B}$. At the same time, it uses fraction μ_B^I of the brown capital tax revenues to subsidize financially unconstrained households' green capital income, $\tau_t^{K_G}$. The remaining fraction, $1 - \mu_B^I$, is devoted to financing debt or other government expenditures. Specifically, the distribution of revenues from taxing brown capital follows:

$$\tau_t^{K_G} \left(R_{G,t}^K u_{G,t} - \Gamma_{u_G,t}\, P_{IG,t} \right) K_{G,t} = \mu_B^I\, \tau_t^{K_B} \left(R_{B,t}^K u_{B,t} - \Gamma_{u_B,t}\, P_{IB,t} \right) K_{B,t} \tag{52}$$

where we assume that brown capital income tax follows the rule $\tau_t^{K_B} = (1 - \rho_{\tau^{K_B}})\tau^{K_B} + \rho_{\tau^{K_B}} \tau_{t-1}^{K_B} + \varepsilon_{\tau^{K_B},t}$, with $\rho_{\tau^{K_B}} \in (0,1)$.

Government budget constraint. In each country the fiscal authority purchases G, a final good which is a composite of non-tradable intermediate goods only ($P_{N,t}$ is the associated deflator). The fiscal authority also makes non-energy-related transfer payments to households, TR_t, issues bonds to refinance its debt, B_t, earns seigniorage on outstanding money holdings, M_{t-1}, and levies taxes. As previously said, there are tax rates on consumption purchases, τ_t^C, and on wage, capital and dividend income (τ_t^N, τ_t^K, τ_t^D, respectively). There are also pay-roll tax rates levied on household wage income, $\tau_t^{W_H}$, and on wages paid by firms (social contributions, $\tau_t^{W_F}$). Therefore the fiscal authority's period-by-period budget constraint is:

$$
\begin{aligned}
& P_{NT,t}\, G_t + TR_t + TR_t^{E_G} + B_t \\
& = \tau_t^C C_t + \left(\tau_t^N + \tau_t^{W_H}\right)\left(W_{I,t}N_{I,t} + W_{J,t}N_{J,t}\right) + \tau_t^{W_F} W_t N_t \\
& + \tau_t^K \left(R_t^K u_t - \left(\Gamma_{u,t} + \delta\right) P_{I,t}\right) K_t + (1-\mu_B^I)\tau_t^{K_B}\left(R_{B,t}^K u_{B,t} - \left(\Gamma_{u_B,t} + \delta_B\right) P_{IB,t}\right) K_{B,t} \\
& + \tau_t^D D_t + T_t + R_t^{-1} B_{t+1} + \Delta M_t + (1 - \varsigma_E^Y - \varsigma_E^C)\tau_t^{E_B} P_{B,t}\left(E_{BT,t} + E_{BN,t} + C_{B,t}(I) + C_{B,t}(J)\right)
\end{aligned} \tag{53}
$$

where $E_{BT,t} = \frac{1}{s^H}\int_0^{s^H} E_{B,t}(h)\, dh$ and $E_{BN,t} = \frac{1}{s^H}\int_0^{s^H} E_{B,t}(n)\, dn$ is the total demand for brown energy by the domestic tradable good and the non-tradable good sector, respectively. While $C_{B,t}(I) = \frac{1}{s^H}\int_0^{s^H(1-\omega)} C_{B,t}(i)\, di$ and $C_{B,t}(J) = \frac{1}{s^H}\int_{s^H(1-\omega)}^{s^H} C_{B,t}(j)\, dj$ represent the aggregate consumption of energy goods by type of households (Ricardian I or not J). Lump-sum taxes as a fraction of steady-state nominal output, $\tau_t \equiv \frac{T_t}{P_Y Y}$, are adjusted to make public debt stable according to the following rule: $\tau_t = \phi_{B_Y}\left(\frac{B_t}{P_Y Y} - \overline{BY}\right)$, where $\overline{BY}$ is the fiscal authority's target for the ratio of government debt to output and $\phi_{B_Y} > 0$ is a parameter.

3 Calibration

This section assigns values to the model's parameters. For brevity, we focus on the new parameters introduced by the energy extension. Non-energy parameters, such as preference and policy parameters or those governing real and nominal rigidities, follow closely the standard EAGLE model (Gomes et al., 2012).

3.1 Energy-related steady-state shares and great ratios

The top panel of Table 1 reports the energy-related shares implied by our calibrated model. Across all three regions, the share of energy in final private consumption hovers around 4-5%, with brown energy accounting for roughly two-thirds of it. These values are consistent with data from the OECD Input/Output Tables (discussed below) and with Coenen et al. (2024). Similarly, the share of brown energy used as input in the production of intermediate goods (both tradables and non-tradables) is roughly twice that of green energy. Taken together, the two types of energy underscore the non-negligible role of energy in production, accounting for around 6-7% of total inputs. Again, these figures align broadly with those from the OECD Input/Output Tables, as shown below.[12]

The bottom rows of the top panel in Table 1 report steady-state energy investment as a share of GDP. While empirical data on this component remain limited, Pisani-Ferry and Tagliapietra (2024) suggest that energy-related investment in Europe likely hovered around 2 to 3 percent of GDP in recent years. We calibrate our model to fall within that range, with brown energy investment approximately twice as large as green energy investment. This distinction reflects the still dominant role of fossil fuel mentioned above.

Lastly, the bottom panel of Table 1 reports standard great ratios, including private consumption, public expenditure, private investment, and import shares. These values are broadly in line with empirical data for the three regions. For instance, average national account data over the period 2000-2019 indicate that private consumption accounted for approximately 53% of GDP in the EA, 63% in the US, and 54% in the RW. The model generates comparable values of 59%, 64%, and 65%, respectively. Similarly, the empirical share of public expenditure ranges from 19% to 25%, and private investment from 17% to 23%, both aligned satisfactorily with the model's predictions.[13] Trade ratios also show good consistency: the model implies an import share of total consumption, investment and exports close to observed values.[14]

[12] In fact, the dominance of brown energy in consumption and production reflects a wider global trend. According to the International Energy Agency, for example, renewable energy accounted for 20% of global final energy consumption in 2024, with shares of 13% in high-income economies and 23% in middle-income countries.

[13] OECD Input/Output data do not distinguish between private and public investment. Therefore, public investment share as calculated from Eurostat data has been used in order to separate public investment from the total one and add public investment to public expenditure.

[14] The share of import content of exports is calculated based on the corresponding indicator within the Trade in value-added (TiVA) database. It captures the foreign value-added content of exports, i.e. how much of the

3.1.1 OECD Input/Output tables

As noted above, some of the energy shares reported in Table 1 are based on the OECD Input/Output tables.[15] These tables provide a detailed breakdown of economic activity by industry and country, mapping flows of production, consumption, and international trade. We now briefly describe how these values are constructed. However, readers not interested in the underlying data sources and construction methods may skip this subsection without loss of continuity.

We construct a dataset spanning the period from 2000 to 2019, thereby excluding the COVID-19 pandemic, and covering three regions: the EA, the US, and the RW.[16] Since the Input–Output tables are more detailed than our model, we aggregate the sectoral data into a three-sector structure.[17] The energy sector includes industries B05_06, C19 and D. The tradable sector comprises industries A, B (except B05_06), C (except C19) and G. The non-tradable sector aggregates all industries from E to T.

Finally, we classify energy as either brown or green following the approach in Coenen et al. (2024). Specifically, we apply a fixed ratio that assigns 72% of total energy use to brown energy. This corresponds to their estimate of dirty energy, which includes solid fossil fuels, peat and peat products, oil shale and oil sands, natural gas, oil and petroleum products (excluding biofuels), and non-renewable waste.[18] The remaining 28% is treated as green energy, including renewables, biofuels, and nuclear heat.

The resulting energy shares are broadly consistent with those implied by our model's steady state. On average over the 2000–2019 period, the share of energy in final consumption was 4.9% in the EA, 3.6% in the US, and 4.2% in the RW. Brown energy made up roughly two-thirds

value of a country's exports originates from imported inputs.

[15] Link: *OECD database*

[16] Rest of the world (RW) countries consist of all countries available in the OECD Input/Output data except euro area and US (these being Argentina, Australia, Bangladesh, Belarus, Brazil, Brunei Darussalam, Bulgaria, Cambodia, Cameroon, Canada, Chile, China, Chinese Taipei, Colombia, Costa Rica, Côte d'Ivoire, Czechia, Denmark, Egypt, Hungary, Iceland, India, Indonesia, Israel, Japan, Jordan, Kazakhstan, Korea, Lao (People's Democratic Republic), Malaysia, Mexico, Morocco, Myanmar, New Zealand, Nigeria, Norway, Pakistan, Peru, Philippines, Poland, Romania, Russian Federation, Saudi Arabia, Senegal, Singapore, South Africa, Sweden, Switzerland, Thailand, Tunisia, Turkey, Ukraine, United Kingdom and Vietnam).

[17] OECD Input-Output tables use the ISIC (International Standard Industrial Classification) Rev. 4 for industry classification.

[18] There is no universally accepted definition of brown and green energy. Estimates vary: Diluiso et al. (2020) classify 75% of energy as fossil-based and 25% as low-carbon; Auclert et al. (2023) report that fossil fuels make up 69% of gross available energy; Bartocci et al. (2024) find that oil, gas, and coal account for 71.2% of firms' and households' energy use; Airaudo et al. (2022) estimate that 53% of total energy output is brown.

of these totals, in line with the fixed ratio we adopt. In intermediate-good production, brown energy shares ranged from 4.1% to 6.3%, while green energy accounted for 1.6% to 2.5%, again reflecting the empirical pattern that brown energy is used more intensively than green.

3.2 Energy-related structural parameters

Tables 2 and 3 present the energy-related structural parameters used to generate the results in Table 1. Throughout this section, we draw on Coenen et al. (2024), whose parameter choices offer a useful benchmark for incorporating energy into large DSGE models.

We set the intra-temporal elasticity of substitution between non-energy and energy consumption goods, ϵ_C, to 0.4, following their calibration. For the elasticity of substitution between brown and green energy within the household energy bundle, ϵ_{BG}, empirical evidence remains limited. Varga et al. (2022), for example, choose a value of 6, indicating that households view brown and green energy as substitutes. This view is supported by Papageorgiou et al. (2017), who estimate substitution elasticities well above one using data from 26 countries. Similarly, Acemoglu et al. (2012) adopt values ranging from 3 to 10 in a model of endogenous technical change. Coenen et al. (2024) set the substitution elasticity between brown and green energy in aggregate energy production to 1.8. In line with these studies, and for consistency across consumption and production, we set $\epsilon_{BG} = 1.8$.[19]

Next, we set the share of energy in final consumption, $1 - \nu_C$, to 5% in the EA and 4% in the US and the RW, in line with the Input/Output data discussed earlier. The share of green energy in household energy use, $1 - \nu_B$, is fixed at 28% in all regions, consistent with the 72% brown energy share explained above.

In the production of tradable and non-tradable intermediate goods, we follow standard practice by setting capital shares, α_T and α_N, to around one-third. We again follow Coenen et al. (2024) in setting the elasticity of substitution between energy and non-energy inputs, ϵ_T and ϵ_N, to 0.4. The share of non-energy inputs, ν_{YT} and ν_{YN}, is set to 96%, allowing the model to generate the energy input shares reported in Table 1. The share of green energy in the energy

[19] We use a common value of ϵ_{BG} across regions for tractability and to maintain a clear focus on our core mechanisms. We acknowledge that geographic and climatic conditions likely affect the substitutability between green and brown energy sources. Exploring region-specific elasticities would be a valuable extension.

composite, ν_{ET} and ν_{EN}, is set to roughly one-third, as in the consumption bundle. The elasticity of substitution between brown and green energy, ϵ_E, is also set to 1.8, again following Coenen et al. (2024).

Regarding CO_2 emissions, we follow Coenen et al. (2024) and set the carbon intensity parameters for brown energy goods (ϕ_0), tradable goods (ϕ_1), and non-tradable goods (ϕ_2) in the EA to 380 and 41 for both tradable and non-tradable goods. In the US and the RW, these parameters are slightly higher, at 865 and 63 for both tradable and non-tradable goods. In energy production, the capital bias parameters (γ_B and γ_G) are close to 70% for both brown and green energy and are similar across sectors. This choice again follows Coenen et al. (2024).

Turning to the structure of brown and green investment goods, we adopt the elasticities used in the standard EAGLE model, given the limited empirical evidence specific to energy investment. The elasticity of substitution between tradable and non-tradable inputs is set to 0.5; between domestic and imported tradables to 1.5; and across imported tradables to 2.5. For bias parameters, the share of tradables in investment is 0.45 in all regions. The bias toward domestic tradables over imported ones is 0.5 in the EA and the US, and 0.75 in the RW. These values yield an imported share of brown and green investment goods of about 20%, consistent with external trade data derived from the OECD Input-Output tables and the OECD TiVA database.

As in Coenen et al. (2024), we set the price elasticities of demand for brown and green energy (θ_B and θ_G) to 6 in all regions, implying a steady-state gross markup of 1.2. Investment adjustment costs and capital utilization costs follow standard EAGLE values. For nominal rigidities, we set Calvo price stickiness and indexation parameters to 0.25 and 0, respectively, in both energy sectors. This implies an average price duration of 1.3 quarters, shorter than in intermediate goods sectors, again consistent with Coenen et al. (2024).

For fiscal instruments, we take the steady-state carbon tax, τ^{E_B}, from Känzig (2023) and set it at 3.9%. The tax on brown capital income, τ^{K_B}, is set to 16% in all regions, mirroring the treatment of regular capital in the EAGLE model. Lastly, green subsidies, ς_E^Y, ς_E^C, and μ_B^I, are set to zero in the baseline for simplicity.

3.3 Non-energy sectors

As noted earlier, non-energy parameters (such as preference and policy parameters, as well as those governing real and nominal rigidities) follow closely the standard EAGLE model (Gomes et al., 2012). Table 4 reports the selected parameter values. We set the net price markup in the EA to 20% in the tradable sector, 30% in the labor market, and 50% in the non-tradable sector. In the US and the RW, the corresponding markups are 20%, 10%, and 50%. Across all regions, the tradable sector markup is the same, and the markup in the non-tradable sector is larger than that in the labor market.

Regarding real rigidities, investment adjustment costs are set to 6 in the EA and to 4 in the US and the RW. Adjustment costs on consumption and investment imports are identical across regions and equal to 2 and 1, respectively. As for nominal rigidities, the Calvo parameters for price setting in the domestic tradable and non-tradable sectors are set to 0.90 in the EA and 0.75 in the US and the RW. Calvo parameters for wages are set to 0.9 in the EA and 0.75 across the remaining regions. Price and wage indexation parameters are set to 0.5. Region sizes are chosen to match their respective shares of world GDP.

Table 5 reports parameters driving households behavior. Preferences are the same across household types and regions. The discount factor, the habit persistence parameter, the intertemporal elasticity of substitution and the Frisch elasticity are set respectively to 0.9926 (consistent with a steady-state annualized real interest rate of about 3 percent), 0.90, 1 and 0.50. The quarterly depreciation rate of capital equals to 0.025, implying an annual depreciation rate of 10 percent for all types of investment, and the share of non-Ricardian households equals to 0.33 for the EA (following Cardani et al., 2023) and 0.25 for the US and RW.

Finally, Table 6 reports the parameters governing monetary and fiscal policy rules. The interest rate responds to its own lag (capturing policy inertia), to annual CPI inflation excluding energy, and to quarterly output growth. In the monetary union, policy responds to EA-wide aggregates. All parameters in the monetary policy rule are set to standard values. On the fiscal side, lump-sum taxes adjust to stabilize public debt. The steady-state ratio of government debt to quarterly output is set to 2.40 in all regions (equivalent to 0.60 in annual terms). Steady-state tax rates on consumption and labor income are set to 0.183 and 0.122, respectively, in the EA;

and to 0.077 and 0.154 outside the EA. Employer social contributions are 0.219 in the EA and 0.071 outside, while employee contributions are 0.118 in the EA and 0.071 elsewhere.

4 Quantitative Analysis

This section examines the responses of key macroeconomic variables in the EA to different climate policy instruments. It begins by analyzing the effects of a carbon tax increase, $\tau_t^{E_B}$, which raises the price of brown energy by 1 percent on impact. The fiscal authority raises the carbon tax for 10 quarters. Thereafter, the tax declines gradually with high persistence ($\rho\tau^{E_B} = 0.95$).

We first analyze the effects of a carbon tax implemented within the EA without any redistribution of tax revenues, that is $\varsigma_E^Y = \varsigma_E^C = 0$ in (50) and (51), respectively. Redistribution to green energy-producing firms is then introduced by setting $\varsigma_E^Y = 0.33$. Additional redistribution to financially constrained households follows, with ς_E^C also set to 0.33. We then study the full redistribution of carbon tax revenues between these two groups, resulting in a primary-balance-neutral policy ($\varsigma_E^Y = \varsigma_E^C = 0.5$). Finally, we analyze the implementation of globally raised carbon taxes under the second redistribution scheme ($\varsigma_E^Y = \varsigma_E^C = 0.33$).

Then, we turn our focus to brown capital rental income taxes. We assume that the fiscal authority raises the brown capital income tax for 10 quarters, until it starts declining with high persistence ($\rho_{\tau^{K_B}} = 0.95$). To make our results comparable to those from a carbon tax, we consider an increase in the brown capital income tax with an initial impact on the primary balance in the government budget constraint equal to that of the carbon tax above. For brevity, we consider two limiting scenarios: one where the government does not redistribute the revenues, namely $\mu_B^I = 0$ in (52), and another where it distributes all the revenues subsidizing rental green capital income (i.e. $\mu_B^I = 1$). Throughout, ς_E^Y and ς_E^C are at their baseline values of 0.

4.1 Increase in the carbon tax without redistributing its revenue

We start by considering a carbon tax levied on consumers and intermediate goods producers in the EA, applied as a surcharge on brown energy. In this initial simulation, we abstract from any subsidies to the green energy sector or to financially constrained households, keeping $\varsigma_E^Y = \varsigma_E^C = 0$

in (50) and (51), respectively. The solid blue lines in Figures 2, 3 and 4 display the resulting impulse responses.

Let us first consider the energy-related variables shown in Figure 3. The increase in the carbon tax raises the effective price of brown energy, leading to a decline in its output and an expansion of green energy production. This reallocation reflects substitution responses on both the demand and production sides. As shown in Figure 4, households shift expenditure toward green energy consumption goods in response to the higher relative price of brown energy. A similar adjustment occurs in the production of tradable and non-tradable goods, as firms substitute away from brown energy inputs. In both cases, the substitution is governed by the same elasticity of 1.8, implying that while brown and green energy are imperfect substitutes, relative price changes lead to significant reallocation. This shift raises green energy inflation and lowers before-tax brown energy inflation, making carbon taxes disinflationary in the brown energy market, as demand effects outweigh supply pressures. The brown energy output decline reduces total carbon emissions in the EA by up to 2.5% at the trough relative to steady state.

Turning to energy investment goods (third row of Figure 3), investment in brown capital declines sharply in response to reduced total demand for brown energy. This drop in demand also lowers the rental rate on brown capital, which falls by more than 10 percentage points at its trough, around 10 quarters after the tax is introduced. The dynamics for green capital are the mirror image: investment rises as firms scale up green energy production, and the rental rate on green capital increases in response to stronger demand for the green capital input.

Broadening the scope to the macroeconomic effects of the carbon tax, two features stand out. First, output declines in both the tradable and non-tradable goods sectors due to the higher price of brown energy inputs and their imperfect substitutability with green energy (first row of Figure 3). However, the contraction is more pronounced in the tradables sector. This asymmetry reflects the greater labor intensity of the non-tradables sector (see Table 2), which partly offsets the energy cost shock by benefiting from lower wages. Second, the carbon tax acts like a supply-side shock (see Figure 2). Output falls, inflation rises, and both total investment and the rental rate of capital decline. Private consumption and hours worked also contract. The increase in inflation reflects the rise in the after-tax price of brown energy and the green energy inflation described above, both of which raise the overall cost of energy. It is further reinforced by the persistent decline in the supply of tradable and non-tradable goods. In response, the real interest rate overshoots in the medium run, reducing the present discounted value of wealth for financially unconstrained households. This amplifies the downward pressure on aggregate consumption already triggered by higher energy prices.

From an international perspective, the rise in inflation prompts an increase in the policy rate, which leads to an appreciation of the euro *vis à vis* the currency basket of its trading partners.[20] This appreciation contributes to the initial deterioration in the trade balance. Due to limited exchange rate pass-through under local currency pricing, the stronger euro does not offset the inflationary effects of the carbon tax. Moreover, the appreciation contributes to the sharper contraction in the tradable goods sector relative to the non-tradable sector, in addition to the latter's higher labor intensity discussed earlier.

For completeness, Figures D.1 and D.2 in online Appendix D show the spillover effects of the EA carbon tax on the US and the RW. The key message is clear: the broad macroeconomic effects are mild. This is consistent with the limited trade exposure of the US and RW to the Euro Area. Imports represent 15% and 8.5% of GDP in the US and RW, respectively, of which 12% and 35% originate from the EA. As expected, the only foreign variables that exhibit non-trivial movements are the real exchange rate and total imports. As noted earlier, the euro appreciates against other currencies because the EA monetary authority raises nominal interest rates to contain inflation, harming the international competitiveness of the EA.

4.2 Subsidies to green energy firms

We now turn to the scenario where the fiscal authority redistributes part of the carbon tax revenues to green energy-producing firms. Specifically, ς_E^Y is equal to 1/3 in (50), while ς_E^C in (51) remains at zero. The remaining 66% of the carbon tax revenues are used to finance government debt or expenditures. Red-dashed lines in Figures 2, 3, and 4 display the resulting impulse responses.

Beginning with energy-related variables, the responses remain qualitatively similar to those

[20] A decline in the exchange rate corresponds to an appreciation.

observed without fiscal redistribution: brown energy output declines, while green energy output rises. These shifts reflect households reallocating expenditure toward green energy consumption and firms' substitution away from brown energy inputs. However, some of the responses in the energy related variables are now more pronounced. The subsidy to green energy producers reduces the optimal price set by re-optimizing firms, leading to a decline in green energy inflation five quarters after the shock. This price adjustment reinforces the substitution effect. In parallel, the stronger increase in green energy production raises the attractiveness of investment in green capital, while further discouraging investment in brown capital. This amplifies the divergence in the corresponding rental rates. Overall, redistributing part of the carbon tax revenues to green energy producers clearly strengthens the shift toward green energy. As a result, in the medium-run total emissions in the EA fall more than in the baseline. However, the difference remains modest, a pattern we will also observe under the other redistribution schemes discussed below.

Looking more broadly at economic activity, the subsidy mitigates the adverse effects of the carbon tax. For example, it leads to smaller declines in output across both tradable and non-tradable sectors, as well as in hours worked, total investment and private consumption. Consequently, the drop in GDP is roughly halved compared to the no-redistribution scenario. Similarly, inflation remains closer to its steady-state level, resulting in a smaller rise in the nominal interest rate and, therefore, more muted effects on the exchange rate and trade balance.

4.3 Subsidies to green energy firms and to financially-constrained households

Let us now assume that the fiscal authority redistributes carbon tax revenues to both green energy-producing firms and financially constrained households. In this scenario, both ς_E^Y and ς_E^C are equal to 1/3 in (50) and (51). The remaining 33% of the carbon tax revenues are used to finance government debt or expenditures. Black dashed-dotted lines in Figures 2, 3, and 4 display the resulting impulse responses.

Introducing a subsidy to financially constrained households has only a marginal impact on the effects of the carbon tax, relative to the case where revenues are redistributed solely to green energy producers. In fact, the impulse responses for most variables are nearly identical across the two scenarios. The main exception is the consumption of financially constrained households, now increasing rather than declining (second row of Figure 2). The mechanism is straightforward: channeling a share of carbon tax revenues to these households through lump-sum transfers raises their disposable income.[21] Since they lack access to capital and bond markets, they use these additional resources primarily to boost consumption.

Beyond this distributional effect, however, the subsidy to constrained households does not contribute further to the green transition. This suggests that a more targeted approach, such as subsidizing the consumption of green energy goods directly, might be more effective in fostering the shift away from brown energy. As a first pass at this question, Figures D.4, D.5, and D.6 in the online Appendix D study an alternative redistribution scheme in which transfers to financially constrained households are no longer lump-sum but instead cover part of their green energy expenditures. We keep the size of the redistribution scheme unchanged at 33% of total carbon tax revenues.

Under this new redistribution scheme, where transfers to financially constrained households are earmarked for green energy consumption, their demand for green energy surges, as intuition would suggest. In response, green energy production rises, but not enough to fully absorb the increased demand. As a result, green energy inflation accelerates. This rise in prices partly crowds out green energy consumption by unconstrained households and intermediate goods producers, whose demand falls slightly below the levels observed in the previous scenario. Consequently, their substitution away from brown energy is more limited, resulting in a smaller decline in before-tax brown energy inflation. At the macroeconomic level, aggregate responses remain qualitatively similar to those seen under the untargeted transfer scheme. However, the results indicate a more pronounced increase in overall inflation, partly attributable to higher green energy inflation and a more muted decline in before-tax brown energy prices, a more moderate contraction in total investment and a slightly less pronounced decline in GDP.

[21] Figure D.3 in the online Appendix D exhibits the total net lump-sum transfers received by financially constrained households under this scenario and the one discussed in the previous subsection.

4.4 Primary-balance-neutral policy

We now assume that the government redistributes the entire carbon tax revenue equally between green energy-producing firms and financially constrained households, i.e. $\varsigma_E^Y = \varsigma_E^C = 0.5$ in (50) and (51). Hence, this policy leaves the government's primary budget balance unchanged *ex-ante*. Green-circled lines in Figures 2, 3, and 4 display the resulting impulse responses.

Since the mechanisms at work have already been discussed in detail, we keep the discussion short. Qualitatively, impulse responses closely resemble those in the previous subsection, where only a partial redistribution to green energy producers and financially constrained households was implemented. However, because the magnitude of redistribution is now larger, the responses are more pronounced. The shift toward green energy is stronger and the decline in aggregate economic activity is correspondingly milder. As shown previously, reallocation toward green energy is primarily driven by subsidies to green energy producers, which reduce green energy prices and strengthen substitution effects. Accordingly, in this case, the drop in green energy inflation is the most pronounced across all scenarios.

4.5 The costs of the various energy related fiscal schemes

In the analysis above, we provided an impulse response comparison of the various fiscal schemes associated with carbon policy. In this subsection, we formalize this comparison by computing the associated sacrifice ratio of each policy computed as the negative of the ratio of the cumulative response of GDP over the cumulative response of annualized inflation. We show the sacrifice ratios in Figure 5. Clearly, the case without subsidies (blue bars) entails the higher output costs not only on impact but at later horizons. Practically, given the inflationary nature of the carbon tax, if inflation were to be reduced by 1% this would entail a decline in GDP from its steady state level by 2%, approximately, on impact. Though not so evident in the impulse responses, the sacrifice ratios reveal that the case where subsidies are provided to financially constrained households as well (orange bars) is superior to the case with subsidies to green energy firms only, as the induced output losses are consistently and non-negligibly lower. The balanced budget policy appears to result in the lowest sacrifice ratios at all horizons.

4.6 Policy coordination

So far, we have considered a carbon tax implemented unilaterally in the EA. We now assume a coordinated global policy where the carbon tax is raised simultaneously in all three regions: the EA, the US, and the RW. We choose the size of the shock for the US and RW to be the same as in the baseline above for the EA. All regions implement transfers to green energy firms and the constrained households ($\varsigma_E^Y = \varsigma_E^C = 1/3$). Figure 6 presents the results. For reference, solid blue lines show the scenario with an EA-only carbon tax (as discussed above), while dashed black lines depict the new global carbon tax scenario.

Economic activity in the EA contracts somewhat more when the carbon tax rises globally. EA inflation is also higher in the global tax scenario, driven primarily by a stronger increase in non-energy inflation. Higher brown energy prices raise production costs in tradable sectors worldwide, pushing up the prices of internationally traded intermediate goods. As a result, import prices rise and import demand weakens. Combined with high price stickiness and persistent inflation dynamics, this amplifies inflationary pressures over time. With softer domestic and global demand for tradables, output in the EA's tradable goods sector falls more sharply (not shown for brevity). As a result, the demand for general capital declines further, leading to a deeper contraction in total investment.

That said, the quantitative differences remain modest. For instance, EA GDP falls by about 5-10 basis points more at its trough (in percent deviations from steady state) under a global carbon tax compared to a unilateral tax implemented by the EA alone, while the decline in total EA emissions is nearly identical across both scenarios. This helps explain why the impulse responses of energy-related variables, such as brown and green energy production, look broadly similar across the two scenarios: these variables exhibit much larger swings (often between 5 to 20 percent), and are therefore less sensitive to relatively minor differences in overall macroeconomic conditions.

It is also worth noting that when carbon taxes are raised globally, the real effective exchange rate appreciates far less than under a unilateral EA tax. This is because monetary authorities in the rest of the world and the US also raise their policy rates in response to domestic inflation, limiting the relative rise in EA interest rates. The weaker euro reduces the purchasing power of

EA households, contributing to the sharper decline in total consumption under the global tax. It also leads, albeit modestly, to higher non-energy inflation, since imported goods represent a non-trivial share of the non-energy consumption basket.

4.7 Taxing brown capital investment

We now consider taxes on brown capital income. As outlined in Subsection 2.6.2, the government imposes a tax $\tau_t^{K_B}$ on the rental income from brown capital earned by financially unconstrained households. We examine two scenarios: one where the government does not redistribute the revenues, i.e. $\mu_B^I = 0$ in (52), and another where it fully recycles them as subsidies to green capital income, i.e. $\mu_B^I = 1$. The capital tax shock is calibrated to match the immediate fiscal impact of the carbon tax. Figures 7, 8, and 9 show the results.

We begin with the scenario without redistribution (solid blue lines). Qualitatively, the impulse responses of energy-related variables resemble those under the carbon tax. The mechanism is straightforward. Taxing the rental income from brown capital reduces the after-tax return on such investments, making brown capital less attractive. As a result, investment in brown capital falls, lowering its supply and pushing up its rental rate. This raises the cost of producing brown energy, which contracts its output and increases its price. Households and firms in both tradable and non-tradable sectors respond by shifting demand toward green capital and energy, in line with the substitution patterns embedded in the model's energy composites.

However, because brown and green energy are imperfect substitutes, the decline in brown energy production is not fully offset by the expansion of green energy. As a result, total energy input falls, contributing to the contraction in the output of tradable and non-tradable goods in the first row of Figure 8. As in the carbon tax scenario, the contraction is more pronounced and persistent in the tradables sector. This asymmetry reflects the greater labor intensity of the non-tradables sector (see Table 2), which helps absorbing the energy cost shock through lower wages.

The ensuing slowdown in GDP and aggregate demand components is then unsurprising. An additional factor contributing to this decline is the fall in the rental rate of regular capital, which reduces the wealth of financially unconstrained households and leads them to further cut consumption. An important difference from the carbon tax scenario emerges, however: inflation now declines on impact. This reflects the broader demand-driven slowdown described above. Therefore, unlike the carbon tax, which resembles a negative supply shock, taxing brown capital income has the characteristics of a negative demand shock, as it pushes output and inflation in the same direction.

We now turn to the case in which the government redistributes all tax revenues to subsidize green capital income (i.e. $\mu_B^I = 1$). Qualitatively, the response of most energy-related variables remains similar to the no-redistribution case, but the effects are substantially more pronounced. The subsidy makes investment in green capital highly attractive, sharply increasing its stock. This surge in supply more than offsets the upward pressure from higher demand, leading to a decline in the rental rate of green capital. As a result, green energy production expands more strongly than before, and green energy inflation falls in the medium term instead of rising as in the no-redistribution case.

Lastly, given the stronger expansion in green energy supply, the contraction in tradable and non-tradable output is smaller than in the no-redistribution case, resulting in a more moderate decline in GDP. In addition, the milder drop in aggregate demand leads to a smaller fall in capital income for financially unconstrained households. As a result, their consumption remains stable initially and declines less than in the baseline scenario.

In sum, the tax on brown capital income fosters the switch toward green energy. Unlike the carbon tax, it moves output and inflation in the same direction, avoiding a policy tradeoff for a central bank that follows a standard Taylor rule. Redistributing the proceeds to subsidize green capital investment further mitigates the adverse macroeconomic effects.

5 Sensitivity Analysis

In this section we implement robustness checks of our baseline results. We consider five extensions: (i) a permanent carbon tax path aligned with long-term climate targets; (ii) higher price stickiness in the energy sectors; (iii) greater substitutability between brown and green energy in household and firm energy composites; (iv) greater substitutability between tradables and non-tradables in the production of the brown energy investment good; and (v) an alternative

Taylor rule in which the central bank targets headline inflation. Across all cases, our key insights remain robust. To save space we display the corresponding Figures in online Appendix D.

5.1 Permanent carbon tax scenario

We first consider a permanent carbon tax increase to reflect long-term policy objectives. Following Coenen et al. (2024), we calibrate the initial level of the carbon tax such that revenues represent approximately 1.8% of GDP. The policy consists of a linear increase in the carbon tax rate by around 65% over a nine-year period, consistent with a target effective carbon rate of 140 euros per ton of CO_2 by the end of the horizon. As shown in Figures D.7, D.8, and D.9 in the online Appendix, the results are qualitatively similar to those in the baseline scenario. Quantitatively, the effects are more persistent due to the gradual nature of the shock and are broadly in line with the findings of Coenen et al. (2024).

5.2 Higher sticky prices in the energy sectors

Figures D.10, D.11, and D.12 in the online Appendix explore the macroeconomic consequences of our carbon tax shock, $\tau_t^{E_B}$, under alternative assumptions about price stickiness in the energy sectors. These experiments build on the baseline scenario without redistribution ($\varsigma_E^Y = \varsigma_E^C = 0$) discussed in subsection 4.1, where the tax is calibrated to raise the price of brown energy by 1% on impact. The blue-solid lines show the baseline scenario studied in subsection 4.1, which assumes Calvo parameters of 0.25 in both the brown and green energy sectors, implying an average price duration of 1.3 quarters. The red-dashed lines display the effects of raising price stickiness in the brown energy sector ($\xi_B = 0.9$), while the black-dash-dotted lines illustrate the case of higher price stickiness in the green energy sector ($\xi_G = 0.9$).

Qualitatively, the effects of the carbon tax remain similar across all three scenarios: in each case, the tax promotes a shift from brown to green energy, supporting the energy transition. Quantitatively, the main differences emerge when price stickiness is higher in the brown energy sector. In that case, inflation peaks more sharply, exceeding its steady-state level by over 30 basis points at its trough, compared to 20 basis points in the baseline, and the negative impact on GDP is also substantially larger.

Higher price stickiness in the brown energy sector leads to a milder decline in brown energy inflation, before tax, than in the baseline as fewer firms can adjust their prices. This muted price response forces the adjustment to occur more through quantities, leading to a steeper decline in brown energy output and investment. As a result, households and firms shift more decisively toward green energy pushing green energy inflation above its baseline level. These facts result in stronger overall inflationary pressures, prompting a stronger increase in the nominal policy rate. Tighter monetary policy and sharper contraction in brown energy output lead to a deeper downturn and a more pronounced appreciation of the euro.

5.3 Targeting headline inflation

In our baseline setup, the monetary authority stabilizes core inflation, $\Pi^4_{C,t} \equiv P_{C,t}/P_{C,t-4}$, which excludes energy prices. We now consider an alternative specification in which the central bank targets headline CPI inflation, $\Pi^4_{\mathbb{C},t} \equiv \mathcal{P}_{\mathbb{C},t}/\mathcal{P}_{\mathbb{C},t-4}$. Figure D.13 reports the effects of the carbon tax shock without redistribution under this alternative monetary policy rule.

Under this alternative monetary policy rule, economic activity experiences a deeper contraction. The reason is that the carbon tax raises overall CPI inflation more than core inflation. As a result, a central bank that targets headline inflation reacts more forcefully, triggering a sharper increase in the nominal interest rate. This leads to a more pronounced decline in GDP, investment, and consumption. The higher interest rate also induces an appreciation of the euro, which worsens the trade balance further amplifying the downturn. On the upside, the stronger euro and tighter monetary stance help contain headline inflation more effectively than in the baseline scenario.

5.4 Higher substitution between brown and green energy in household and firm composites

Figures D.14, D.15, and D.16 show the effects of the carbon tax shock with no redistribution under a higher elasticity of substitution between brown and green energy in the household and firm energy composites. Specifically, we increase both ϵ_{BG} and ϵ_E from 1.8 in the baseline calibration to 4. This implies a stronger expenditure switching in response to changes in relative prices between brown and green energy.

Once again, the qualitative effects of the carbon tax remain unchanged. However, the higher substitution elasticity amplifies the reallocation from brown to green energy by households and firms. As a result, brown energy output and pre-tax inflation decline more sharply, while the opposite holds for green energy. The increased availability of green energy leads to higher effective energy input for tradable and non-tradables producers, which softens the contraction in their output. Consequently, the decline in GDP is milder than in the baseline scenario. Overall inflation dynamics, however, remain virtually unchanged.

5.5 Higher substitution between tradables and non-tradables in the production of the brown energy investment good

Figures D.17, D.18, and D.19 show the effects of the brown capital income tax, $\tau_t^{K_B}$, under a higher elasticity of substitution between tradable and non-tradable goods, μ_{IB}, in the production of the brown energy investment good. This experiment builds on the baseline scenario without redistribution (i.e. $\mu_B^I = 0$) discussed in subsection 4.7. The blue-solid lines reproduce the baseline case from subsection 4.7, which assumes that tradable and non-tradable goods are complements by setting $\mu_{IB} = 0.5$. The red-dashed lines show the results when both inputs become more substitutable, with μ_{IB} raised to 3.

Broadly speaking, the macroeconomic effects of the brown capital income tax remain robust to a higher elasticity of substitution in the production of the brown energy investment good. The main dynamics observed under the baseline calibration continue to hold. The implications for the energy transition are also largely unchanged, with the tax encouraging a shift from brown to green energy. More notably, however, the increase in μ_{IB} moderates the decline in non-tradable production, while amplifying the contraction in tradable production. As explained earlier, the non-tradable sector is more labor-intensive, which allows it to partly absorb the adverse effects of the tax through lower wages. Higher elasticity of substitution urges firms to shift more intensively toward these non-tradable inputs. This reallocation partly offsets the energy cost shock, resulting in a milder decline in GDP and its aggregate demand components relative to the baseline.

6 Conclusion

Using an extended version of the EAGLE model with an explicit energy sector, we examined how different climate policy instruments affect macroeconomic outcomes in the euro area. Scenario-based simulations show how carbon taxes and brown capital income taxes shape the transition toward green energy, and how redistribution schemes modulate their effects.

First, both policy tools reduce brown energy use and foster green energy expansion, but they differ in their macroeconomic implications. Carbon taxes act like a supply-side shock, raising inflation and lowering output, whereas brown capital income taxes resemble a negative demand shock. This has important implications for monetary policy design under climate transition.

Second, revenue recycling plays a central role. Subsidizing green energy producers strengthens the substitution away from brown energy, eases inflationary pressure, and reduces the output cost of carbon taxes. In contrast, lump-sum transfers to hand-to-mouth households primarily affect distributional outcomes and do little to accelerate the green transition.

Third, carbon taxes are disinflationary in the brown energy market: higher taxes reduce brown energy inflation before tax, reflecting the dominance of demand-side forces. Redistributive policies reinforce this effect. In contrast, green energy inflation rises in the absence of redistribution, as demand strengthens. Targeted subsidies reverse this outcome by expanding supply, while at the same time easing green inflationary pressures during the transition.

Fourth, coordinating carbon taxes globally has incremental effects on euro area energy dynamics. Although output and inflation respond more strongly under a global tax, the quantitative differences are modest. Substitution patterns within the domestic economy largely determine the response of energy production and investment.

Finally, taxing brown capital income offers a viable alternative to carbon pricing. By shifting investment incentives without triggering the same inflationary pressures, it avoids some of the trade-offs associated with carbon taxes. Recycling the proceeds to green capital subsidies enhances this effect and supports a smoother transition.

Taken together, these results stress the importance of pairing carbon pricing or brown capital taxation with well-designed redistribution mechanisms. Fiscal policy can do more than just price externalities; it can shape the pace, cost, and distributional impact of the green transition.

References

Acemoglu, Daron, Philippe Aghion, Leonardo Bursztyn and David Hemous. (2012). "The environment and directed technical change". *American Economic Review*, 102(1), pp. 131-166. https://doi.org/10.1257/aer.102.1.131

Acemoglu, Daron, Ufuk Akcigit, Douglas Hanley and William Kerr. (2016). "Transition to clean technology". *Journal of Political Economy*, 124(1), pp. 52-104. https://doi.org/10.1086/684511

Airaudo, Florencia S., Evi Pappa and Hernán Seoane. (2022). "Greenflation: The cost of green transition in small open economies". CAF Working Paper, 26, Corporación Andina de Fomento.

Auclert, Adrien, Hugo Monnery, Matthew Rognlie and Ludwig Straub. (2023). "Managing an energy shock: Fiscal and monetary policy". CEPR Discussion Papers, 18340 , Central for Economic Policy Research. https://cepr.org/publications/dp18340

Avgousti, Aris, Francesco Caprioli, Giacomo Caracciolo, Marion Cochard, Pietro Dallari, Mar Delgado-Téllez, João Domingues, Marien Ferdinandusse, Daniela Filip, Carolin Nerlich, Doris Prammer, Katja Schmidt and Anastasia Theofilakou. (2023). "The climate change challenge and fiscal instruments and policies in the EU". ECB Occasional Paper Series, 315, European Central Bank. https://doi.org/10.2866/850581

Baldwin, Elizabeth, Yongyang Cai and Karlygash Kuralbayeva. (2020). "To build or not to build? Capital stocks and climate policy". *Journal of Environmental Economics and Management*, 100(102235). https://doi.org/10.1016/j.jeem.2019.05.001

Bartocci, Anna, Alessandro Notarpietro and Massimiliano Pisani. (2024). "'Green' fiscal policy measures and nonstandard monetary policy in the euro area". *Economic Modelling*, 136(106743). https://doi.org/10.1016/j.econmod.2024.106743

Calvin, Katherine, Pralit Patel, Leon Clarke, Ghassem Asrar, Ben Bond-Lamberty, Ryna Yiyun Cui, Alan Di Vittorio, Kalyn Dorheim, Jae Edmonds, Corinne Hartin, Mohamad Hejazi, Russell Horowitz, Gokul Iyer, Page Kyle, Sonny Kim, Robert Link, Haewon McJeon, Steven J. Smith, Abigail Snyder... and Marshall Wise. (2019). "GCAM v5.1: representing the linkages between energy, water, land, climate, and economic systems". *Geoscientific Model Development*, 12(2), pp. 677-698. https://doi.org/10.5194/gmd-12-677-2019

Calvo, Guillermo A. (1983). "Staggered prices in a utility-maximizing framework". *Journal of Monetary Economics*, 12(3), pp. 383–398. https://doi.org/10.1016/0304-3932(83)90060-0

Cardani, Roberta, Philipp Pfeiffer, Marco Ratto and Lukas Vogel. (2023). "The COVID-19 recession on both sides of the Atlantic: A model-based comparison". *European Economic Review*, 158(104556). https://doi.org/10.1016/j.euroecorev.2023.104556

Coenen, Günter, Matija Lozej and Romanos Priftis. (2024). “Macroeconomic effects of carbon transition policies: An assessment based on the ECB’s New Area-Wide Model with disaggregated energy sector”. *European Economic Review*, 167(104798). https://doi.org/10.1016/j.euroecorev.2024.104798

Coenen, Günter, Peter McAdam and Roland Straub. (2008). “Tax reform and labour-market performance in the euro area: A simulation-based analysis using the New Area-Wide Model”. *Journal of Economic Dynamics and Control*, 32(8), pp. 2543-2583. https://doi.org/10.1016/j.jedc.2007.09.007

Del Negro, Marco, Julian di Giovanni and Keshav Dogra. (2023). “Is the green transition inflationary?”. FRB of New York Staff Reports, 1053.

Dhyne, Emmanuel, Luis J. Álvarez, Hervé Le Bihan, Giovanni Veronese, Daniel Dias, Johannes Hoffmann, Nicole Jonker, Patrick Lünnemann, Fabio Rumler and Jouko Vilmunen. (2006). “Price changes in the Euro Area and the United States: Some facts from individual consumer price data”. *Journal of Economic Perspectives*, 20(2), pp. 171-192. https://doi.org/10.1257/jep.20.2.171

Dietrich, Jan Philipp, Benjamin Leon Bodirsky, Florian Humpenöder, Isabelle Weindl, Miodrag Stevanović, Kristine Karstens, Ulrich Kreidenweis, Xiaoxi Wang, Abhijeet Mishra, David Klein, Geanderson Ambrósio, Ewerton Araujo, Amsalu Woldie Yalew, Lavinia Baumstark, Stephen Wirth, Anastasis Giannousakis, Felicitas Beier, David Meng-Chuen Chen... and Alexander Popp. (2019). “MAgPIE 4 - a modular open-source framework for modeling global land systems”. *Geoscientific Model Development*, 12(4), pp. 1299-1317. https://doi.org/10.5194/gmd-12-1299-2019

Diluiso, Francesca, Barbara Annicchiarico, Matthias Kalkuhl and Jan C. Minx. (2020). “Climate actions and stranded assets: The role of financial regulation and monetary policy”. CESifo Working Paper, 8486.

Golosov, Mikhail, John Hassler, Per Krusell and Aleh Tsyvinski. (2014). “Optimal taxes on fossil fuel in general equilibrium”. *Econometrica*, 82(1), pp. 41–88. https://doi.org/10.3982/ECTA10217

Gomes, Sandra, Pascal Jacquinot and Massimiliano Pisani. (2010). “The EAGLE. A model for policy analysis of macroeconomic interdependence in the Euro Area”. ECB Working Paper Series, 1195, European Central Bank. https://doi.org/10.2139/ssrn.1601272

Gomes, Sandra, Pascal Jacquinot and Massimiliano Pisani. (2012). “The EAGLE. A model for policy analysis of macroeconomic interdependence in the Euro Area”. *Economic Modelling*, 29(5), pp. 1686-1714. https://doi.org/10.1016/j.econmod.2012.04.002

Känzig, Diego R. (2023). “The unequal economic consequences of carbon pricing”. NBER Working Paper Series, w31221, National Bureau of Economic Research. https://doi.org/10.3386/w31221

Lanteri, Andrea, and Adriano A Rampini. (2025). “Financing the adoption of clean technology”. NBER Working Paper Series, w33545, National Bureau of Economic Research. https://doi.org/10.3386/w33545

Nordhaus, William D. (2017). “Evolution of assessments of the economics of global warming: Changes in the DICE model, 1992-2017”. NBER Working Paper Series, w23319, National Bureau of Economic Research. https://doi.org/10.3386/w23319

Papageorgiou, Chris, Marianne Saam and Patrick Schulte. (2017). “Substitution between clean and dirty energy inputs: A macroeconomic perspective”. *The Review of Economics and Statistics*, 99(2), pp. 281-290. https://doi.org/10.1162/REST_a_00592

Pisani-Ferry, Jean, and Simone Tagliapietra. (2024). *An investment strategy to keep the european green deal on track*. Policy Brief, 31/2024, Bruegel.

Varga, Janos, Werner Roeger and Jan in ’t Veld. (2022). “E-QUEST - A multisector dynamic general equilibrium model with energy and a model-based assessment to reach the EU climate targets”. *Economic Modelling*, 114(105911). https://doi.org/10.1016/j.econmod.2022.105911

Table 1. Steady-state shares of energy use and energy production & great ratios

Description	EA	US	RW
Energy-related variables			
Energy share in consumption	5.1	3.8	3.6
Brown energy share in consumption	3.5	2.7	2.5
Green energy share in consumption	1.5	1.1	1.1
Brown energy share in intermediate goods production	4.7	5.0	3.8
Production of tradable goods	2.7	2.8	2.2
Production of non-tradable goods	2.1	2.3	1.6
Green energy share in intermediate goods production	2.3	2.3	1.7
Production of tradable goods	1.3	1.4	1.0
Production of non-tradable goods	1.0	0.9	0.8
Energy investment to GDP	3.1	2.9	2.3
Brown investment to GDP	2.1	2.0	1.6
Green investment to GDP	1.0	0.9	0.7
Great ratios (as a share of GDP)			
Private consumption	59	64	65
Public expenditure	25	19	21
Private investment	15	15	14
Imports total	19	15	8.5
Imports consumption	12	9.5	8.3
Imports investment	3.7	4.2	2.7
Import content of exports	2.5	0.9	1.5

Notes. This table reports the calibrated steady-state shares of energy consumption and energy production. All values are expressed in percent. The calibration targets are mostly based on data from the OECD, Eurostat, and Coenen et al. (2024). EA denotes the Euro Area, US the United States, and RW the Rest of the World.

Table 2. Energy-related structural parameters I

	EA	US	RW
Consumption basket			
Substitution btw non-energy and energy (ϵ_C)	0.40	0.40	0.4
Substitution btw brown and green energy (ϵ_{BG})	1.80	1.80	1.8
Share of non-energy (ν_C)	0.95	0.96	0.9
Share of brown energy in total energy consumption (ν_B)	0.72	0.72	0.7
Intermediate-good firms: tradable sector			
Capital share (α_T)	0.30	0.30	0.3
Substitution btw non-energy and energy (ϵ_T)	0.4	0.4	0.4
Share of non-energy (ν_{YT})	0.96	0.96	0.9
Substitution btw brown and green energy (ϵ_E)	1.8	1.8	1.8
Bias towards brown energy (ν_{ET})	0.69	0.69	0.7
Intermediate-good firms (non-tradable sector)			
Capital share (α_N)	0.27	0.27	0.2
Substitution btw non-energy and energy (ϵ_N)	0.4	0.4	0.4
Share of non-energy (ν_{YN})	0.96	0.96	0.9
Bias towards brown energy (ν_{EN})	0.70	0.73	0.7
Carbon emissions			
Carbon intensity of brown energy (ϕ_0)	380	865	86
Carbon intensity of tradable goods (ϕ_1)	41	63	63
Carbon intensity of non-tradable goods (ϕ_2)	41	63	63
Brown energy sector			
Bias towards brown capital (γ_B)	0.71	0.71	0.7
Green energy sector			
Bias towards green capital (γ_G)	0.71	0.71	0.7
Final brown investment-good firms			
Substitution btw. domestic and imported trad. goods (μ_{TIB})	1.50	1.50	1.5
Bias towards domestic tradables goods (υ_{TIB})	0.52	0.52	0.7
Substitution btw. tradables and non-tradables (μ_{IB})	0.50	0.50	0.5
Bias towards tradable goods (υ_{IB})	0.45	0.45	0.3
Substitution across imported goods (μ_{IMIB})	2.50	2.50	2.5
Final green investment-good firms			
Substitution btw. domestic and imported trad. goods (μ_{TIG})	1.50	1.50	1.5
Bias towards domestic tradables goods (υ_{TIG})	0.52	0.52	0.7
Substitution btw. tradables and non-tradables (μ_{IG})	0.50	0.50	0.5
Bias towards tradable goods (υ_{IG})	0.45	0.45	0.3
Substitution across imported goods (μ_{IMIG})	2.50	2.50	2.5

EA = Euro Area; US = United States; RW = Rest of World

Table 3. Energy-related structural parameters II

	EA	US	RW
Mark-up			
Price elasticity of demand for brown energy varieties (θ_B)	6	6	6
Price elasticity of demand for green energy varieties (θ_G)	6	6	6
Real rigidities			
Brown energy investment (γ_{IB})	5	5	5
Green energy investment (γ_{IG})	5	5	5
Import of brown energy investment (γ_{IMIB})	2	2	2
Import of green energy investment (γ_{IMIG})	2	2	2
Utilization of brown capital (γ_{uB})	2000	2000	2000
Utilization of green capital (γ_{uG})	2000	2000	2000
Nominal rigidities			
Brown energy goods sector			
Price stickiness (ξ_B)	0.25	0.25	0.25
Price indexation (χ_B)	0	0	0
Green energy goods sector			
Price stickiness (ξ_G)	0.25	0.25	0.25
Price indexation (χ_G)	0	0	0
Fiscal instruments			
Carbon tax (τ^{E_B})	0.039	0.039	0.039
Tax on I-households brown capital income (τ^{K_B})	0.16	0.16	0.16
Fraction of subsidy to green energy firms (ς_E^Y)	0	0	0
Fraction of subsidy to non-Ricardian households (ς_E^C)	0	0	0
Fraction of subsidy to green investment (μ_B^I)	0	0	0

EA = Euro Area; US = United States; RW = Rest of World

Table 4. Non-energy economy: Rigidities

	EA	US	RW
Mark-up			
Wages – households	1.30	1.10	1.10
Prices – domestic tradable goods	1.20	1.20	1.20
Prices – domestic non-tradable goods	1.50	1.50	1.50
Real rigidities			
General capital utilization (γ_u)	2000	2000	2000
Non-energy Investment (γ_I)	6.00	4.00	4.00
Imports – consumption	2.00	2.00	2.00
Imports – investment	1.00	1.00	1.00
Nominal rigidities			
Households			
Wage stickiness	0.90	0.75	0.75
Wage indexation	0.5	0.5	0.5
Tradable goods sector			
Price stickiness (domestic goods)	0.9	0.75	0.75
Price indexation (domestic goods)	0.50	0.50	0.50
Non-tradable goods sector			
Price stickiness (domestic goods)	0.9	0.75	0.75
Price indexation (domestic goods)	0.50	0.50	0.50
Region sizes	0.18	0.26	0.56

EA = Euro Area; US = United States; RW = Rest of World

Table 5. Households

	EA	US	RW
Discount factor (β)	$1.03^{-\frac{1}{4}}$	$1.03^{-\frac{1}{4}}$	$1.03^{-\frac{1}{4}}$
Intertemporal elasticity of substitution (σ^{-1})	1.00	1.00	1.00
Inverse of the Frisch elasticity of labor (ζ)	2.00	2.00	2.00
Habit persistence (κ)	0.90	0.90	0.90
Share of non-Ricardian households (ω)	0.33	0.25	0.25
Depreciation rate (δ)	0.025	0.025	0.025
Depreciation rate (δ_B)	0.025	0.025	0.025
Depreciation rate (δ_G)	0.025	0.025	0.025

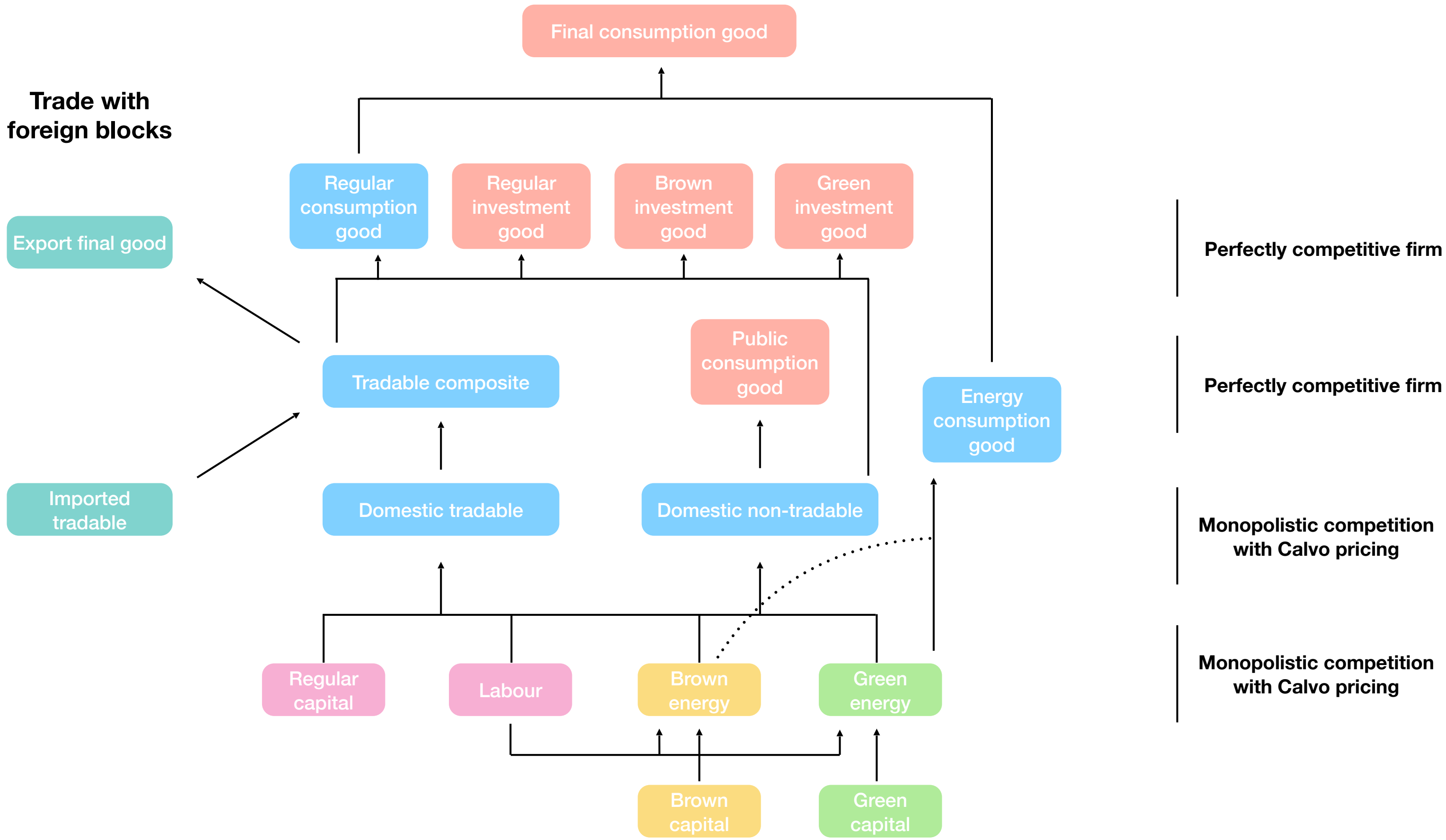
Note: EA = Euro Area; US = United States; RW = Rest of World

Table 6. Monetary and Fiscal Policy

	EA	US	RW
Monetary authority			
Inflation target ($\overline{\Pi}^4$)	1.02	1.02	1.02
Interest rate inertia (ϕ_R)	0.87	0.87	0.87
Interest rate sensitivity to inflation gap (ϕ_Π)	1.70	1.70	1.70
Interest rate sensitivity to output growth (ϕ_Y)	0.10	0.10	0.10
Fiscal authority			
Government debt-to-output ratio ($\overline{BY}$)	2.40	2.40	2.40
Sensitivity of lump-sum taxes to debt-to-output ratio (ϕ_{B_Y})	0.10	0.10	0.10
Consumption tax rate (τ^C)	0.183	0.077	0.07
Dividend tax rate (τ^D)	0.00	0.00	0.00
Capital income tax rate (τ^K)	0.19	0.16	0.16
Labor income tax rate (τ^N)	0.122	0.154	0.15
Rate of social security contribution by firms (τ^{W_F})	0.219	0.071	0.07
Rate of social security contribution by households (τ^{W_H})	0.118	0.071	0.07

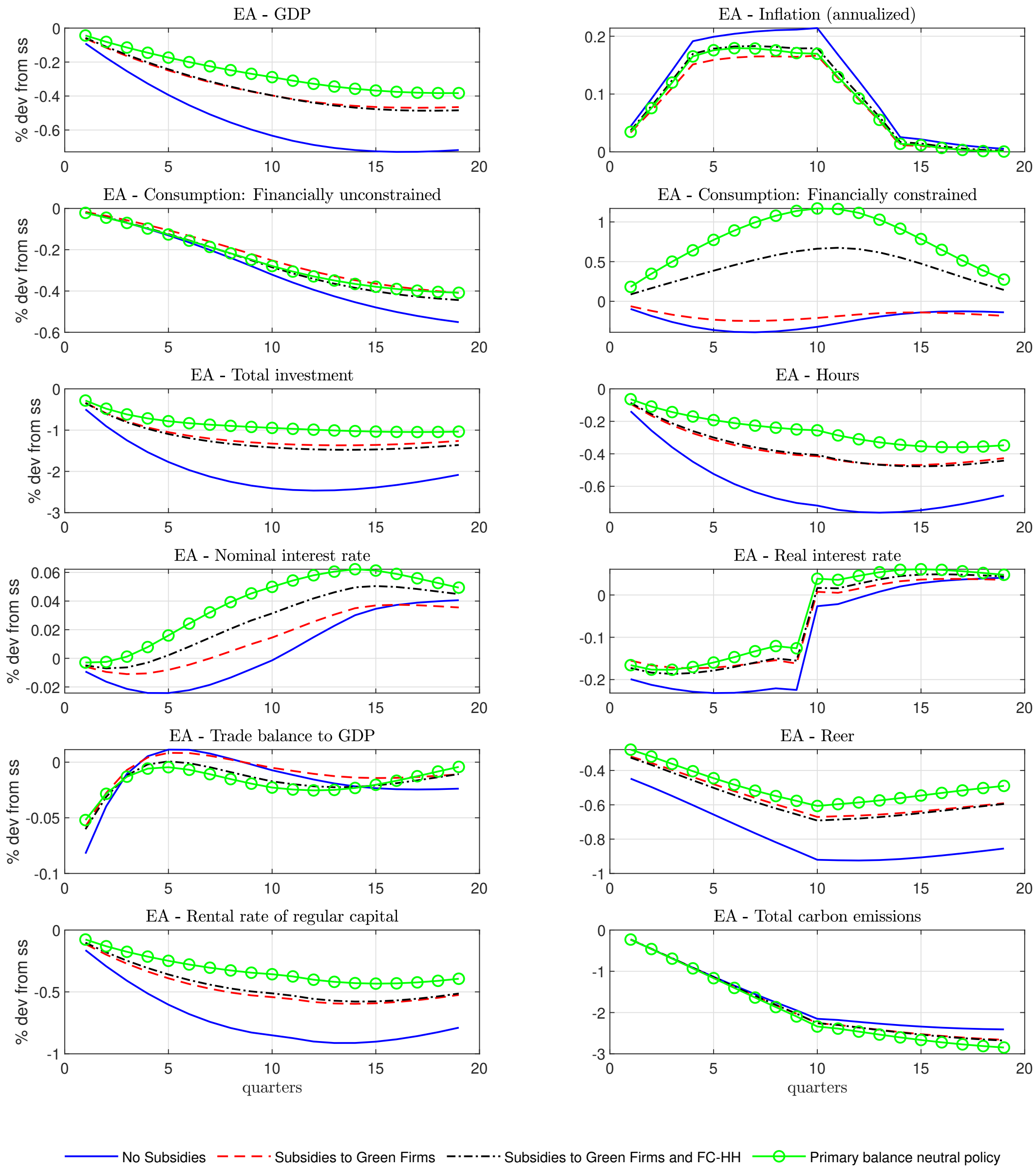
Note: EA = Euro Area; US = United States; RW = Rest of World

Figure 1. Schematic representation of the model



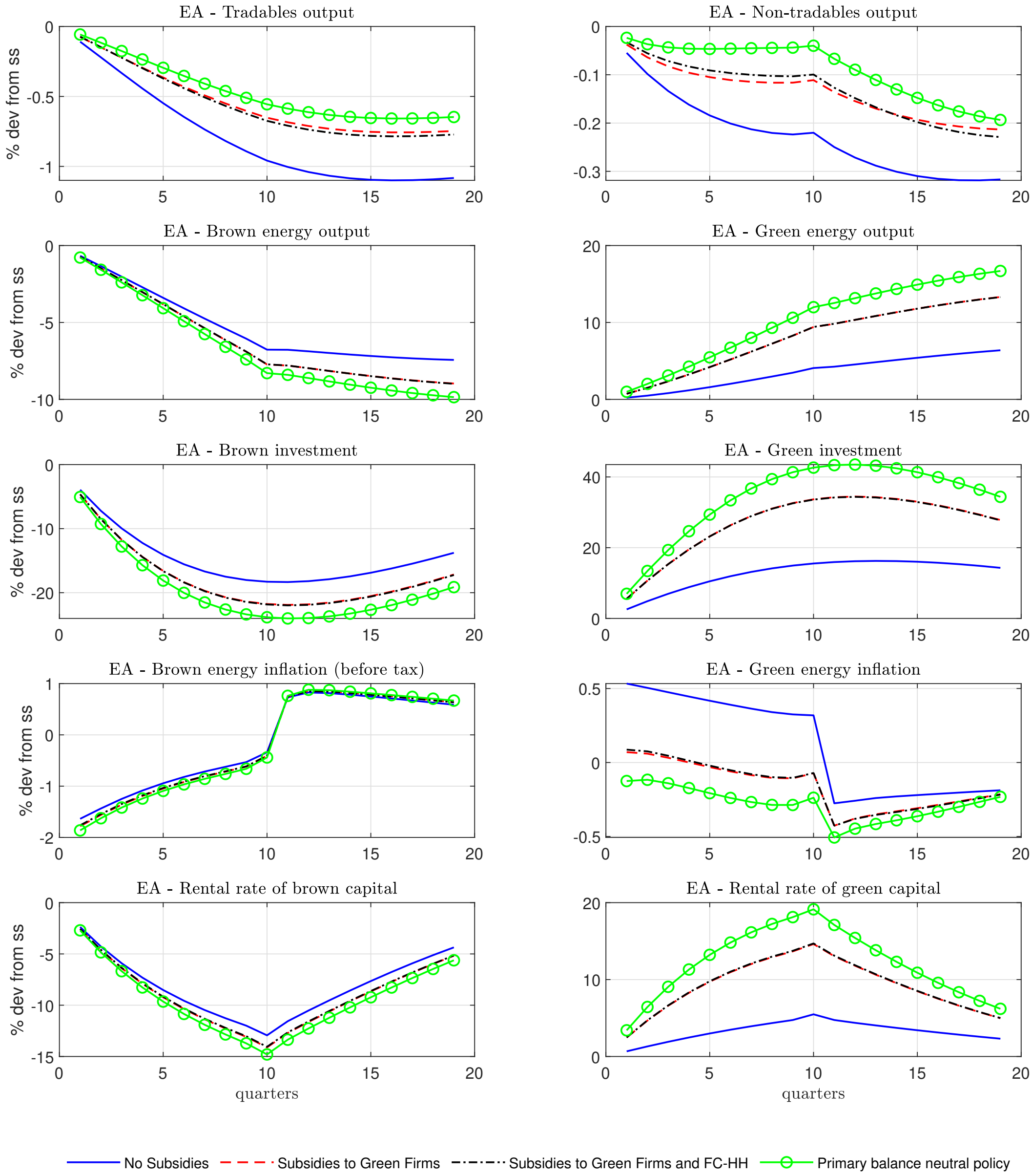
Notes: This figure shows a simple chart of the input and output flows across production sectors in the extended version of the C-EAGLE model.

FIGURE 2. Impulse Responses to a carbon tax shock in the EA



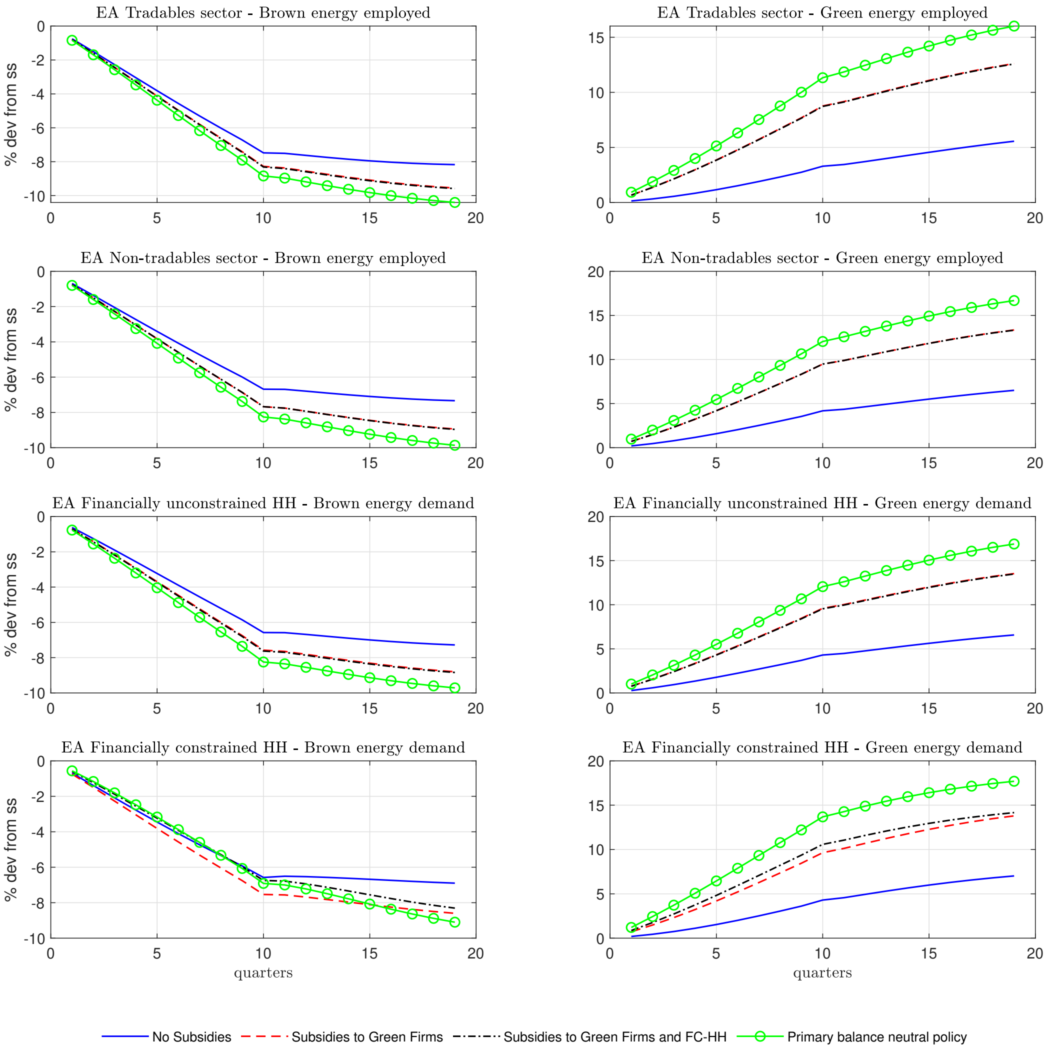
Notes: Impulse responses to a rise in carbon tax in the EA that raises the price of brown energy by 1% on impact. Horizontal axis: quarters. Vertical axis: percentage deviations from the baseline, except for inflation and interest rates (annualized percentage-point deviations), and the trade balance-to-GDP ratio (percentage-point deviations). GDP and its components are reported in real terms. Blue-solid lines represent impulse responses after a carbon tax shock without subsidies. Red-dashed lines represent impulse responses after a carbon tax shock with subsidies to green energy-producing firms with $\varsigma_E^Y = 0.33$. Black-dashed-dotted lines represent impulse responses after a carbon tax shock with subsidies to green energy-producing firms and financially constrained households (FC-HH) with $\varsigma_E^Y = \varsigma_E^C = 0.33$. Green-circled lines represent impulse responses after a carbon tax shock with subsidies to green energy-producing firms and financially constrained households (FC-HH) under a primary balance neutral policy, i.e. $\varsigma_E^Y = \varsigma_E^C = 0.5$.

FIGURE 3. Impulse Responses to a carbon tax shock in the EA



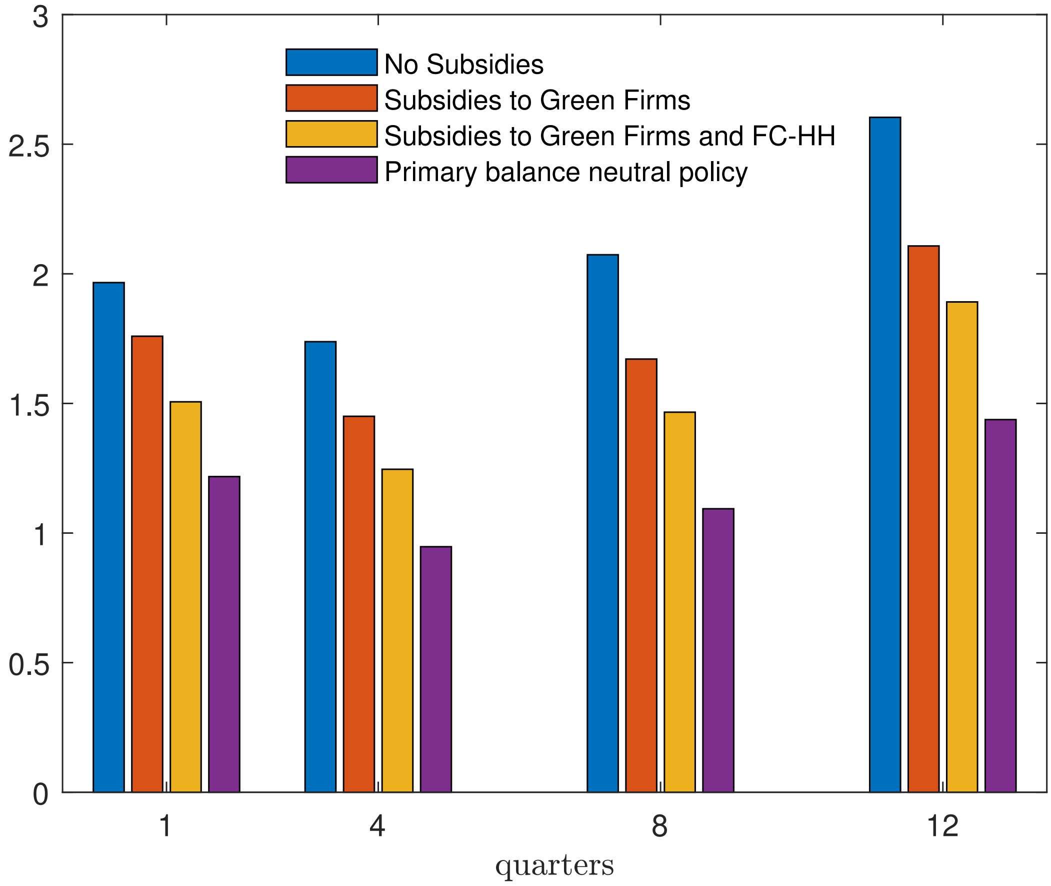
Notes: Impulse responses to a rise in carbon tax in the EA that raises the price of brown energy by 1% on impact. Horizontal axis: quarters. Vertical axis: percentage deviations from the baseline, except for inflation and interest rates (annualized percentage-point deviations), and the trade balance-to-GDP ratio (percentage-point deviations). GDP and its components are reported in real terms. Blue-solid lines represent impulse responses after a carbon tax shock without subsidies. Red-dashed lines represent impulse responses after a carbon tax shock with subsidies to green energy-producing firms with $\varsigma_E^Y = 0.33$. Black-dashed-dotted lines represent impulse responses after a carbon tax shock with subsidies to green energy-producing firms and financially constrained households (FC-HH) with $\varsigma_E^Y = \varsigma_E^C = 0.33$. Green-circled lines represent impulse responses after a carbon tax shock with subsidies to green energy-producing firms and financially constrained households (FC-HH) under a primary balance neutral policy, i.e. $\varsigma_E^Y = \varsigma_E^C = 0.5$.

FIGURE 4. Impulse Responses to a carbon tax shock in the EA



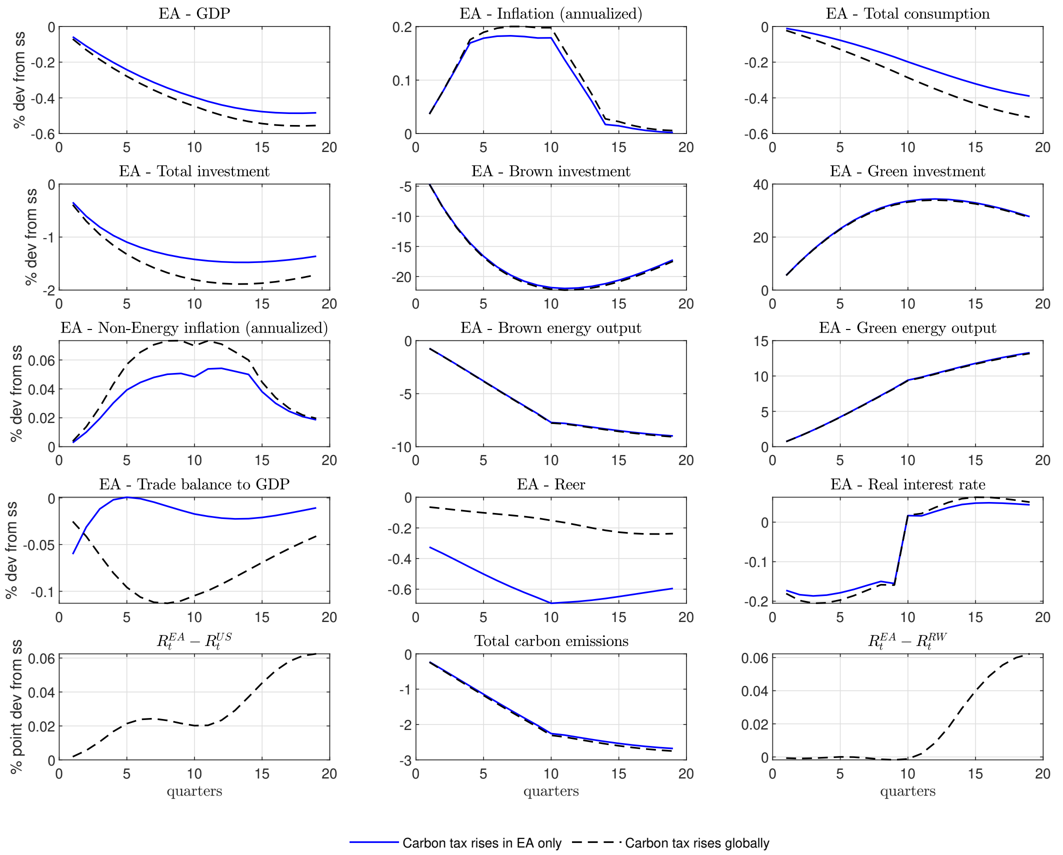
Notes: Impulse responses to a rise in carbon tax in the EA that raises the price of brown energy by 1% on impact. Horizontal axis: quarters. Vertical axis: percentage deviations from the baseline, except for inflation and interest rates (annualized percentage-point deviations), and the trade balance-to-GDP ratio (percentage-point deviations). GDP and its components are reported in real terms. Blue-solid lines represent impulse responses after a carbon tax shock without subsidies. Red-dashed lines represent impulse responses after a carbon tax shock with subsidies to green energy-producing firms with $\varsigma_E^Y = 0.33$. Black-dashed-dotted lines represent impulse responses after a carbon tax shock with subsidies to green energy-producing firms and financially constrained households (FC-HH) with $\varsigma_E^Y = \varsigma_E^C = 0.33$. Green-circled lines represent impulse responses after a carbon tax shock with subsidies to green energy-producing firms and financially constrained households (FC-HH) under a primary balance neutral policy, i.e. $\varsigma_E^Y = \varsigma_E^C = 0.5$.

FIGURE 5. Sacrifice ratios



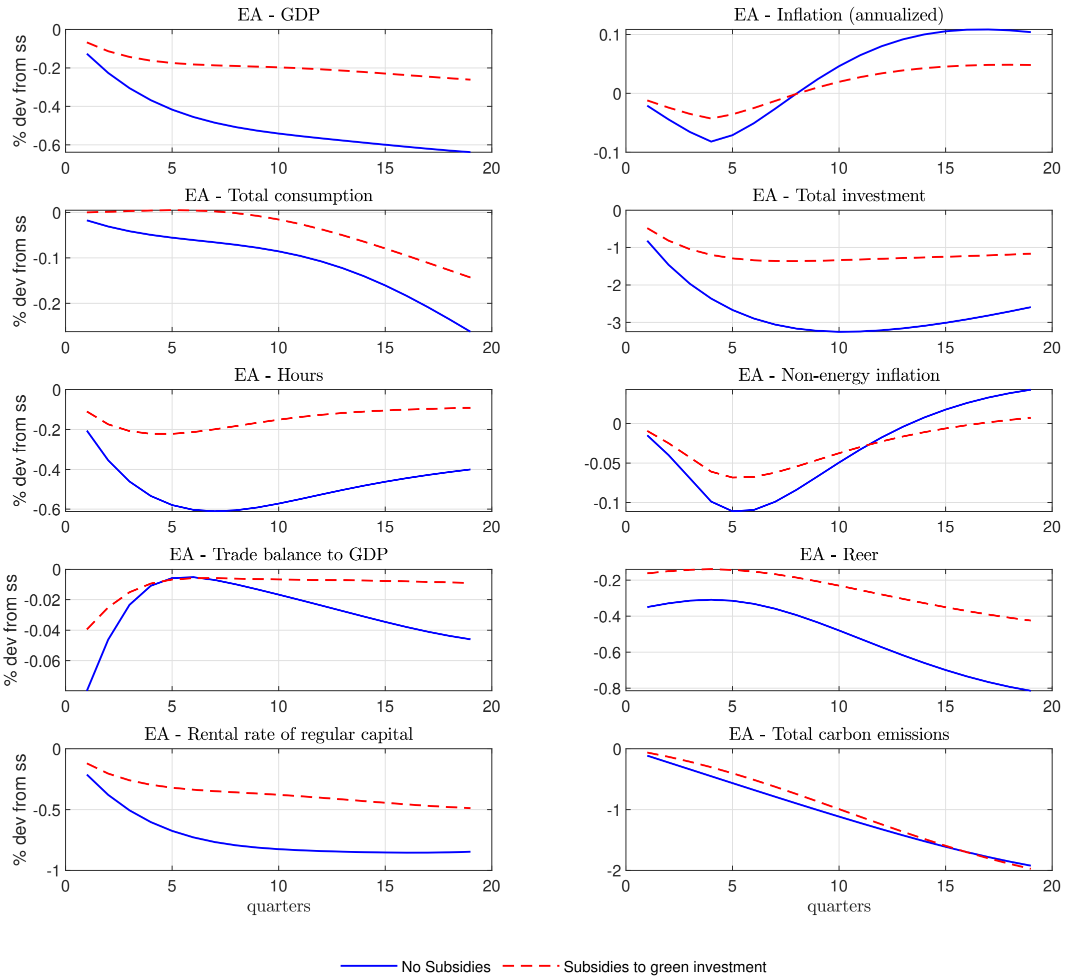
Notes: Sacrifice ratios of carbon tax and subsidy policies on impact, 4 quarters, 8 quarters and 12 quarters ahead, respectively. The ratios are computed as the cumulative response of GDP over the cumulative response of annualized inflation.

FIGURE 6. Impulse Responses to a global carbon tax shock with subsidies



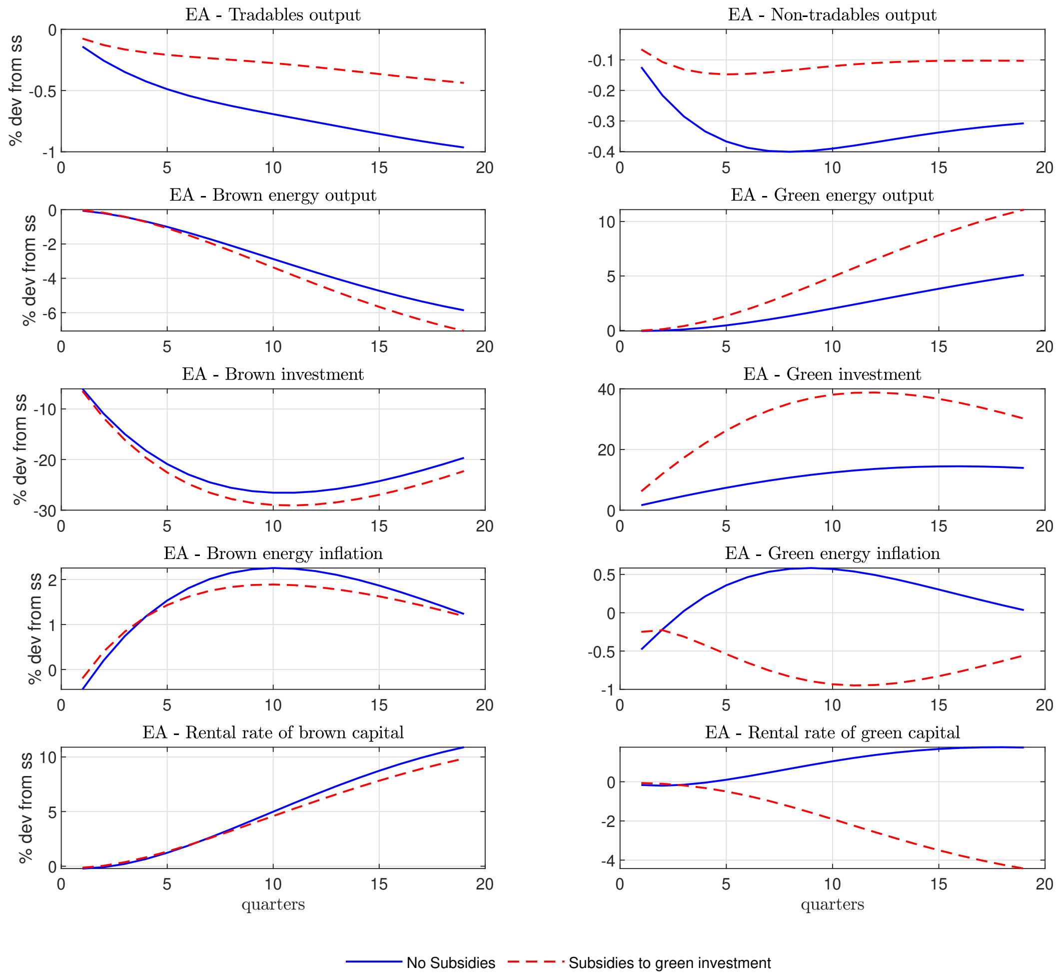
Notes: Impulse responses to a rise in carbon tax in the EA, the US and the RW when all regions implement transfers to green energy firms and the constrained households. $R_t^{EA} - R_t^{US}$ and $R_t^{EA} - R_t^{RW}$ denote the spread between the policy rate in the EA and the US and the spread between the policy rate in the EA and the RW, respectively. Horizontal axis: quarters. Vertical axis: percentage deviations from the baseline, except for inflation and interest rates (annualized percentage-point deviations), and the trade balance-to-GDP ratio (percentage-point deviations). GDP and its components are reported in real terms.

Figure 7. Impulse Responses to a brown-capital rental income tax shock in the EA



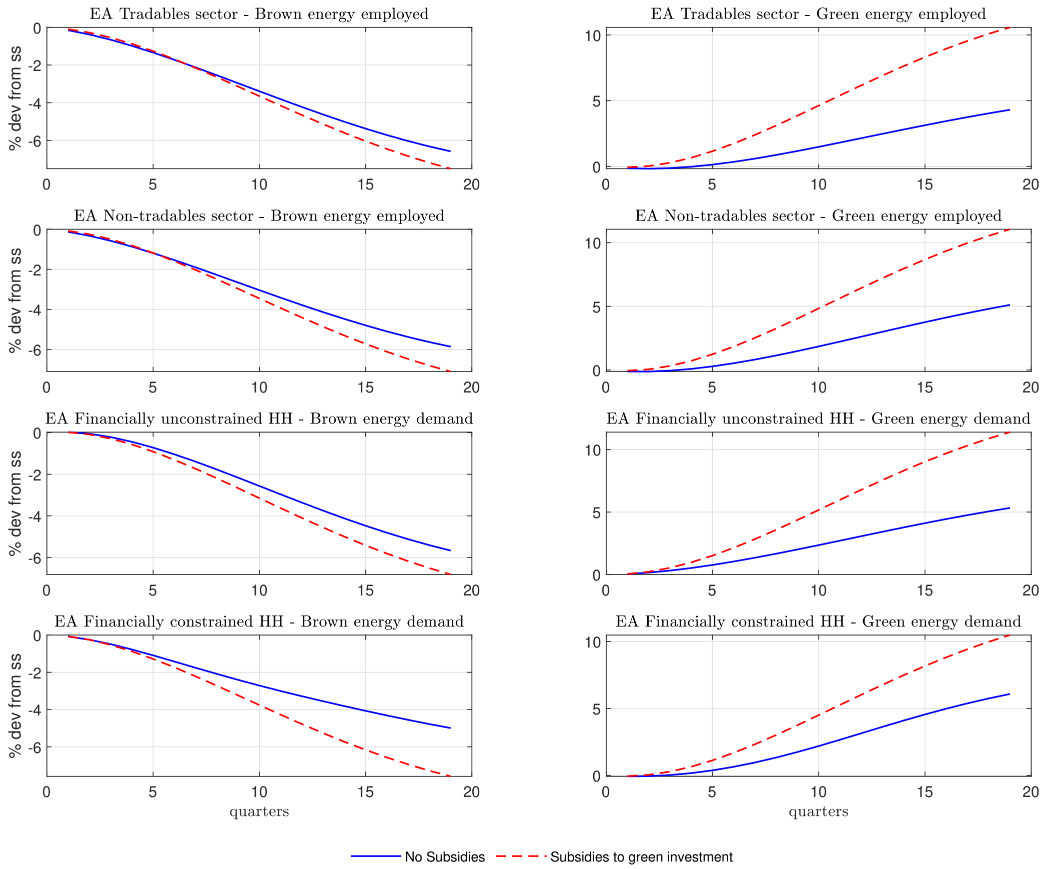
Notes: Impulse responses to a rise in tax on rental brown capital income in the EA. Horizontal axis: quarters. Vertical axis: percentage deviations from the baseline, except for inflation and interest rates (annualized percentage-point deviations), and the trade balance-to-GDP ratio (percentage-point deviations). GDP and its components are reported in real terms.

FIGURE 8. Impulse Responses to a brown-capital rental income tax shock in the EA



Notes: Impulse responses to a rise in tax on rental brown capital income in the EA. Horizontal axis: quarters. Vertical axis: percentage deviations from the baseline, except for inflation and interest rates (annualized percentage-point deviations), and the trade balance-to-GDP ratio (percentage-point deviations). GDP and its components are reported in real terms.

FIGURE 9. Impulse Responses to a brown-capital rental income tax shock in the EA



Notes: Impulse responses to a rise in tax on rental brown capital income in the EA. Horizontal axis: quarters. Vertical axis: percentage deviations from the baseline, except for inflation and interest rates (annualized percentage-point deviations), and the trade balance-to-GDP ratio (percentage-point deviations). GDP and its components are reported in real terms.

Online Appendix Not for Publication

A Production Structure of the Economy

This appendix complements Figure 1 by presenting the key equations that define each stage of production. We begin at the bottom right of the figure with energy production and move upward through the stages until we reach the final consumption good composite. While we aim for a symmetric structure across subsections, we include additional details where necessary for clarity.

A.1 Brown and green energy producers

Brown and green energy producers operate under monopolistic competition and use Cobb-Douglas production technologies. Each brown brand is produced by a firm b from a continuum of mass s^H ($b \in [0, s^H]$), and each green brand by a firm g from the same continuum ($g \in [0, s^H]$). Output net of fixed costs is given by:

$$Y^S_{B,t}(b) = z_{B,t} \left(K^D_{B,t}(b)\right)^{\gamma_B} \left(N^D_t(b)\right)^{1-\gamma_B} - \psi_B \tag{A.1}$$

$$Y^S_{G,t}(g) = z_{G,t} \left(K^D_{G,t}(g)\right)^{\gamma_G} \left(N^D_t(g)\right)^{1-\gamma_G} - \psi_G \tag{A.2}$$

Here, ψ_B and ψ_G are fixed costs common to all firms in each sector. Inputs include homogeneous capital services, $K^D_{B,t}(b)$ and $K^D_{G,t}(g)$, and differentiated labor services, $N^D_t(b)$ and $N^D_t(g)$. Capital is supplied competitively by households, while labor services are supplied under monopolistic competition. Sector-specific productivity is captured by $z_{B,t}$ and $z_{G,t}$.

Firms choose inputs to minimize costs, taking factor prices as given. Since all firms face the same input prices and use identical technologies, nominal marginal costs are the same for every firm within each sector. This leads to the following marginal cost expressions:

$$MC_{B,t} = \frac{1}{z_{B,t}\gamma_B^{\gamma_B}(1-\gamma_B)^{1-\gamma_B}} \left(R^K_{B,t}\right)^{\gamma_B} \left((1+\tau_t^{W_F})W_t\right)^{1-\gamma_B} \tag{A.3}$$

$$MC_{G,t} = \frac{1}{z_{G,t}\gamma_G^{\gamma_G}(1-\gamma_G)^{1-\gamma_G}} \left(R^K_{G,t}\right)^{\gamma_G} \left((1+\tau_t^{W_F})W_t\right)^{1-\gamma_G} \tag{A.4}$$

where $R^K_{B,t}$ and $R^K_{G,t}$ are the rental rates of brown and green capital, respectively, and W_t is the aggregate wage index.

Prices are set *à la* Calvo (1983). Optimal reset prices satisfy:

$$\frac{\widetilde{P}_{B,t}}{P_{B,t}} = \frac{\theta_B}{\theta_B - 1}\frac{F_{B,t}}{G_{B,t}} \tag{A.5}$$

$$\frac{\widetilde{P}_{G,t}}{P_{G,t}} = \frac{\theta_G}{\theta_G - 1}\frac{F_{G,t}}{G_{G,t}} \tag{A.6}$$

$\widetilde{P}_{B,t}$ and $\widetilde{P}_{G,t}$ are the optimal reset prices, θ_B and θ_G are the elasticities of substitution across varieties, and $F_{j,t}$, $G_{j,t}$ (for $j \in B, G$) are standard sector-specific terms reflecting expected discounted profits and demand. Their definitions are provided in the main text.

Lastly, the aggregate brown energy price index is a weighted average of the price reset in the current period and the past price adjusted by past and steady-state brown energy inflation. The aggregate green energy price index follows the same structure, formally given as:

$$P_{B,t} = \left[\xi_B \left(P_{B,t-1}\pi^{\chi_B}_{B,t-1}\pi_B^{1-\chi_B}\right)^{1-\theta_B} + (1-\xi_B)\left(\widetilde{P}_{B,t}\right)^{1-\theta_B}\right]^{\frac{1}{1-\theta_B}} \tag{A.7}$$

$$P_{G,t} = \left[\xi_G \left(P_{G,t-1}\pi^{\chi_G}_{G,t-1}\pi_G^{1-\chi_G}\right)^{1-\theta_G} + (1-\xi_G)\left(\widetilde{P}_{G,t}\right)^{1-\theta_G}\right]^{\frac{1}{1-\theta_G}} \tag{A.8}$$

A.2 Intermediate goods firms

Firms produce tradable and non-tradable intermediate goods under monopolistic competition. Each tradable brand is produced by a firm h from a continuum of mass s^H ($h \in [0, s^H]$). Similarly, each non-tradable brand is produced by a firm n from the same continuum ($n \in [0, s^H]$). Both sectors use brown and green energy goods.

Technology. Each non-tradable and tradable intermediate good, respectively n and h, is produced according to:

$$Y^S_{T,t}(h) = z_{T,t}\left[\nu_{YT}^{\frac{1}{\varepsilon_T}}\left(K^D_t(h)^{\alpha_T} N^D_t(h)^{1-\alpha_T}\right)^{\frac{\varepsilon_T-1}{\varepsilon_T}} + (1-\nu_{YT})^{\frac{1}{\varepsilon_T}}\left(E^D_t\right)^{\frac{\varepsilon_T-1}{\varepsilon_T}}\right]^{\frac{\varepsilon_T}{\varepsilon_T-1}} - \psi_T \tag{A.9}$$

$$Y_{N,t}^{S}(n) = z_{N,t}\left[\nu_{YN}^{\frac{1}{\varepsilon_N}}\left(K_t^D(n)^{\alpha_N} N_t^D(n)^{1-\alpha_N}\right)^{\frac{\varepsilon_N-1}{\varepsilon_N}} + (1-\nu_{YN})^{\frac{1}{\varepsilon_N}}\left(E_t^D\right)^{\frac{\varepsilon_N-1}{\varepsilon_N}}\right]^{\frac{\varepsilon_N}{\varepsilon_N-1}} - \psi_N \tag{A.10}$$

with total energy, $E_t^D(\cdot)$, decomposed as:

$$E_t^D(h) = \left(\nu_{ET}^{\frac{1}{\epsilon_E}}\left(E_{B,t}(h)\right)^{\frac{\epsilon_E-1}{\epsilon_E}} + (1-\nu_{ET})^{\frac{1}{\epsilon_E}}\left(E_{G,t}(h)\right)^{\frac{\epsilon_E-1}{\epsilon_E}}\right)^{\frac{\epsilon_E}{\epsilon_E-1}} \tag{A.11}$$

$$E_t^D(n) = \left(\nu_{EN}^{\frac{1}{\epsilon_E}}\left(E_{B,t}(n)\right)^{\frac{\epsilon_E-1}{\epsilon_E}} + (1-\nu_{EN})^{\frac{1}{\epsilon_E}}\left(E_{G,t}(n)\right)^{\frac{\epsilon_E-1}{\epsilon_E}}\right)^{\frac{\epsilon_E}{\epsilon_E-1}} \tag{A.12}$$

ψ_T and ψ_N are fixed costs, identical for all firms within each sector. The inputs include homogeneous capital services, $K_t^D(n)$ and $K_t^D(h)$, and differentiated labor services, $N_t^D(n)$ and $N_t^D(h)$. Capital is supplied by domestic households under perfect competition, while labor is supplied under monopolistic competition. In turn, $E_{B,t}(z)$ and $E_{G,t}(z)$ denote the demand for brown and green energy goods by intermediate goods firms. The parameter $\nu_{z,E}$ represents the share of brown energy in their total energy consumption, and ϵ_E is the elasticity of substitution between brown and green energy goods. Finally, $z_{N,t}$ and $z_{T,t}$ are sector-specific productivity shocks.

Tradable and non-tradable goods producers face a carbon tax, $\tau_t^{E_B}$, levied as a surcharge on the price of brown energy. As a result, the energy price index for intermediate goods producers is defined as:

$$\mathcal{P}_{ET,t} = \left(\nu_{ET}\left((1+\tau_t^{E_B})P_{B,t}\right)^{1-\epsilon_E} + (1-\nu_{ET})P_{G,t}^{1-\epsilon_E}\right)^{\frac{1}{1-\epsilon_E}} \tag{A.13}$$

$$\mathcal{P}_{EN,t} = \left(\nu_{EN}\left((1+\tau_t^{E_B})P_{B,t}\right)^{1-\epsilon_E} + (1-\nu_{EN})P_{G,t}^{1-\epsilon_E}\right)^{\frac{1}{1-\epsilon_E}} \tag{A.14}$$

where $P_{B,t}$ and $P_{G,t}$ denote the prices of brown and green energy goods, respectively. Expenditure minimization yields the following standard demands for brown and green energy:

$$E_{B,t}(z) = \left(\frac{(1+\tau_t^{E_B})P_{B,t}}{\mathcal{P}_{E,t}}\right)^{-\epsilon_E}\nu E_t(z) \tag{A.15}$$

$$E_{G,t}(z) = \left(\frac{P_{G,t}}{\mathcal{P}_{E,t}}\right)^{-\epsilon_E}(1-\nu)E_t(z), \qquad \text{for } z = h, n$$

where $\mathcal{P}_{E,t}$ and ν correspond to $\mathcal{P}_{EN,t}$ and ν_{EN} for non-tradable firms, and to $\mathcal{P}_{ET,t}$ and ν_{ET} for tradable firms.

Cost minimization. Firms belonging to the intermediate sectors take the rental cost of capital R_t^K and the aggregate wage index W_t as given. Firms belonging to the tradables sector demand capital and labor services to minimize total input cost $R_t^K K_t^D(h) + \mathcal{P}_{ET,t} E_{E,t}^D(h) + \left(1+\tau_t^{W_F}\right) W_t N_t^D(h)$ subject to the production function (A.9). Similarly, firms in the non-tradables intermediate sector minimize the cost $R_t^K K_t^D(n) + \mathcal{P}_{EN,t} E_t^D(n) + \left(1+\tau_t^{W_F}\right) W_t N_t^D(n)$ subject to the production function (A.10).

The first-order conditions of the firms' cost minimization problem with respect to capital and labor inputs - respectively $K_t^D(n)$ and $N_t^D(n)$ for the non-tradables sector, $K_t^D(h)$ and $N_t^D(h)$ for the tradables sector - are sector-specific. Given that all firms face the same factor prices and all firms use the same technology, the nominal marginal cost is identical across firms within each sector (i.e. $MC_{N,t} = MC_t(n)$ and $MC_{T,t} = MC_t(h)$):

$$MC_{T,t} = z_{T,t}^{-1}\left[\nu_{YT}\left(\frac{\left(R_t^K\right)^{\alpha_T}(\Omega_t)^{1-\alpha_T}}{(\alpha_T)^{\alpha_T}(1-\alpha_T)^{1-\alpha_T}}\right)^{1-\varepsilon_T} + (1-\nu_{YT})\,\mathcal{P}_{ET,t}^{1-\varepsilon_T}\right]^{\frac{1}{1-\varepsilon_T}} \tag{A.16}$$

$$MC_{N,t} = z_{N,t}^{-1}\left[\nu_{YN}\left(\frac{\left(R_t^K\right)^{\alpha_N}(\Omega_t)^{1-\alpha_N}}{(\alpha_N)^{\alpha_N}(1-\alpha_N)^{1-\alpha_N}}\right)^{1-\varepsilon_N} + (1-\nu_{YN})\,\mathcal{P}_{EN,t}^{1-\varepsilon_N}\right]^{\frac{1}{1-\varepsilon_N}} \tag{A.17}$$

where $\Omega_t = \left(1+\tau_t^{W_F}\right) W_t$.

Price setting. Firms in the tradable and non-tradable goods sectors operate under monopolistic competition and set prices infrequently following Calvo (1983). Tradable goods firms sell domestically and abroad using local currency pricing, setting different prices by destination market. Non-tradable goods firms sell only domestically. The price setting setup follows Gomes et al. (2012) and is not reproduced here for brevity.

A.3 Final goods sector: non-energy consumption goods

Each perfectly competitive final non-energy consumption good firm $x \in [0, s^H]$ produces a non-energy consumption good, $\mathcal{Q}_t^C(x)$, with the following CES technology:

$$\mathcal{Q}_t^C(x) = \left[\nu_C^{\frac{1}{\mu_C}} TT_t^C(x)^{\frac{\mu_C-1}{\mu_C}} + (1-\nu_C) NT_t^C(x)^{\frac{\mu_C-1}{\mu_C}}\right]^{\frac{\mu_C}{\mu_C-1}} \tag{A.18}$$

where:

$$TT_t^C(x) = \left[\nu_{TC}^{\frac{1}{\mu_{TC}}} HT_t^C(x)^{\frac{\mu_{TC}-1}{\mu_{TC}}} + (1-\nu_{TC}) IM_t^C(x)^{\frac{\mu_{TC}-1}{\mu_{TC}}} \right]^{\frac{\mu_{TC}}{\mu_{TC}-1}} \tag{A.19}$$

In the expressions above, $TT_t^C(x)$ and $NT_t^C(x)$ denote the tradable and non-tradable goods, respectively, used to produce the final non-energy consumption good. Parameter $\nu_C \in [0,1]$ captures the share of tradables in the production process while parameter $\mu_C > 0$ denotes the elasticity of substitution between tradables and non-tradables in production. Subsequently, $HT_t^C(x)$ and $IM_t^C(x)$ in the tradable goods aggregator (A.19) denote the home and the imported tradable goods used in the production of the final non-energy consumption good. The parameter $\nu_{TC} \in [0,1]$ captures home bias while parameter $\mu_{TC} > 0$ is the trade elasticity. Imports $IM_t^C(x)$ are a CES function of basket of goods imported from other countries:

$$IM_t^C(x) = \left[\sum_{CO \neq H} \left(\upsilon_{IMC}^{H,CO} \right)^{\frac{1}{\mu_{IMC}}} \left(IM_{C,t}^{H,CO}(x) \left(1 - \Gamma_{IM^C,t}^{H,CO}(x) \right) \right)^{\frac{\mu_{IMC}-1}{\mu_{IMC}}} \right]^{\frac{\mu_{IMC}}{\mu_{IMC}-1}} \tag{A.20}$$

where $\mu_{IMC} > 0$ and the coefficients $\upsilon_{IMC}^{H,CO}$ are such that:

$$0 \leq \upsilon_{IMC}^{H,CO} \leq 1, \quad \sum_{CO \neq H} \upsilon_{IMC}^{H,CO} = 1 \tag{A.21}$$

The term $\Gamma_{IM^C,t}^{H,CO}(x)$ represents adjustment costs on bilateral investment imports of country H from country CO:

$$\Gamma_{IM^C,t}^{H,CO}(x) \equiv \frac{\gamma_{IMC}}{2} \left(\frac{IM_{C,t}^{H,CO}(x) / \mathcal{Q}_t^C(x)}{IM_{C,t-1}^{H,CO} / \mathcal{Q}_{t-1}^C} - 1 \right)^2, \quad \gamma_{IMC} \geq 0 \tag{A.22}$$

A.4 Final goods sector: non-energy investment goods

Similar to the non-energy final consumption good firm above, the competitive final non-energy investment good firm $x \in [0, s^H]$ produces a non-energy investment good, $\mathcal{Q}_t^I(x)$, with the following CES technology:

$$\mathcal{Q}_t^I(x) = \left[\nu_I^{\frac{1}{\mu_I}} TT_t^I(x)^{\frac{\mu_I-1}{\mu_I}} + (1-\nu_I) NT_t^I(x)^{\frac{\mu_I-1}{\mu_I}} \right]^{\frac{\mu_I}{\mu_I-1}} \tag{A.23}$$

where:

$$TT_t^I(x) = \left[\nu_{TI}^{\frac{1}{\mu_{TI}}} HT_t^I(x)^{\frac{\mu_{TI}-1}{\mu_{TI}}} + (1-\nu_{TI}) IM_t^I(x)^{\frac{\mu_{TI}-1}{\mu_{TI}}}\right]^{\frac{\mu_{TI}}{\mu_{TI}-1}} \tag{A.24}$$

In the expressions above, $TT_t^I(x)$ and $NT_t^I(x)$ denote the tradable and non-tradable goods, respectively, used to produce the final non-energy consumption good. Parameter $\nu_I \in [0,1]$ captures the share of tradables in the production process while parameter $\mu_I > 0$ denotes the elasticity of substitution between tradables and non-tradables in production. Subsequently, $HT_t(x)$ and $IM_t^I(x)$ in the tradable goods aggregator (A.24) denote the home and the imported tradable goods used in the production of the final non-energy investment good. The parameter $\nu_{TI} \in [0,1]$ captures home bias while parameter $\mu_{TI} > 0$ is the trade elasticity. The imported goods aggregator $IM_t^I(x)$ is a CES function defined in a similar fashion as in (A.20) above.

A.5 Final goods sector: brown energy investment goods

Each perfectly competitive final brown energy investment good firm $x \in [0, s^H]$ produces a brown energy investment good, $\mathcal{Q}_t^{IB}(x)$, with the following CES technology:

$$\mathcal{Q}_t^{IB}(x) = \left[v_{IB}^{\frac{1}{\mu_{IB}}} TT_t^{IB}(x)^{\frac{\mu_{IB}-1}{\mu_{IB}}} + (1-v_{IB})^{\frac{1}{\mu_{IB}}} NT_t^{IB}(x)^{\frac{\mu_{IB}-1}{\mu_{IB}}}\right]^{\frac{\mu_{IB}}{\mu_{IB}-1}} \tag{A.25}$$

where:

$$TT_t^{IB}(x) = \left[v_{TIB}^{\frac{1}{\mu_{TIB}}} HT_t^{IB}(x)^{\frac{\mu_{TIB}-1}{\mu_{TIB}}} + (1-v_{TIB})^{\frac{1}{\mu_{TIB}}} IM_t^{IB}(x)^{\frac{\mu_{TIB}-1}{\mu_{TIB}}}\right]^{\frac{\mu_{TIB}}{\mu_{TIB}-1}} \tag{A.26}$$

The brown investment good is produced using two intermediate inputs: a basket NT_t^{IB} of non-tradable intermediate goods and a composite bundle TT_t^{IB} of domestic (HT_t^{IB}) and imported (IM_t^{IB}) tradable goods. The parameter $\mu_{IB} > 0$ denotes the intra-temporal elasticity of substitution between tradable and non-tradable goods, while $v_{IB} \in [0,1]$ captures the share of tradable goods in production. For the tradable bundle, $\mu_{TIB} > 0$ denotes the elasticity of substitution between domestic and foreign tradable intermediate goods, and $v_{TIB} \in [0,1]$ indicates the share of domestic goods.

Imports $IM_t^{IB}(x)$ are themselves a CES aggregate of goods imported from other countries:

$$IM_t^{IB}(x) = \left[\sum_{CO \neq H} \left(v_{IMIB}^{H,CO} \right)^{\frac{1}{\mu_{IMIB}}} \left(IM_{IB,t}^{H,CO}(x) \left(1 - \Gamma_{IM^{IB},t}^{H,CO}(x) \right) \right)^{\frac{\mu_{IMIB}-1}{\mu_{IMIB}}} \right]^{\frac{\mu_{IMIB}}{\mu_{IMIB}-1}} \tag{A.27}$$

where $\mu_{IMIB} > 0$ and the coefficients $v_{IMIB}^{H,CO}$ are such that:[22]

$$0 \leq v_{IMIB}^{H,CO} \leq 1, \quad \sum_{CO \neq H} v_{IMIB}^{H,CO} = 1 \tag{A.28}$$

The term $\Gamma_{IM^{IB},t}^{H,CO}(x)$ represents adjustment costs on bilateral investment imports of country H from country CO:

$$\Gamma_{IM^{IB},t}^{H,CO}(x) \equiv \frac{\gamma_{IMIB}}{2} \left(\frac{IM_{IB,t}^{H,CO}(x) / \mathcal{Q}_t^{IB}(x)}{IM_{IB,t-1}^{H,CO} / \mathcal{Q}_{t-1}^{IB}} - 1 \right)^2, \quad \gamma_{IMIB} \geq 0 \tag{A.29}$$

A.6 Final goods sector: green energy investment goods

The production structure for green energy investment goods mirrors that of brown investment goods, with the same nested CES framework and analogous parameters specific to the green sector. Therefore, we simply report the key equations below, as detailed in the main text:

$$\mathcal{Q}_t^{IG}(x) = \left[v_{IG}^{\frac{1}{\mu_{IG}}} TT_t^{IG}(x)^{\frac{\mu_{IG}-1}{\mu_{IG}}} + (1 - v_{IG})^{\frac{1}{\mu_{IG}}} NT_t^{IG}(x)^{\frac{\mu_{IG}-1}{\mu_{IG}}} \right]^{\frac{\mu_{IG}}{\mu_{IG}-1}} \tag{A.30}$$

$$TT_t^{IG}(x) = \left[v_{TIG}^{\frac{1}{\mu_{TIG}}} HT_t^{IG}(x)^{\frac{\mu_{TIG}-1}{\mu_{TIG}}} + (1 - v_{TIG})^{\frac{1}{\mu_{TIG}}} IM_t^{IG}(x)^{\frac{\mu_{TIG}-1}{\mu_{TIG}}} \right]^{\frac{\mu_{TIG}}{\mu_{TIG}-1}} \tag{A.31}$$

$$\Gamma_{IM^{IG},t}^{H,CO}(x) \equiv \frac{\gamma_{IMIG}}{2} \left(\frac{IM_{IG,t}^{H,CO}(x) / \mathcal{Q}_t^{IG}(x)}{IM_{IG,t-1}^{H,CO} / \mathcal{Q}_{t-1}^{IG}} - 1 \right)^2, \quad \gamma_{IMIG} \geq 0 \tag{A.32}$$

[22]The subscript letters $IMIB$ refer to imports of tradable goods to produce a brown investment good x.

A.7 Households: energy and non-energy consumption bundles

Both financially constrained ($z = j$) and unconstrained ($z = i$) households consume energy and non-energy goods via a CES aggregator:

$$\mathbb{C}t(z) = \left(\nu_C^{\frac{1}{\epsilon_C}} Ct(z)^{\frac{\epsilon_C - 1}{\epsilon_C}} + (1 - \nu_C)^{\frac{1}{\epsilon_C}} C_{E,t}(z)^{\frac{\epsilon_C - 1}{\epsilon_C}} \right)^{\frac{\epsilon_C}{\epsilon_C - 1}} \tag{A.33}$$

where $C_t(z)$ is non-energy consumption, $C_{E,t}(z)$ is energy consumption, $\nu_C \in [0, 1]$ is the weight on non-energy goods, and $\epsilon_C > 0$ is the elasticity of substitution.

Energy consumption is itself a CES composite of brown and green energy goods:

$$C_{E,t}(z) = \left(\nu_B^{\frac{1}{\epsilon_{BG}}} C_{B,t}(z)^{\frac{\epsilon_{BG} - 1}{\epsilon_{BG}}} + (1 - \nu_B)^{\frac{1}{\epsilon_{BG}}} C_{G,t}(z)^{\frac{\epsilon_{BG} - 1}{\epsilon_{BG}}} \right)^{\frac{\epsilon_{BG}}{\epsilon_{BG} - 1}} \tag{A.34}$$

where $C_{B,t}(z)$ and $C_{G,t}(z)$ denote brown and green energy consumption, $\nu_B \in [0, 1]$ is the share of brown energy, and $\epsilon_{BG} > 0$ is the elasticity of substitution between brown and green energy goods.

For tractability, we assume identical preferences across household types, so that ν_C and ν_B do not vary with z. This guarantees a unique aggregate consumption price index, which we use as the model's numeraire. Therefore, the aggregate price index for the final consumption bundle is:

$$\mathcal{P}_{\mathbb{C},t} = \left(\nu_C P_{C,t}^{1-\epsilon_C} + (1 - \nu_C)\, P_{C_E,t}^{1-\epsilon_C} \right)^{\frac{1}{1-\epsilon_C}} \tag{A.35}$$

where $P_{C,t}$ is the price index of non-energy goods and $P_{C_E,t}$ is the price index of energy goods. Since $\nu_C = \nu_{C,I} = \nu_{C,J}$, this index is common across household types.

The energy goods price index is given by:

$$P_{C_E,t} = \left(\nu_B \left((1 + \tau_t^{E_B}) P_{B,t} \right)^{1-\epsilon_{BG}} + (1 - \nu_B)\, P_{G,t}^{1-\epsilon_{BG}} \right)^{\frac{1}{1-\epsilon_{BG}}} \tag{A.36}$$

where $P_{B,t}$ and $P_{G,t}$ are the prices of brown and green energy goods, and $\tau_t^{E_B}$ is the carbon tax levied on brown energy goods. Since $\nu_B = \nu_{B,I} = \nu_{B,J}$, this energy price index is also common across household types.

B Household Behavior and Decision-Making

This appendix presents the households' optimization problems. We aim to keep the discussion brief while providing a clear view of their behavior. For a full treatment, see Gomes et al. (2012). As explained in the main text, there are two types of households, that can be financially unconstrained (Ricardian) or not. Ricardian households are indexed by $i \in [0, s^H(1-\omega)]$. They participate in financial markets, where they buy and sell domestic government bonds and internationally traded bonds, accumulate physical capital (regular, brown or green) and rent it to firms, and hold money for transaction purposes. Non-Ricardian households are indexed by $j \in (s^H(1-\omega), s^H]$. They do not trade financial or physical assets but can smooth consumption over time by adjusting their money holdings. Both types of households supply differentiated labor services and set wages in monopolistically competitive markets. We first describe the behavior of Ricardian households, then turn to non-Ricardian households.

B.1 Financially unconstrained households

The representative financially unconstrained household i chooses consumption and investment goods, $\mathbb{C}_{I,t}$ and $I_{I,t}$, respectively; the levels and utilization rates of three types of capital: general physical capital $K_{I,t+1}$, brown capital $K_{I,B,t+1}$, and green capital $K_{I,G,t+1}$, along with their utilization rates $u_{I,t}$, $u_{I,B,t}$, and $u_{I,G,t}$; holdings of domestic government bonds $B_{I,t+1}$ and internationally traded bonds $B^*_{I,t+1}$; and money balances $M_{I,t}$, in order to maximize lifetime utility:

$$E_t \left[\sum_{k=0}^{\infty} \beta^k \left(\frac{1-\kappa}{1-\sigma} \left(\frac{\mathbb{C}_{I,t+k} - \kappa \mathbb{C}_{I,t+k-1}}{1-\kappa} \right)^{1-\sigma} - \frac{1}{1+\zeta} N_{I,t+k}^{1+\zeta} \right) \right] \tag{B.1}$$

subject to its budget constraint equation (45) in the main text. The resulting optimality conditions are standard. The marginal utility of consumption is captured by the Lagrange multiplier:

$$\Lambda_{I,t} = \frac{\left(\frac{\mathbb{C}_{I,t} - \kappa \mathbb{C}_{I,t-1}}{1-\kappa} \right)^{-\sigma}}{1 + \tau_t^C + \Gamma_{v_I,t} + \Gamma'_{v_I,t} \, v_{I,t}} \tag{B.2}$$

which accounts for the fact that consumption expenditures are subject to a value-added tax and to a proportional transaction cost. Intertemporal choices involving domestic and foreign bond holdings are governed by Euler equations. For domestic bonds, the condition is:

$$\beta R_t E_t \left[\frac{\Lambda_{I,t+1}}{\Lambda_{I,t}} \Pi_{\mathbb{C},t+1}^{-1} \right] = 1 \tag{B.3}$$

while for internationally traded bonds it is:

$$\beta R_t^{US} \left(1 - \Gamma_{B^*,t}\right) E_t \left[\frac{\Lambda_{I,t+1}}{\Lambda_{I,t}} \Pi_{\mathbb{C},t+1}^{-1} \frac{S_{t+1}^{H,US}}{S_t^{H,US}} \right] = 1 \tag{B.4}$$

where, as explained in the main text, $S_t^{H,US}$ is the nominal exchange rate, expressed in terms of units of Home currency per unit of the US dollar. In addition, rp_t is a risk premium shock. The adjustment cost for foreign bond holdings is given by:

$$\Gamma_{B^*,t} \equiv \gamma_{B^*} \left(\exp\left(\frac{S_t^{H,US} B_{t+1}^*}{P_{Y,t} Y_t} - \overline{B_Y^*} \right) - 1 \right) - rp_t \tag{B.5}$$

Optimal money holdings are governed by another Euler condition:

$$\beta E_t \left[\frac{\Lambda_{I,t+1}}{\Lambda_{I,t}} \Pi_{\mathbb{C},t+1}^{-1} \right] = 1 - v_{I,t}^2 \, \Gamma'_{v_I,t} \tag{B.6}$$

with the velocity of money defined as:

$$v_{I,t} = \frac{(1+\tau_t^C) P_{\mathbb{C},t} \mathbb{C}_{I,t}}{M_{I,t}} \tag{B.7}$$

The function $\Gamma_{v,t}$ captures the cost of using money for transactions:

$$\Gamma_{v_I,t} \equiv \gamma_{v,1} v_{I,t} + \gamma_{v,2} \, v_{I,t}^{-1} - 2\sqrt{\gamma_{v,1}\gamma_{v,2}} \tag{B.8}$$

with marginal cost:

$$\Gamma'_{v_I,t} \equiv \gamma_{v,1} - \gamma_{v,2} \, v_{I,t}^{-2} \tag{B.9}$$

Capital accumulation in regular, brown and green capital evolves by:

$$K_{I,t+1} = (1-\delta) K_{I,t} + (1 - \Gamma_{I,t}) I_{I,t} \tag{B.10}$$

$$K_{I,B,t+1} = (1-\delta_B)\, K_{I,B,t} + (1-\Gamma_{IB,t})\, I_{I,B,t} \tag{B.11}$$

$$K_{I,G,t+1} = (1-\delta_G)\, K_{I,G,t} + (1-\Gamma_{IG,t})\, I_{I,G,t} \tag{B.12}$$

where investment adjustment costs for regular capital are modeled as:

$$\Gamma_{I,t} \equiv \frac{\gamma_I}{2}\left(\frac{I_{I,t}}{I_{I,t-1}} - 1\right)^2 \tag{B.13}$$

and its derivative is:

$$\Gamma'_{I,t} \equiv \gamma_I \left(\frac{I_{I,t}}{I_{I,t-1}} - 1\right) / I_{I,t-1} \tag{B.14}$$

Adjustment costs for brown and green investment follow the same functional form as for regular capital, and are omitted for brevity. Varying the intensity of regular capital utilization gives rise to the standard optimality conditions:

$$R^K_t = \Gamma'_{u,t}\, P_{I,t} \tag{B.15}$$

$$R^K_{B,t} = \Gamma'_{u_B,t}\, P_{IB,t} \tag{B.16}$$

$$R^K_{G,t} = \Gamma'_{u_G,t}\, P_{IG,t} \tag{B.17}$$

with the utilization cost function for regular capital given by:

$$\Gamma_{u,t} = \frac{(1/\beta - 1 + \delta)\overline{q} - \delta\overline{\tau_k}\overline{P_I}}{(1-\overline{\tau_k})\overline{P_I}}(u_{I,t} - 1) + \frac{\gamma_{u,2}}{2}(u_{I,t} - 1)^2 \tag{B.18}$$

and its derivative:

$$\Gamma'_{u,t} = \frac{(1/\beta - 1 + \delta)\overline{q} - \delta\overline{\tau_k}\overline{P_I}}{(1-\overline{\tau_k})\overline{P_I}} + \gamma_{u,2}(u_{I,t} - 1) \tag{B.19}$$

Adjustment costs for brown and green investment follow the same functional form as for regular capital, and are omitted for brevity. The first-order condition for investment equates the marginal cost of investment to its marginal benefit:

$$\frac{P_{I,t}}{P_{\mathbb{C},t}} = Q_{I,t}\left(1-\Gamma_{I,t}-\Gamma'_{I,t}\, I_{,t}\right) + \beta E_t\left[\frac{\Lambda_{I,t+1}}{\Lambda_{I,t}} Q_{I,t+1}\,\Gamma'_{I,t+1}\,\frac{I^2_{t+1}}{I_t}\right] \tag{B.20}$$

$$\frac{P_{IB,t}}{P_{\mathbb{C},t}} = Q_{IB,t}\left(1-\Gamma_{IB,t}-\Gamma'_{IB,t}\, I_{B,t}\right) + \beta E_t\left[\frac{\Lambda_{I,t+1}}{\Lambda_{I,t}} Q_{IB,t+1}\,\Gamma'_{IB,t+1}\,\frac{I^2_{B,t+1}}{I_{B,t}}\right] \tag{B.21}$$

$$\frac{P_{IG,t}}{P_{\mathbb{C},t}} = Q_{IG,t}\left(1-\Gamma_{IG,t}-\Gamma'_{IG,t}\, I_{G,t}\right) + \beta E_t\left[\frac{\Lambda_{I,t+1}}{\Lambda_{I,t}} Q_{IG,t+1}\,\Gamma'_{IG,t+1}\,\frac{I^2_{G,t+1}}{I_{G,t}}\right] \tag{B.22}$$

Finally, the arbitrage condition for holding physical capital is:

$$\begin{aligned} Q_{I,t} = \beta E_t \Bigg[\frac{\Lambda_{I,t+1}}{\Lambda_{I,t}} \Bigg((1-\delta)\, Q_{I,t+1} + \Bigg((1-\tau^K_{t+1}) \frac{R^K_{t+1}}{P_{\mathbb{C},t+1}} u_{t+1} \\ + \left(\tau^K_{t+1}\delta - (1-\tau^K_{t+1})\,\Gamma_{u,t+1}\right)\frac{P_{I,t+1}}{P_{\mathbb{C},t+1}}\Bigg)\Bigg)\Bigg] \end{aligned} \tag{B.23}$$

$$\begin{aligned} Q_{IB,t} = \beta E_t \Bigg[\frac{\Lambda_{I,t+1}}{\Lambda_{I,t}} \Bigg((1-\delta_B)\, Q_{IB,t+1} + \Bigg((1-\tau^{K_B}_{t+1}) \frac{R^K_{B,t+1}}{P_{\mathbb{C},t+1}} u_{B,t+1} \\ + \left(\tau^{K_B}_{t+1}\delta_B - (1-\tau^{K_B}_{t+1})\,\Gamma_{u_B,t+1}\right)\frac{P_{IB,t+1}}{P_{\mathbb{C},t+1}}\Bigg)\Bigg)\Bigg] \end{aligned} \tag{B.24}$$

$$\begin{aligned} Q_{IG,t} = \beta E_t \Bigg[\frac{\Lambda_{I,t+1}}{\Lambda_{I,t}} \Bigg((1-\delta_G)\, Q_{IG,t+1} + \Bigg((1+\tau^{K_G}_{t+1}) \frac{R^K_{G,t+1}}{P_{\mathbb{C},t+1}} u_{G,t+1} \\ + \left(\tau^{K_G}_{t+1}\delta_G - (1+\tau^{K_G}_{t+1})\,\Gamma_{u_G,t+1}\right)\frac{P_{IG,t+1}}{P_{\mathbb{C},t+1}}\Bigg)\Bigg)\Bigg] \end{aligned} \tag{B.25}$$

Each household acts as a wage setter for its differentiated labor services $N_{I,t}$ in monopolistically competitive markets. Wages are determined by staggered nominal contracts *à la* Calvo (1983). Each household receives permission to optimally reset its nominal wage contract in a given period t with probability $1-\xi_I$. All households that receive permission to reset their wage contracts in a given period t choose the same wage rate $\widetilde{W}_{I,t}$. Those households that do not receive permission to re-optimize are allowed to update their wage contracts according to the following indexation scheme:

$$W_t(i) = (\Pi_{\mathbb{C},t-1})^{\chi_I}\, \overline{\Pi}^{1-\chi_I} W_{t-1}(i), \tag{B.26}$$

that is, the nominal wage contracts are indexed to a geometric average of past (gross) consumer price index (CPI) inflation, $\Pi_{\mathbb{C},t-1}$, and the monetary authority's (gross) inflation objective $\overline{\Pi}$. $\chi_I \in [0,1]$ is an indexation parameter. Letting η_I denote the elasticity of substitution between the differentiated services of labor varieties supplied by unconstrained households leads to the standard pricing equations:

$$\left(\frac{\widetilde{W}_{I,t}}{P_{\mathbb{C},t}}\right)^{1+\zeta\eta_I} = \frac{\eta_I}{\eta_I - 1}\,\frac{f_{I,t}}{g_{I,t}} \tag{B.27}$$

$$f_{I,t} = \left(\frac{W_{I,t}}{P_{\mathbb{C},t}}\right)^{\eta_I(1+\zeta)} \left(N^D_{I,t}\right)^{1+\zeta} + \beta\xi_I E_t\left[\left(\frac{\Pi_{\mathbb{C},t+1}}{\Pi^{\chi_I}_{\mathbb{C},t}\overline{\Pi}^{1-\chi_I}}\right)^{\eta_I(1+\zeta)} f_{I,t+1}\right] \tag{B.28}$$

$$g_{I,t} = \Lambda_{I,t}\left(1 - \tau^N_t - \tau^{W_H}_t\right)\left(\frac{W_{I,t}}{P_{\mathbb{C},t}}\right)^{\eta_I} N^D_{I,t} + \beta\xi_I E_t\left[\left(\frac{\Pi_{\mathbb{C},t+1}}{\Pi^{\chi_I}_{\mathbb{C},t}\overline{\Pi}^{1-\chi_I}}\right)^{\eta_I-1} g_{I,t+1}\right] \tag{B.29}$$

$$W_{I,t} = \left[\xi_I\left(\left(\Pi_{\mathbb{C},t-1}\right)^{\chi_I}\overline{\Pi}^{1-\chi_I} W_{I,t-1}\right)^{1-\eta_I} + (1-\xi_I)\left(\widetilde{W}_{I,t}\right)^{1-\eta_I}\right]^{\frac{1}{1-\eta_I}} \tag{B.30}$$

B.2 Financially constrained households

Financially constrained households are almost identical to those who are unconstrained, the only difference being that the former are cut from financial markets. Nonetheless, they can smooth consumption by adjusting their holdings of money. The representative financially constrained household j chooses consumption $\mathbb{C}_{J,t}$ and money balances $M_{J,t}$ in order to maximize lifetime utility:

$$E_t\left[\sum_{k=0}^{\infty}\beta^k\left(\frac{1-\kappa}{1-\sigma}\left(\frac{\mathbb{C}_{J,t+k} - \kappa\mathbb{C}_{I,t+k-1}}{1-\kappa}\right)^{1-\sigma} - \frac{1}{1+\zeta}N^{1+\zeta}_{J,t+k}\right)\right] \tag{B.31}$$

subject to its budget constraint equation (49) in the main text. The marginal utility of consumption is:

$$\Lambda_{J,t} = \frac{\left(\frac{\mathbb{C}_{J,t} - \kappa\mathbb{C}_{J,t-1}}{1-\kappa}\right)^{-\sigma}}{1 + \tau^C_t + \Gamma_{v_J,t} + \Gamma'_{v_J,t}\, v_{J,t}} \tag{B.32}$$

where $v_{J,t}$ is the ratio of consumption purchases to money holdings:

$$v_{J,t} = \frac{(1+\tau^C_t)P_{\mathbb{C},t}\mathbb{C}_{J,t}}{M_{J,t}} \tag{B.33}$$

and $\Gamma_{v,t}$ is the transaction cost function, given by:

$$\Gamma_{v_J,t} = \gamma_{v,1}v_{J,t} + \gamma_{v,2}v^{-1}_{J,t} - 2\sqrt{\gamma_{v,1}\gamma_{v,2}} \tag{B.34}$$

with derivative:

$$\Gamma'_{v_J,t} = \gamma_{v,1} - \gamma_{v,2} v_{J,t}^{-2} \tag{B.35}$$

The Euler equation for real money holdings is:

$$\beta E_t \left[\frac{\Lambda_{J,t+1}}{\Lambda_{J,t}} \Pi_{\mathbb{C},t+1}^{-1} \right] = 1 - \Gamma'_{v_J,t} v_{J,t}^2 \tag{B.36}$$

Wage settings are identical for both types of households. The resulting pricing equations are:

$$\left(\frac{\widetilde{W}_{J,t}}{P_{\mathbb{C},t}} \right)^{1+\zeta\eta_J} = \frac{\eta_J}{\eta_J - 1} \frac{f_{J,t}}{g_{J,t}} \tag{B.37}$$

$$f_{J,t} = \left(\frac{W_{J,t}}{P_{\mathbb{C},t}} \right)^{\eta_J(1+\zeta)} (N_{J,t}^D)^{1+\zeta} + \beta\xi_J E_t \left[\left(\frac{\Pi_{\mathbb{C},t+1}}{\Pi_{\mathbb{C},t}^{\chi_J} \overline{\Pi}^{1-\chi_J}} \right)^{\eta_J(1+\zeta)} f_{J,t+1} \right] \tag{B.38}$$

$$g_{J,t} = \Lambda_{J,t}(1 - \tau_t^N - \tau_t^{W_H}) \left(\frac{W_{J,t}}{P_{\mathbb{C},t}} \right)^{\eta_J} N_{J,t}^D + \beta\xi_J E_t \left[\left(\frac{\Pi_{\mathbb{C},t+1}}{\Pi_{\mathbb{C},t}^{\chi_J} \overline{\Pi}^{1-\chi_J}} \right)^{\eta_J - 1} g_{J,t+1} \right] \tag{B.39}$$

$$W_{J,t} = \left[\xi_J \left((\Pi_{\mathbb{C},t-1})^{\chi_J} \overline{\Pi}^{1-\chi_J} W_{J,t-1} \right)^{1-\eta_J} + (1-\xi_J)(\widetilde{W}_{J,t})^{1-\eta_J} \right]^{\frac{1}{1-\eta_J}} \tag{B.40}$$

C Market Clearing Conditions

Having summarized the key equations for each stage of production and the behavior of households, we conclude by stating the main market clearing conditions. The market clearing condition for the non-tradable intermediate good n is:

$$Y_{N,t}^S(n) = NT_t^C(n) + NT_t^I(n) + NT_t^{IB}(n) + NT_t^{IG}(n) + G_t(n), \ \forall n \tag{C.1}$$

Aggregating over the continuum of firms (s^H is the size of the domestic economy):

$$\begin{aligned} Y_{N,t}^{S} &= \frac{1}{s^H}\int_0^{s^H} Y_{N,t}^{S}(n)\;dn \\ &= \frac{1}{s^H}\left(\int_0^{s^H}\left(NT_t^{C}(n)+NT_t^{I}(n)+NT_t^{IB}(n)+NT_t^{IG}(n)+G_t(n)\right)\;dn\right) \\ &= NT_t^{C}+NT_t^{I}+NT_t^{IB}+NT_t^{IG}+G_t \end{aligned} \tag{C.2}$$

For each tradable intermediate good, aggregating across firms, the following market clearing condition holds:

$$\begin{aligned} Y_{T,t}^{S}(h) &= HT_t^{C}(h)+HT_t^{I}(h)+HT_t^{IB}(h)+HT_t^{IG}(h)+\sum_{CO\neq H} IM_t^{C,CO}(h) \\ &+\sum_{CO\neq H} IM_t^{I,CO}(h)+\sum_{CO\neq H} IM_t^{IB,CO}(h)+\sum_{CO\neq H} IM_t^{IG,CO}(h), \qquad \forall h \end{aligned} \tag{C.3}$$

Aggregating across firms:

$$\begin{aligned} Y_{T,t}^{S} &= \frac{1}{s^H}\int_0^{s^H} Y_{T,t}^{S}(h)\;dh \\ &= \frac{1}{s^H}\left(\int_0^{s^H}\left(HT_t^{C}(h)+HT_t^{I}(h)+HT_t^{IB}(h)+HT_t^{IG}(h)\right)\;dh\right) \\ &+\frac{1}{s^H}\left(\int_0^{s^H}\sum_{CO\neq H}\left(IM_t^{C,CO}(h)+IM_t^{I,CO}(h)+IM_t^{IB,CO}(h)+IM_t^{IG,CO}(h)\right)\;dh\right) \end{aligned} \tag{C.4}$$

Total supply of the composite labor bundle equals total demand by firms in tradables and non-tradables intermediate sectors:

$$\begin{aligned} N_t &= \frac{1}{s^H}\left(\int_0^{s^H} N_t^{D}(n)\,dn+\int_0^{s^H} N_t^{D}(h)\,dh+\int_0^{s^H} N_t^{D}(b)\,db+\int_0^{s^H} N_t^{D}(g)\,dg\right) \\ &= N_{N,t}^{D}+N_{T,t}^{D}+N_{B,t}^{D}+N_{G,t}^{D} \end{aligned} \tag{C.5}$$

The equilibrium in the market for brown energy is summarized by:

$$
\begin{aligned}
&Y_{B,t} = \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad (C.6)\\
&\quad \frac{1}{s^H}\left[\frac{1}{1-\omega}\int_0^{s^H(1-\omega)} C_{B,t}(i)\,di + \frac{1}{\omega}\int_{s^H(1-\omega)}^{s^H} C_{B,t}(j)\,dj + \int_0^{s^H} E_{B,t}(h)\,dh + \int_0^{s^H} E_{B,t}(n)\,dn\right]\\
&\quad = C_{B,t}(I) + C_{B,t}(J) + E_{BT,t} + E_{BN,t}
\end{aligned}
$$

Similarly, the equilibrium in the market for green energy is summarized by:

$$
\begin{aligned}
&Y_{G,t} = \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad (C.7)\\
&\quad \frac{1}{s^H}\left[\frac{1}{1-\omega}\int_0^{s^H(1-\omega)} C_{G,t}(i)\,di + \frac{1}{\omega}\int_{s^H(1-\omega)}^{s^H} C_{G,t}(j)\,dj + \int_0^{s^H} E_{G,t}(h)\,dh + \int_0^{s^H} E_{G,t}(n)\,dn\right]\\
&\quad = C_{G,t}(I) + C_{G,t}(J) + E_{GT,t} + E_{GN,t}
\end{aligned}
$$

where $E^D_{GT,t} = \frac{1}{s^H}\int_0^{s^H} E_{G,t}(h)\,dh$ and $E_{GN,t} = \frac{1}{s^H}\int_0^{s^H} E_{G,t}(n)\,dn$ is the total demand for green energy by the domestic tradable good and the non-tradable good sector, respectively. The market clearing conditions, jointly with the budget constraints of the households and the fiscal authority, imply the following aggregate resource constraint (taking into account that G_t is non-tradable good, and hence, $P_{G,t} = P_{N,t}$):

$$
\begin{aligned}
P_{Y,t}Y_t &= P_{C,t}\; Q^C_t + P_{B,t}C_{B,t} + P_{G,t}C_{G,t} + P_{I,t}\; Q^I_t + P_{IB,t}\; Q^{IB}_t + P_{IG,t}\; Q^{IG}_t \qquad (C.8)\\
&+ P_{NT,t}\; G_t + \sum_{CO\neq H}\frac{\sigma^{CO}}{\sigma^H}\;\mathcal{X}^{H,CO}_t P^{H,CO}_{X,t} IM^{CO,H}_t - \sum_{CO\neq H} P^{H,CO}_{IM,t} IM^{H,CO}_t
\end{aligned}
$$

or identically:

$$
\begin{aligned}
P_{Y,t}Y_t &= P_{C,t}\,(C_t + \Gamma_{v,t}) + P_{B,t}C_{B,t} + P_{G,t}C_{G,t} + P_{I,t}\,(I_t + \Gamma_{u,t}K_t) \qquad (C.9)\\
&+ P_{IB,t}\,(I_{B,t} + \Gamma_{u_B,t}K_{B,t}) + P_{IG,t}\,(I_{G,t} + \Gamma_{u_G,t}K_{G,t}) + P_{NT,t}G_t\\
&+ \sum_{CO\neq H}\frac{\sigma^{CO}}{\sigma^H}\;\mathcal{X}^{H,CO}_t P^{H,CO}_{X,t} IM^{CO,H}_t - \sum_{CO\neq H} P^{H,CO}_{IM,t} IM^{H,CO}_t
\end{aligned}
$$

$$
\Gamma_{v,t} \equiv \int_0^{s^H(1-\omega)} \Gamma_{v_I}(i)\;C_t(i)\;di + \int_{s^H(1-\omega)}^{s^H} \Gamma_{v_J}(j)\;C_t(j)\;dj \qquad (C.10)
$$

where σ, $\mathcal{X}_t$ and $P_{X,t}$ are the size of the country (domestic H or foreign CO), the real exchange rate (euro-dollar) and the export deflator, respectively. Total imports of country H from country CO are defined as:

$$IM_t^{H,CO} \equiv IM_t^{C,CO} \frac{1-\Gamma^{H,CO}_{IM^C,t}}{\Gamma^{H,CO\dagger}_{IM^C,t}} + IM_t^{I,CO} \frac{1-\Gamma^{H,CO}_{IM^I,t}}{\Gamma^{H,CO\dagger}_{IM^I,t}} + IM_t^{IB,CO} \frac{1-\Gamma^{H,CO}_{IM^{IB},t}}{\Gamma^{H,CO\dagger}_{IM^{IB},t}} \tag{C.11}$$

$$\Gamma^{H,CO\dagger}_{IM^Z,t} \equiv 1-\Gamma^{H,CO}_{IM^Z,t} - \left(\Gamma^{H,CO}_{IM^Z,t}\right)' IM_t^Z \qquad Z \in \{C, I, IB\} \tag{C.12}$$

where $\left(\Gamma^{H,CO}_{IM^Z,t}\right)'$ is the first derivative of $\Gamma^{H,CO}_{IM^Z,t}$ with respect to imports IM_t^Z.

Domestic holdings of foreign bonds, denominated in foreign currency, evolve according to:

$$\frac{B^*_{t+1}}{R^*_t} = B^*_t + \frac{TB_t^H}{S_t^{H,US}} \tag{C.13}$$

where TB_t^H stands for the Home economy's trade balance:

$$TB_t^H \equiv \sum_{CO \neq H} \frac{s^{CO}}{s^H} S_t^{H,CO} P_{X,t}^{H,CO} IM_t^{CO,H} - \sum_{CO \neq H} P_{IM,t}^{H,CO} IM_t^{H,CO} \tag{C.14}$$

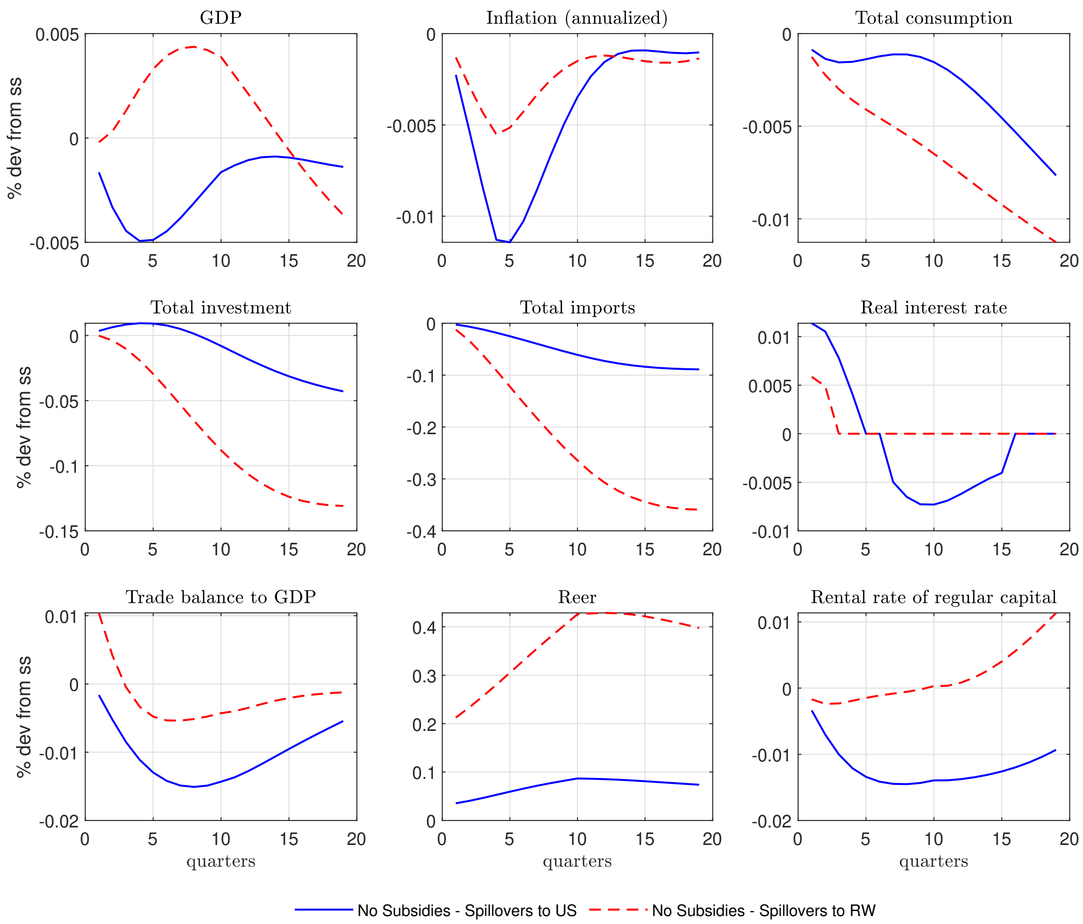
Finally, the aggregate output is defined as follows:

$$P_{Y,t}Y_t = P_{T,t}Y_{T,t}^S + P_{N,t}Y_{N,t}^S + P_{B,t}Y_{B,t} + P_{G,t}Y_{G,t} \tag{C.15}$$

where the price indices have been defined in the sections above.

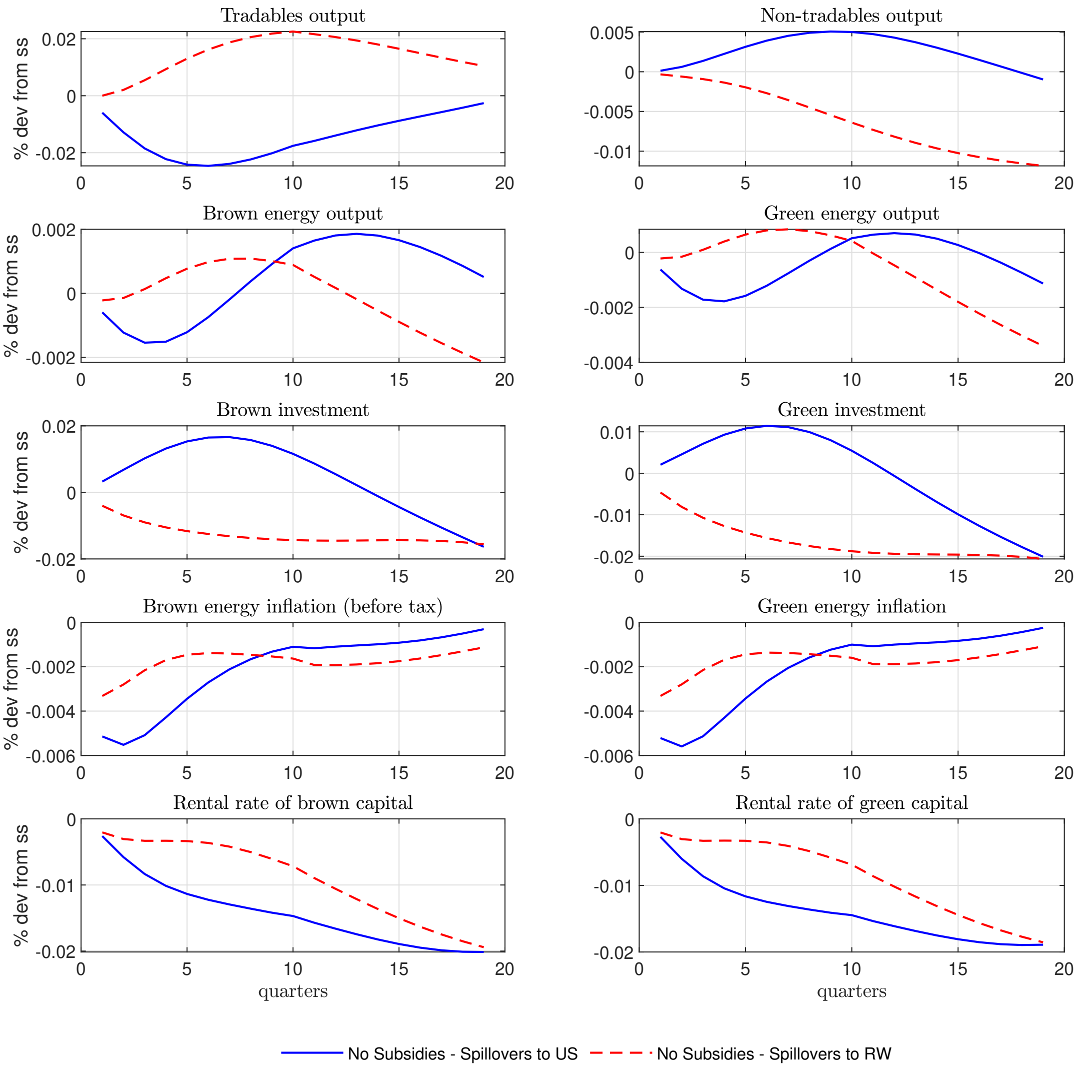
D Additional Figures and Robustness Analysis

Figure D.1. Impulse Responses to a carbon tax shock in the EA – Spillover effects to the US and the rest of the world



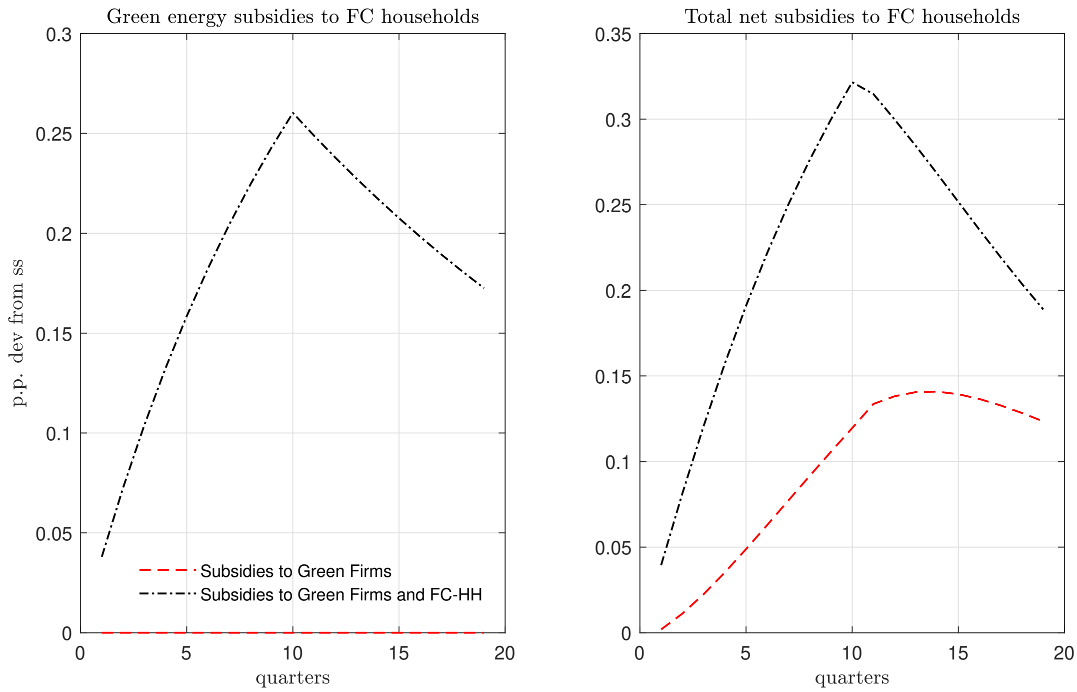
Notes: Impulse responses to a rise in carbon tax in the EA that raises the price of brown energy by 1% on impact. Horizontal axis: quarters. Vertical axis: percentage deviations from the baseline, except for inflation and interest rates (annualized percentage-point deviations), and the trade balance-to-GDP ratio (percentage-point deviations). GDP and its components are reported in real terms. Blue-solid lines represent the spillover effects to the US after a carbon tax shock in the EA without subsidies. Red-dashed lines exhibit the spillover effects to the RW after a carbon tax shock in the EA without subsidies.

FIGURE D.2. Impulse Responses to a carbon tax shock in the EA – Spillover effects to the US and the rest of the world



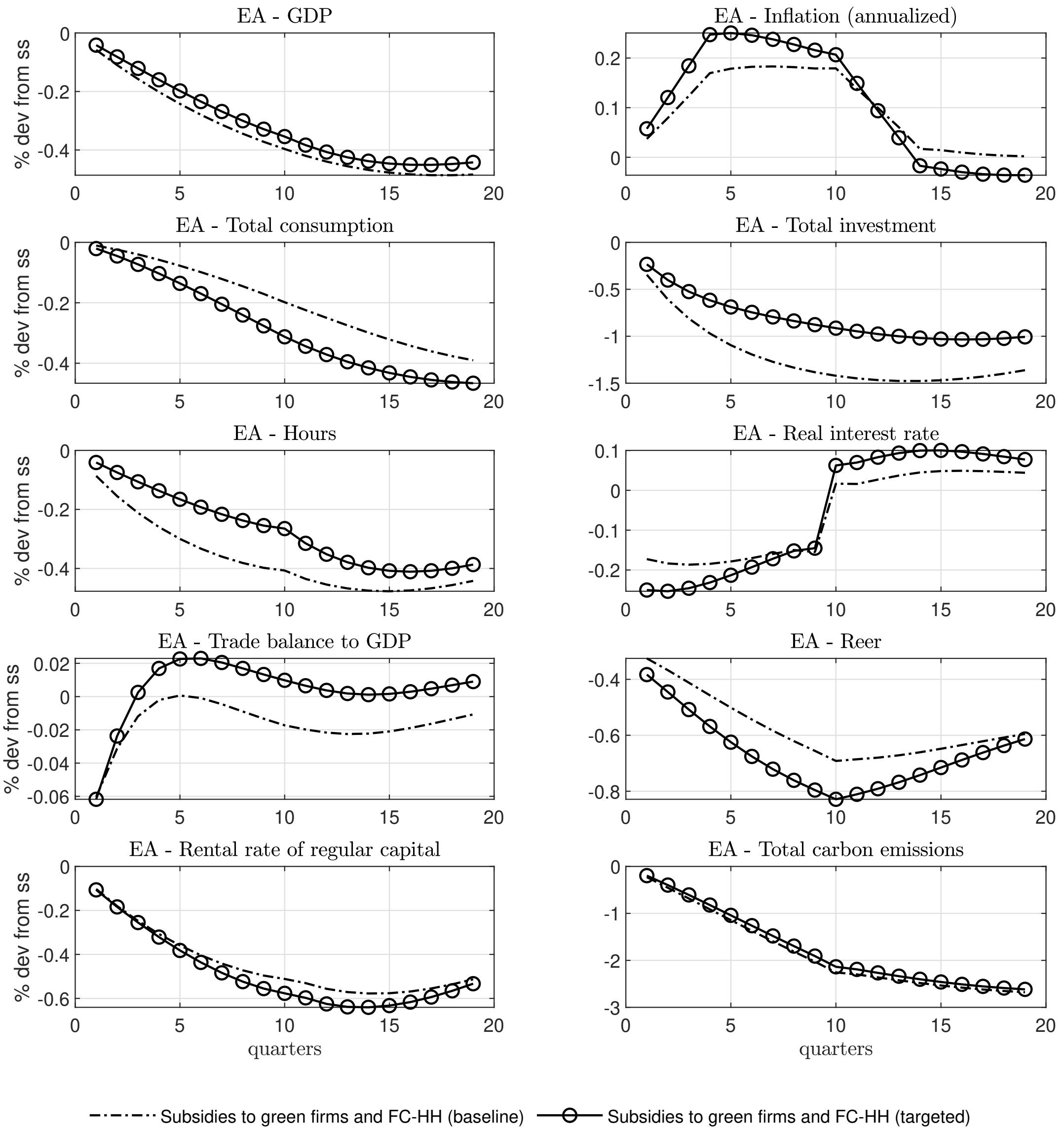
Notes: Impulse responses to a rise in carbon tax in the EA that raises the price of brown energy by 1% on impact. Horizontal axis: quarters. Vertical axis: percentage deviations from the baseline, except for inflation and interest rates (annualized percentage-point deviations), and the trade balance-to-GDP ratio (percentage-point deviations). GDP and its components are reported in real terms. Blue-solid lines represent the spillover effects to the US after a carbon tax shock in the EA without subsidies. Red-dashed lines exhibit the spillover effects to the RW after a carbon tax shock in the EA without subsidies.

FIGURE D.3. Impulse Responses to a carbon tax shock in the EA – Green energy subsidies



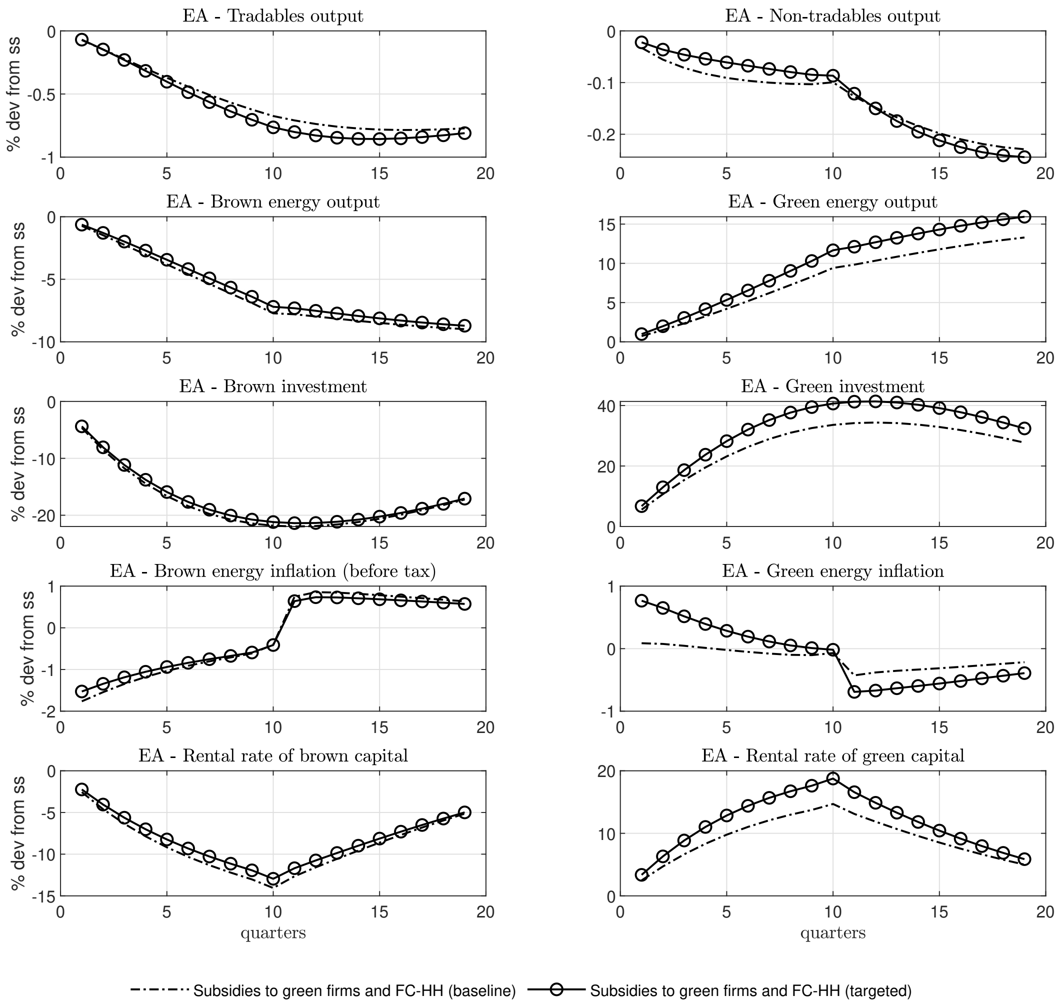
Notes: Red-dashed lines represent impulse responses after a carbon tax shock with subsidies to green energy-producing firms with $\varsigma_E^Y = 0.33$. Black-dashed-dotted lines represent impulse responses after a carbon tax shock with subsidies to green energy-producing firms and financially constrained households (FC-HH) with $\varsigma_E^Y = \varsigma_E^C = 0.33$. The carbon tax-related subsidies shown here are expressed as a percentage of GDP. Horizontal axis: quarters. Vertical axis: percentage-point deviations from the baseline.

Figure D.4. Impulse Responses to a carbon tax shock in the EA – The role of targeted green energy subsidies to FC-HH



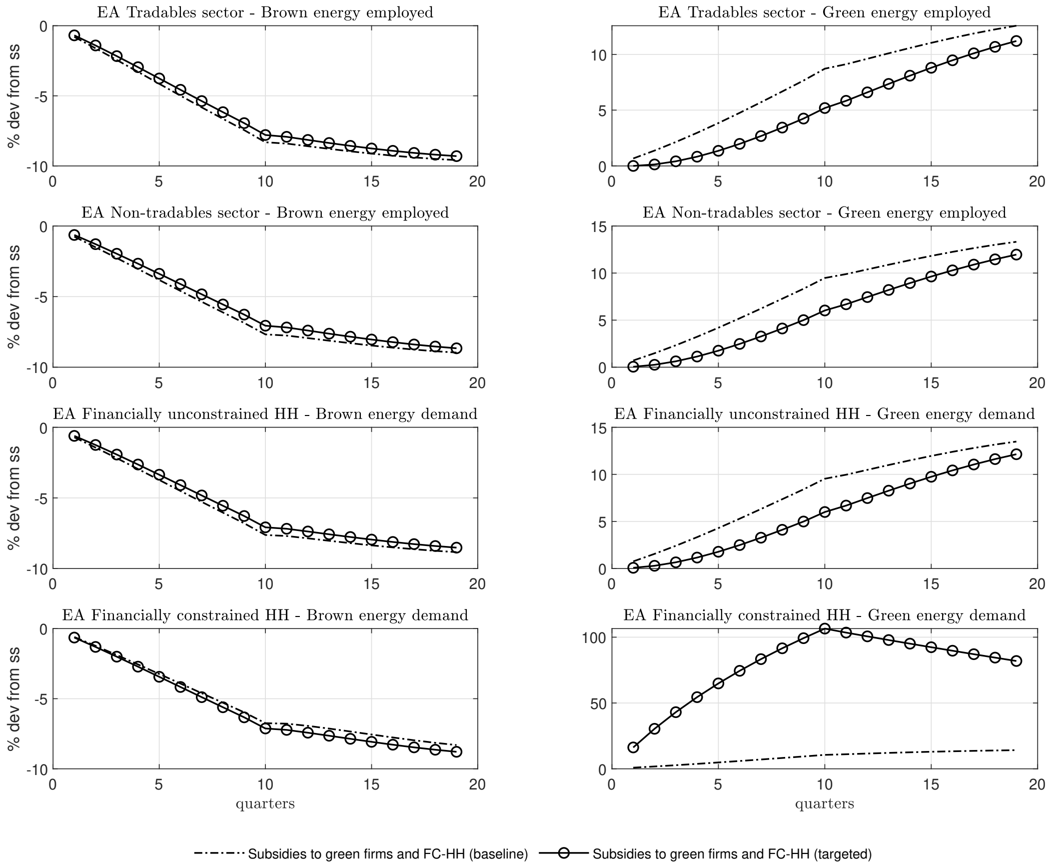
Notes: Black-dashed-dotted lines represent the baseline impulse responses after a carbon tax shock with subsidies to green energy-producing firms and financially constrained households (FC-HH) with $\varsigma_E^Y = \varsigma_E^C = 0.33$. Black-circled lines represent impulse responses after a carbon tax shock with subsidies to green energy-producing firms and *targeted* green subsidies to financially constrained households (FC-HH) with $\varsigma_E^Y = \varsigma_E^C = 0.33$. Horizontal axis: quarters. Vertical axis: percentage deviations from the baseline, except for inflation and interest rates (annualized percentage-point deviations), and the trade balance-to-GDP ratio (percentage-point deviations). GDP and its components are reported in real terms.

Figure D.5. Impulse Responses to a carbon tax shock in the EA – The role of targeted green energy subsidies to FC-HH



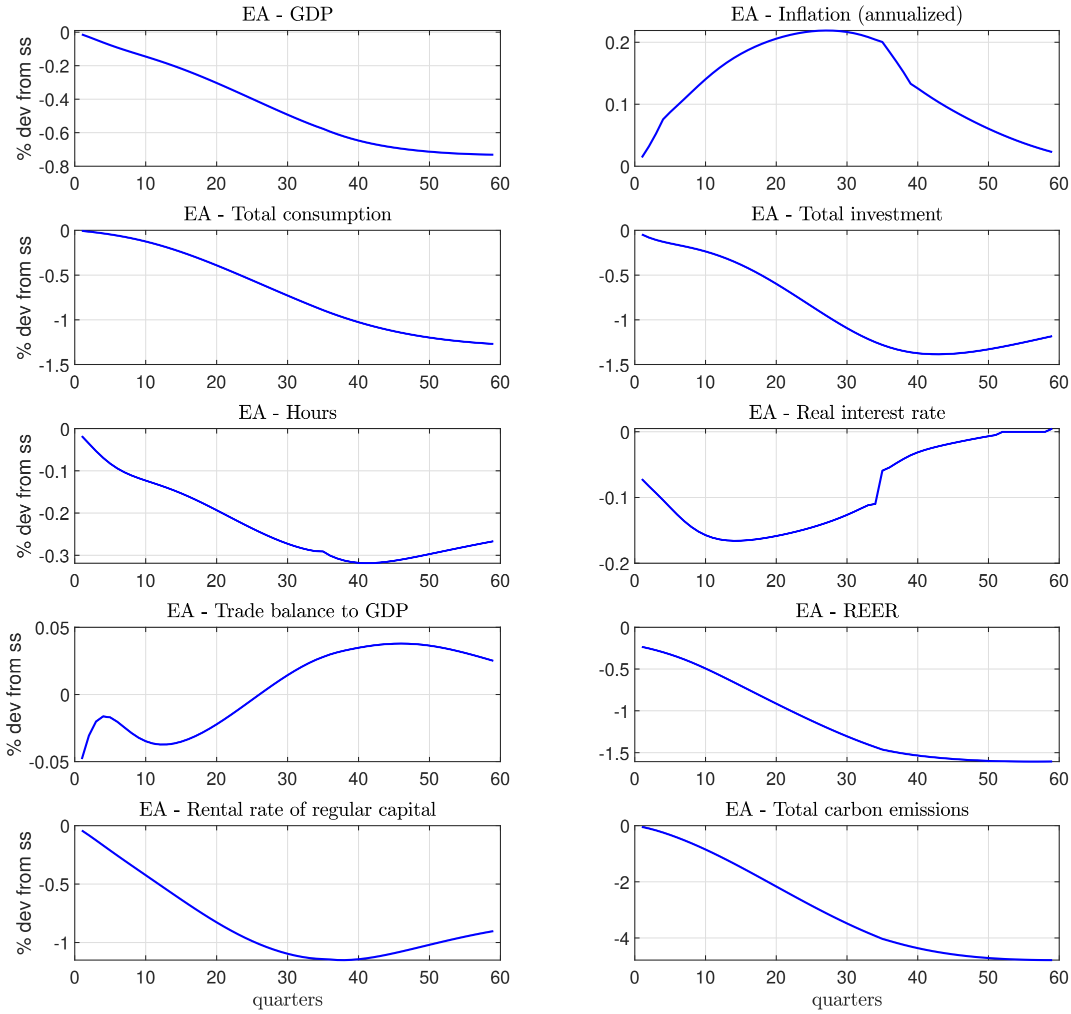
Notes: Black-dashed-dotted lines represent the baseline impulse responses after a carbon tax shock with subsidies to green energy-producing firms and financially constrained households (FC-HH) with $\varsigma_E^Y = \varsigma_E^C = 0.33$. Black-circled lines represent impulse responses after a carbon tax shock with subsidies to green energy-producing firms and *targeted* green subsidies to financially constrained households (FC-HH) with $\varsigma_E^Y = \varsigma_E^C = 0.33$. Horizontal axis: quarters. Vertical axis: percentage deviations from the baseline, except for inflation and interest rates (annualized percentage-point deviations), and the trade balance-to-GDP ratio (percentage-point deviations). GDP and its components are reported in real terms.

Figure D.6. Impulse Responses to a carbon tax shock in the EA – The role of targeted green energy subsidies to FC-HH



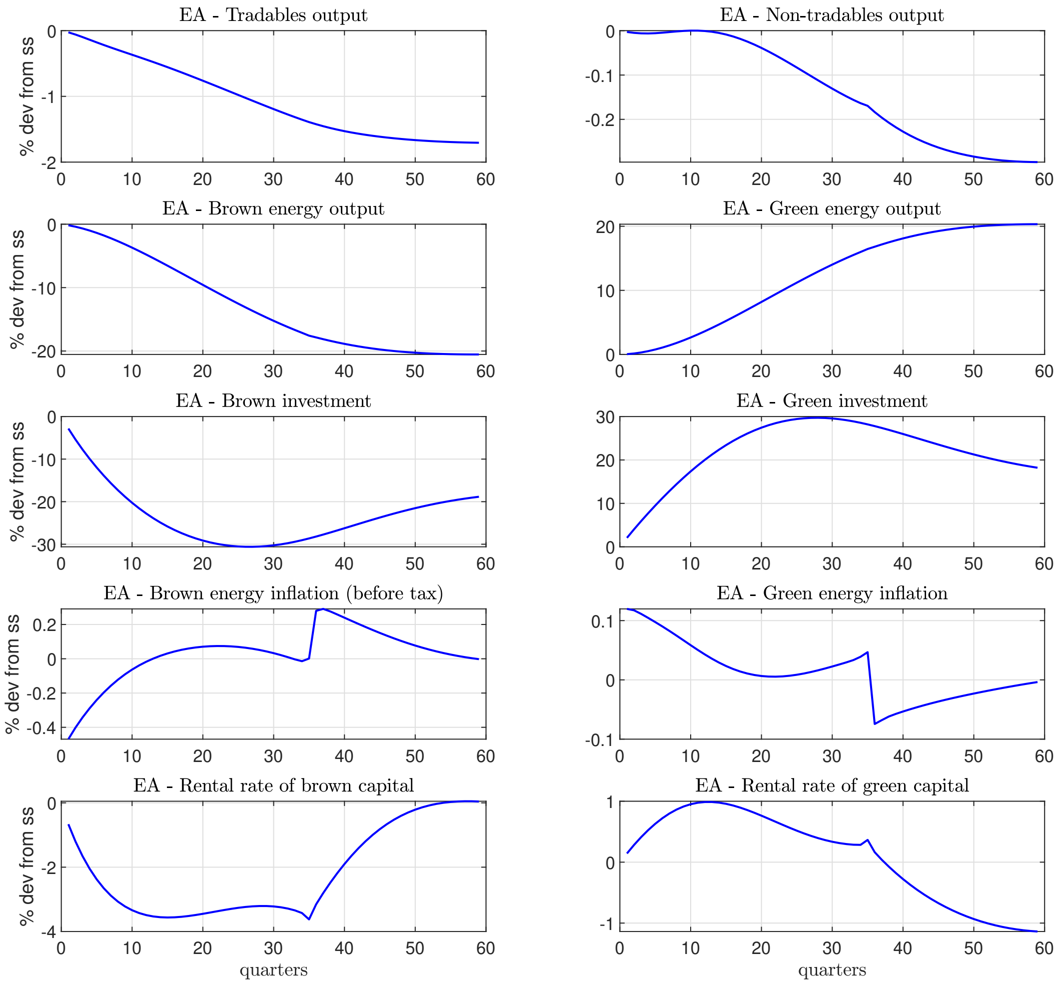
Notes: Black-dashed-dotted lines represent the baseline impulse responses after a carbon tax shock with subsidies to green energy-producing firms and financially constrained households (FC-HH) with $\varsigma_E^Y = \varsigma_E^C = 0.33$. Black-circled lines represent impulse responses after a carbon tax shock with subsidies to green energy-producing firms and *targeted* green subsidies to financially constrained households (FC-HH) with $\varsigma_E^Y = \varsigma_E^C = 0.33$. Horizontal axis: quarters. Vertical axis: percentage deviations from the baseline, except for inflation and interest rates (annualized percentage-point deviations), and the trade balance-to-GDP ratio (percentage-point deviations). GDP and its components are reported in real terms.

FIGURE D.7. Impulse Responses to a permanent carbon tax shock in the EA



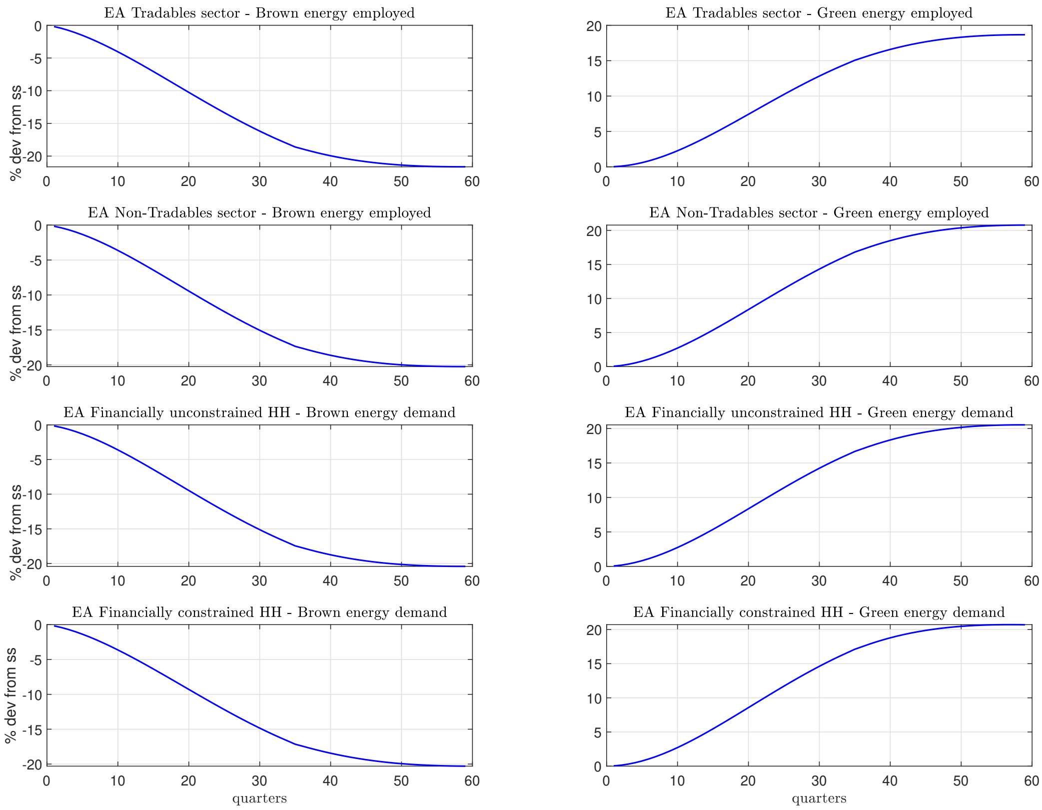
Notes: Following Coenen et al. (2024), we calibrate the initial level of the carbon tax rate such that the resulting carbon tax revenues represent approximately 1.8% of GDP. The policy experiment then consists of a linear increase in the carbon tax rate by around 65% over a nine-year period, aligning with the target effective carbon rate (ECR) of 140 euros per ton of CO_2 by the end of the horizon. We also follow a similar Taylor rule as in Coenen et al. (2024), where the monetary authority is assumed to stabilize annual consumer price inflation, excluding energy, around the target. Horizontal axis: quarters. Vertical axis: percentage deviations from the baseline, except for inflation and interest rates (annualized percentage-point deviations), and the trade balance-to-GDP ratio (percentage-point deviations). GDP and its components are reported in real terms. Blue-solid lines represent impulse responses after a carbon tax shock without subsidies.

Figure D.8. Impulse Responses to a permanent carbon tax shock in the EA



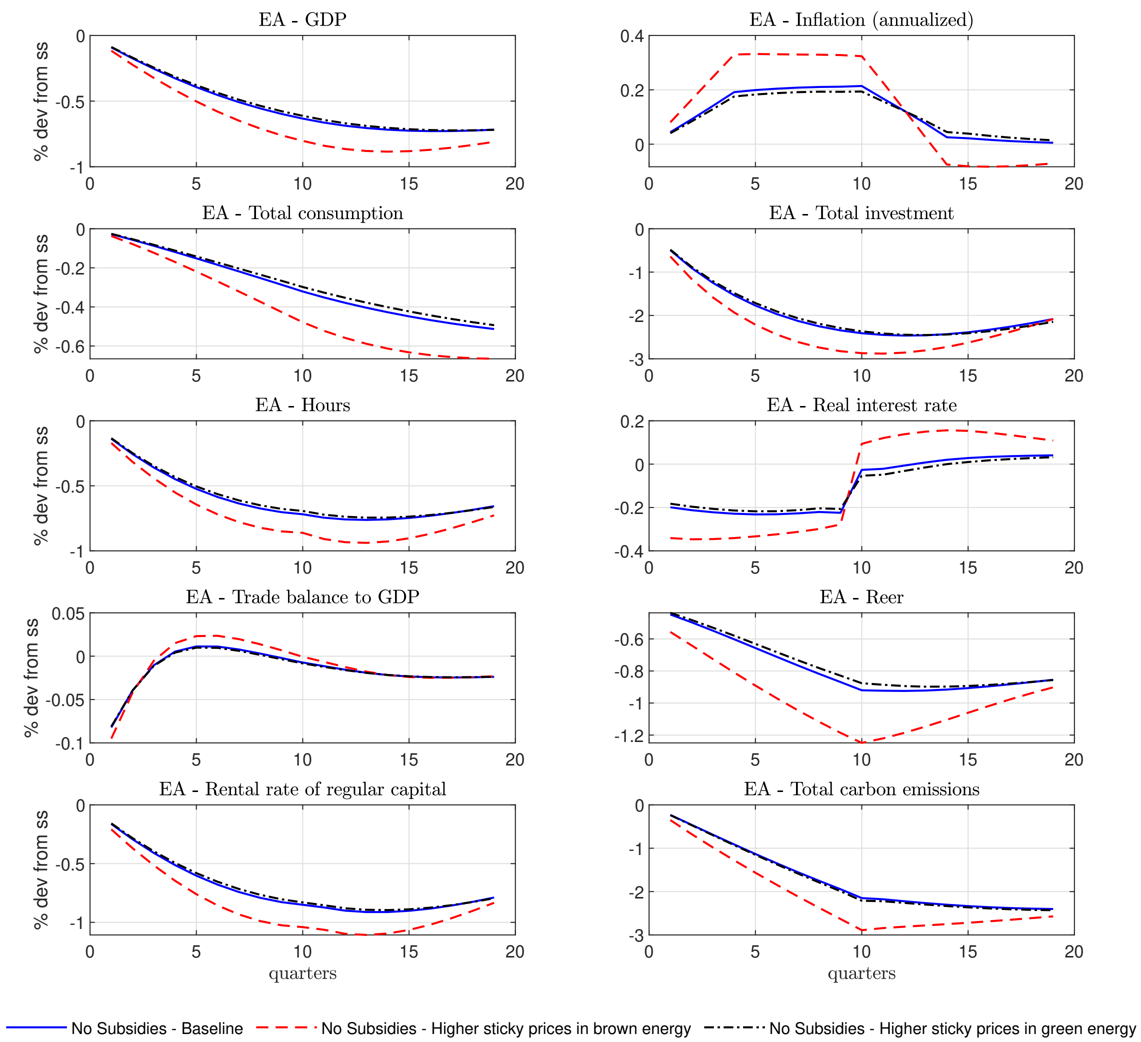
Notes: Following Coenen et al. (2024), we calibrate the initial level of the carbon tax rate such that the resulting carbon tax revenues represent approximately 1.8% of GDP. The policy experiment then consists of a linear increase in the carbon tax rate by around 65% over a nine-year period, aligning with the target effective carbon rate (ECR) of 140 euros per ton of CO_2 by the end of the horizon. We also follow a similar Taylor rule as in Coenen et al. (2024), where the monetary authority is assumed to stabilize annual consumer price inflation, excluding energy, around the target. Horizontal axis: quarters. Vertical axis: percentage deviations from the baseline, except for inflation and interest rates (annualized percentage-point deviations), and the trade balance-to-GDP ratio (percentage-point deviations). GDP and its components are reported in real terms. Blue-solid lines represent impulse responses after a carbon tax shock without subsidies.

FIGURE D.9. Impulse Responses to a permanent carbon tax shock in the EA



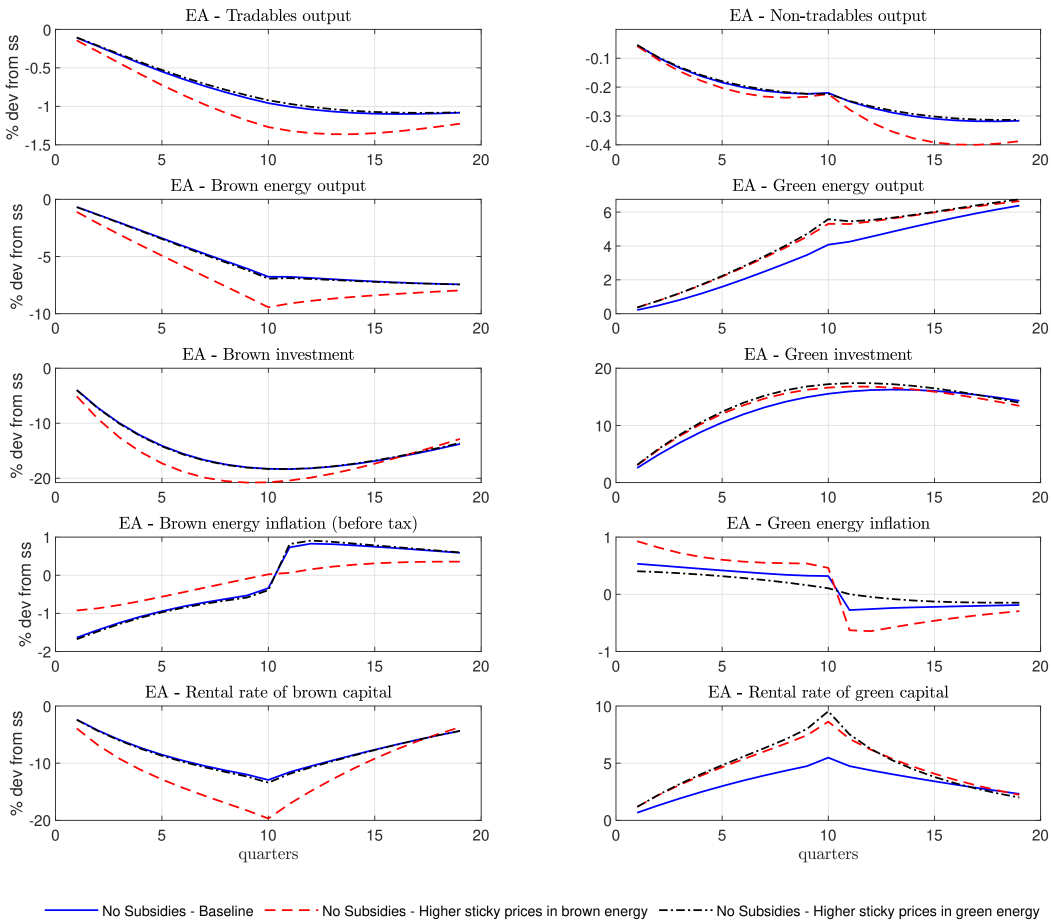
Notes: Following Coenen et al. (2024), we calibrate the initial level of the carbon tax rate such that the resulting carbon tax revenues represent approximately 1.8% of GDP. The policy experiment then consists of a linear increase in the carbon tax rate by around 65% over a nine-year period, aligning with the target effective carbon rate (ECR) of 140 euros per ton of CO_2 by the end of the horizon. We also follow a similar Taylor rule as in Coenen et al. (2024), where the monetary authority is assumed to stabilize annual consumer price inflation, excluding energy, around the target. Horizontal axis: quarters. Vertical axis: percentage deviations from the baseline, except for inflation and interest rates (annualized percentage-point deviations), and the trade balance-to-GDP ratio (percentage-point deviations). GDP and its components are reported in real terms. Blue-solid lines represent impulse responses after a carbon tax shock without subsidies.

FIGURE D.10. Impulse Responses to a carbon tax shock in the EA – The role of sticky prices



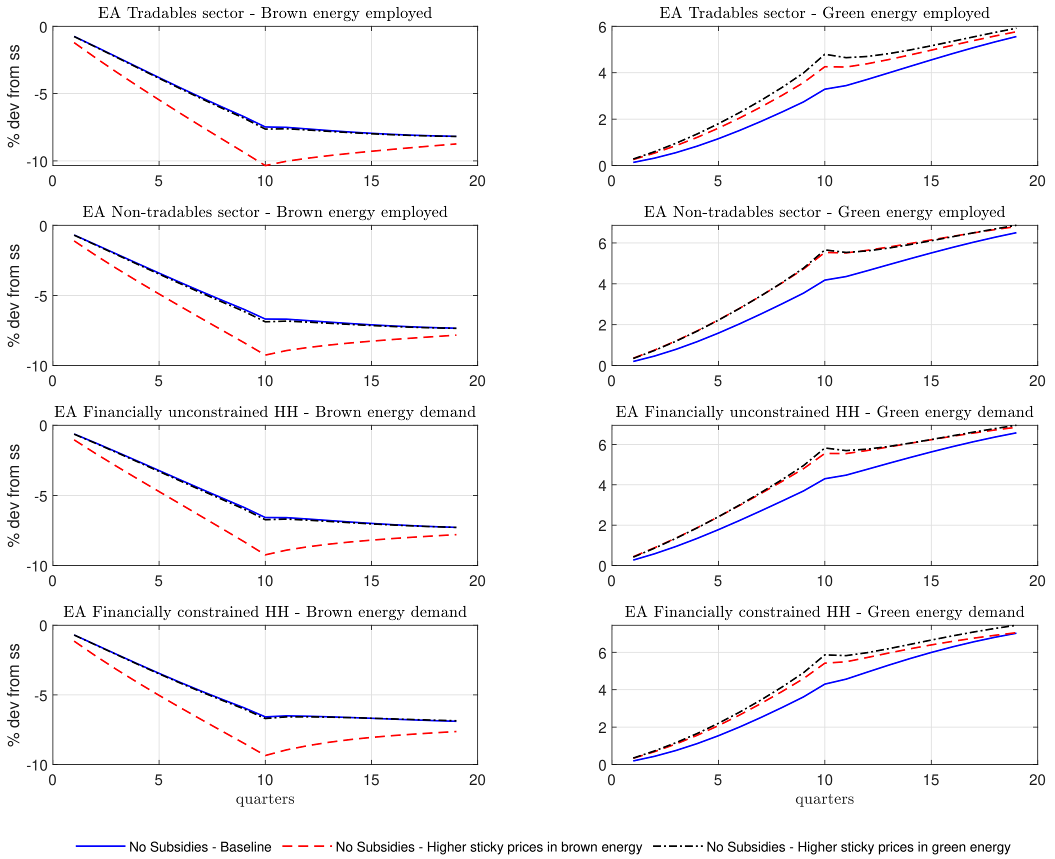
Notes: Impulse responses to a rise in carbon tax in the EA that raises the price of brown energy by 1% on impact. Horizontal axis: quarters. Vertical axis: percentage deviations from the baseline, except for inflation and interest rates (annualized percentage-point deviations), and the trade balance-to-GDP ratio (percentage-point deviations). GDP and its components are reported in real terms. Blue-solid lines represent impulse responses after a carbon tax shock without subsidies in our baseline scenario. Red-dashed lines represent impulse responses after a carbon tax shock without subsidies and higher sticky prices in the brown energy sector ($\xi_B = 0.9$). Black-dashed-dotted lines exhibit impulse responses after a carbon tax shock without subsidies and higher sticky prices in the green energy sector ($\xi_G = 0.9$).

FIGURE D.11. Impulse Responses to a carbon tax shock in the EA – The role of sticky prices



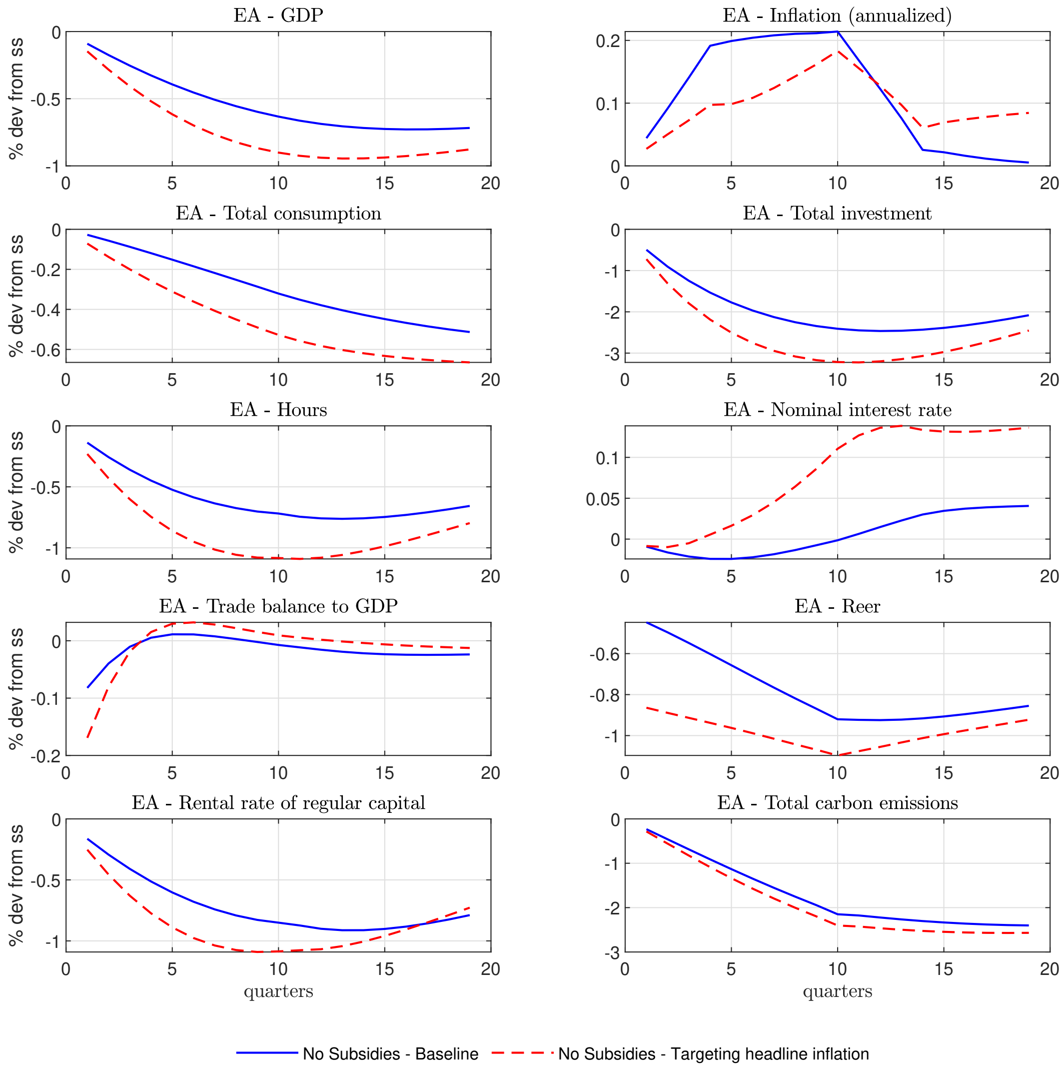
Notes: Impulse responses to a rise in carbon tax in the EA that raises the price of brown energy by 1% on impact. Horizontal axis: quarters. Vertical axis: percentage deviations from the baseline, except for inflation and interest rates (annualized percentage-point deviations), and the trade balance-to-GDP ratio (percentage-point deviations). GDP and its components are reported in real terms. Blue-solid lines represent impulse responses after a carbon tax shock without subsidies in our baseline scenario. Red-dashed lines represent impulse responses after a carbon tax shock without subsidies and higher sticky prices in the brown energy sector ($\xi_B = 0.9$). Black-dashed-dotted lines exhibit impulse responses after a carbon tax shock without subsidies and higher sticky prices in the green energy sector ($\xi_G = 0.9$).

FIGURE D.12. Impulse Responses to a carbon tax shock in the EA – The role of sticky prices



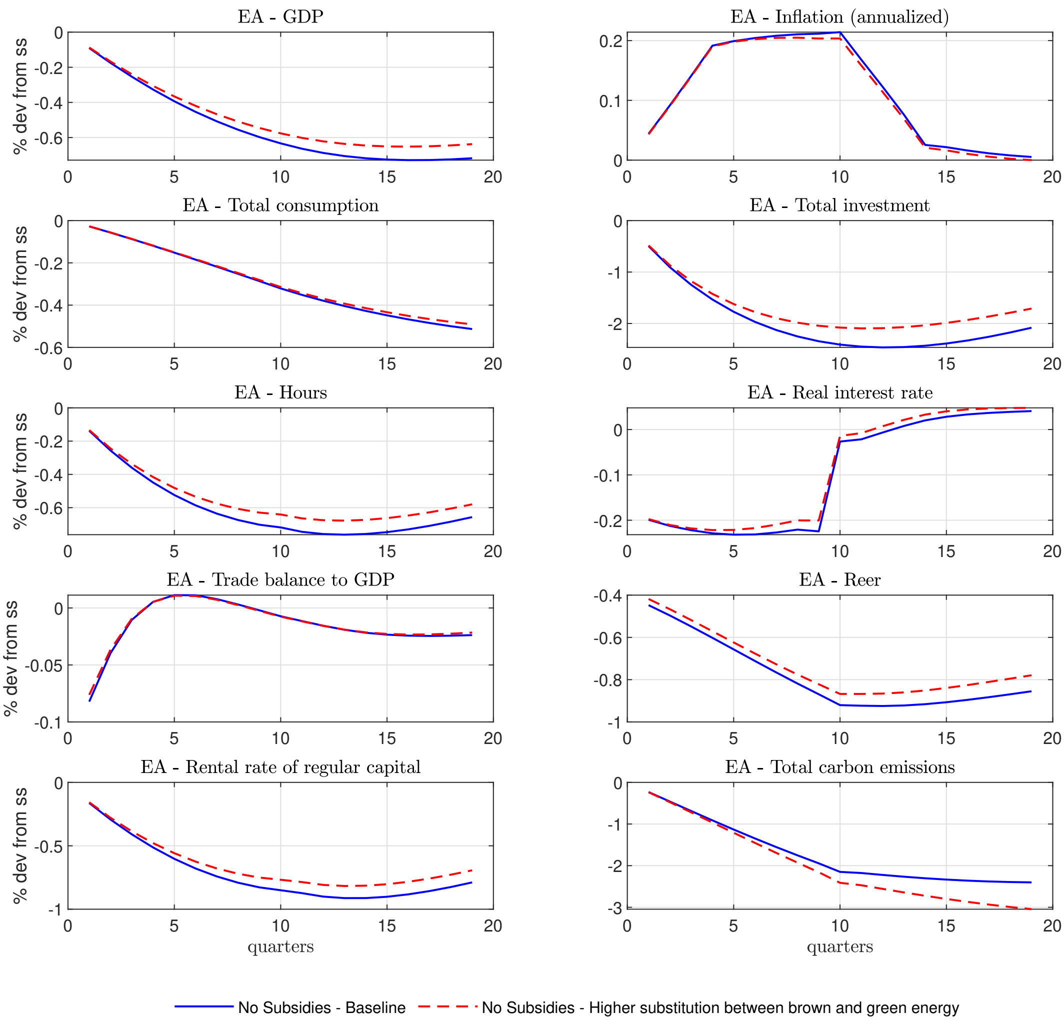
Notes: Impulse responses to a rise in carbon tax in the EA that raises the price of brown energy by 1% on impact. Horizontal axis: quarters. Vertical axis: percentage deviations from the baseline, except for inflation and interest rates (annualized percentage-point deviations), and the trade balance-to-GDP ratio (percentage-point deviations). GDP and its components are reported in real terms. Blue-solid lines represent impulse responses after a carbon tax shock without subsidies in our baseline scenario. Red-dashed lines represent impulse responses after a carbon tax shock without subsidies and higher sticky prices in the brown energy sector ($\xi_B = 0.9$). Black-dashed-dotted lines exhibit impulse responses after a carbon tax shock without subsidies and higher sticky prices in the green energy sector ($\xi_G = 0.9$).

FIGURE D.13. Impulse Responses to a carbon tax shock in the EA – The role of monetary policy



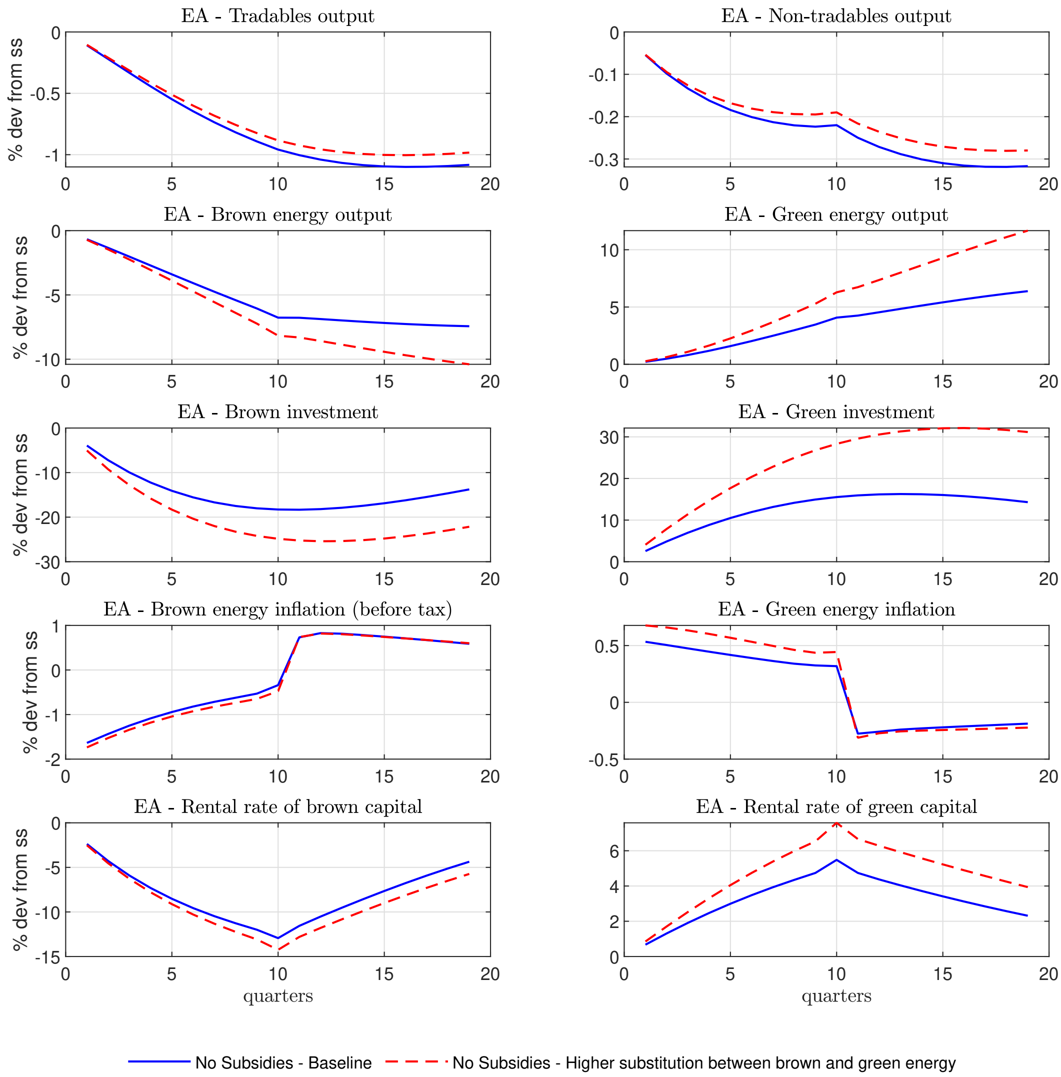
Notes: Impulse responses to a rise in carbon tax in the EA that raises the price of brown energy by 1% on impact. Horizontal axis: quarters. Vertical axis: percentage deviations from the baseline, except for inflation and interest rates (annualized percentage-point deviations), and the trade balance-to-GDP ratio (percentage-point deviations). GDP and its components are reported in real terms. Blue-solid lines represent impulse responses after a carbon tax shock without subsidies in our baseline scenario. Red-dashed lines represent impulse responses after a carbon tax shock without subsidies and targeting headline inflation in the Taylor Rule.

FIGURE D.14. Impulse Responses to a carbon tax shock in the EA – The role of the elasticity of substitution between brown and green energy



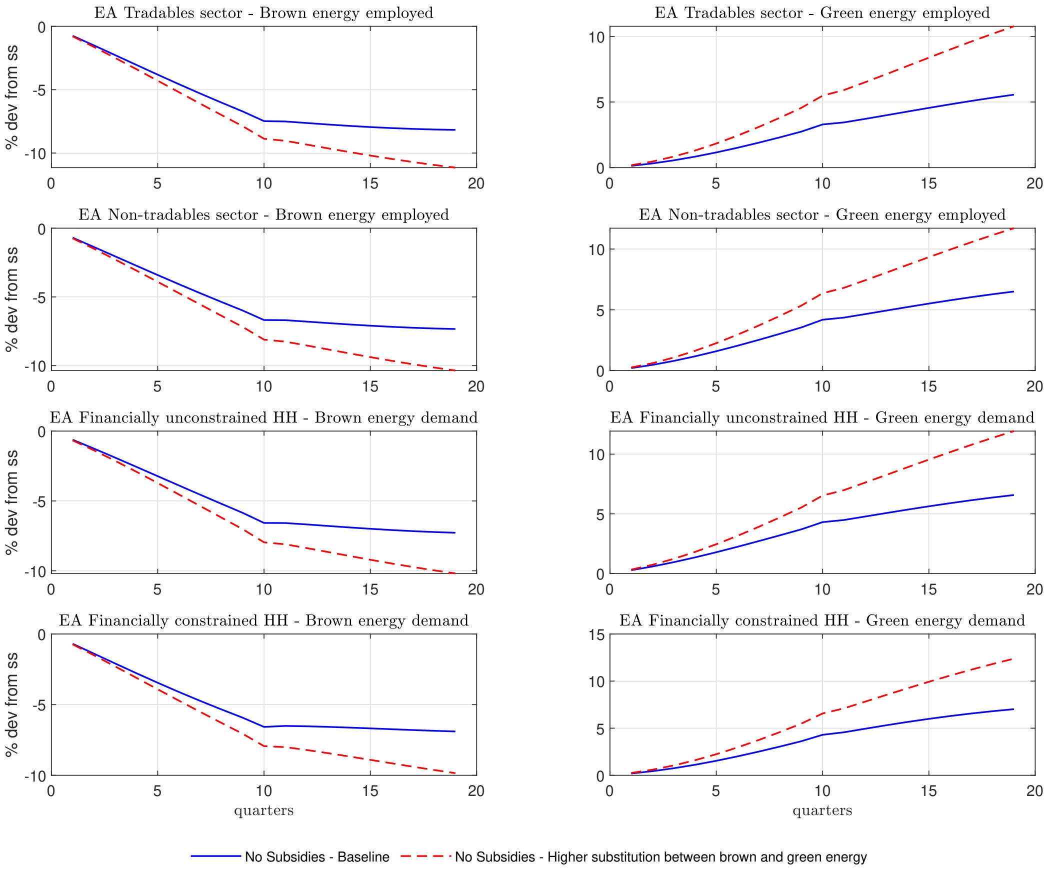
Notes: Impulse responses to a rise in carbon tax in the EA that raises the price of brown energy by 1% on impact. Horizontal axis: quarters. Vertical axis: percentage deviations from the baseline, except for inflation and interest rates (annualized percentage-point deviations), and the trade balance-to-GDP ratio (percentage-point deviations). GDP and its components are reported in real terms. Blue-solid lines represent impulse responses after a carbon tax shock without subsidies in our baseline scenario ($\epsilon_{BG} = 1.8$ and $\epsilon_E = 1.8$). Red-dashed lines represent impulse responses after a carbon tax shock without subsidies and with higher elasticity of substitution between brown and green energy, both at the household and intermediate firm level ($\epsilon_{BG} = 4$ and $\epsilon_E = 4$).

FIGURE D.15. Impulse Responses to a carbon tax shock in the EA – The role of the elasticity of substitution between brown and green energy



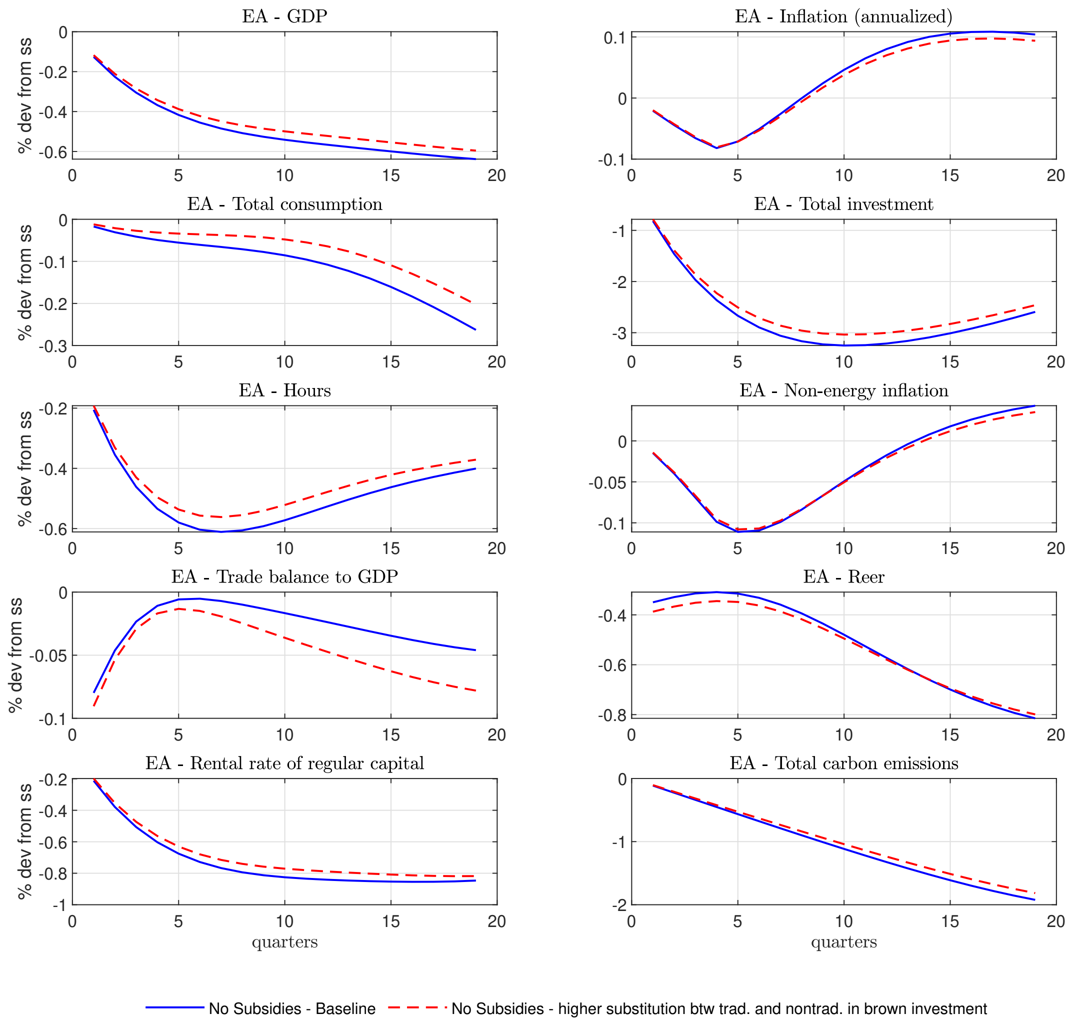
Notes: Impulse responses to a rise in carbon tax in the EA that raises the price of brown energy by 1% on impact. Horizontal axis: quarters. Vertical axis: percentage deviations from the baseline, except for inflation and interest rates (annualized percentage-point deviations), and the trade balance-to-GDP ratio (percentage-point deviations). GDP and its components are reported in real terms. Blue-solid lines represent impulse responses after a carbon tax shock without subsidies in our baseline scenario ($\epsilon_{BG} = 1.8$ and $\epsilon_E = 1.8$). Red-dashed lines represent impulse responses after a carbon tax shock without subsidies and with higher elasticity of substitution between brown and green energy, both at the household and intermediate firm level ($\epsilon_{BG} = 4$ and $\epsilon_E = 4$).

Figure D.16. Impulse Responses to a carbon tax shock in the EA – The role of the elasticity of substitution between brown and green energy



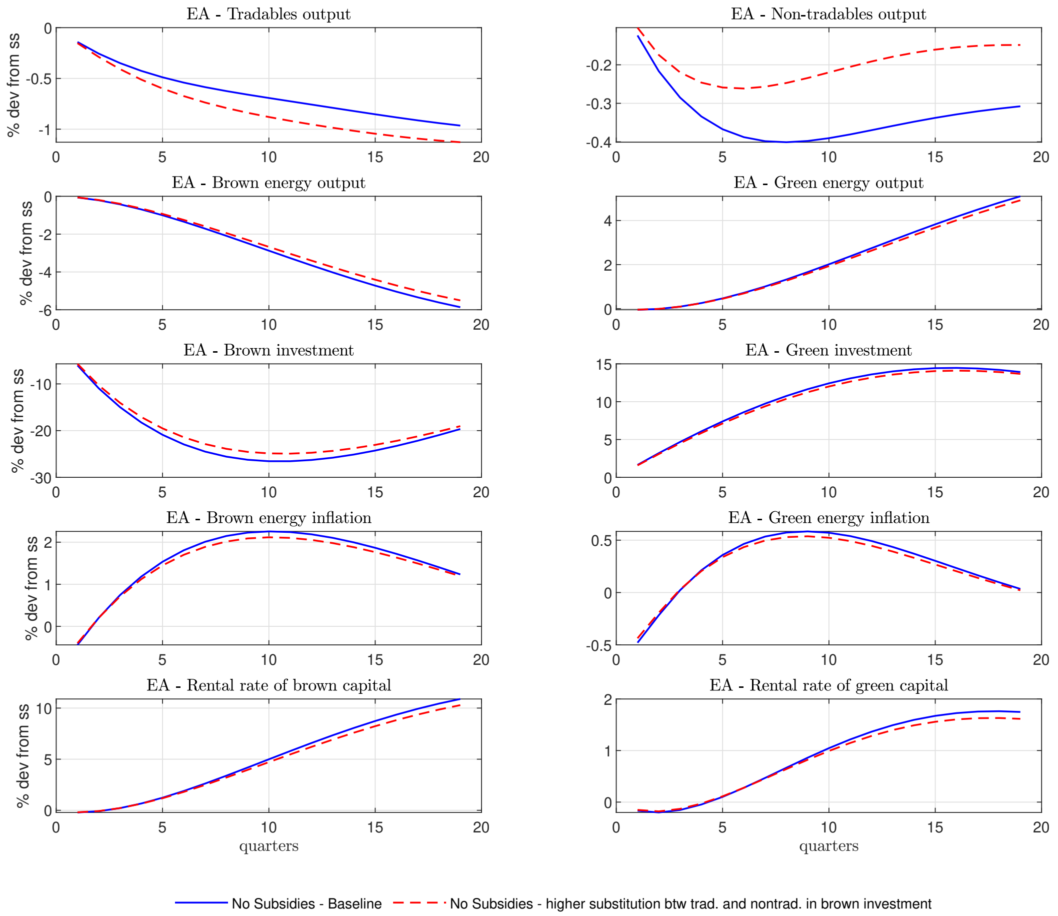
Notes: Impulse responses to a rise in carbon tax in the EA that raises the price of brown energy by 1% on impact. Horizontal axis: quarters. Vertical axis: percentage deviations from the baseline, except for inflation and interest rates (annualized percentage-point deviations), and the trade balance-to-GDP ratio (percentage-point deviations). GDP and its components are reported in real terms. Blue-solid lines represent impulse responses after a carbon tax shock without subsidies in our baseline scenario ($\epsilon_{BG} = 1.8$ and $\epsilon_E = 1.8$). Red-dashed lines represent impulse responses after a carbon tax shock without subsidies and with higher elasticity of substitution between brown and green energy, both at the household and intermediate firm level ($\epsilon_{BG} = 4$ and $\epsilon_E = 4$).

Figure D.17. Impulse Responses to a brown-capital rental income tax shock in the EA – Higher substitutability between tradables and non-tradables in final brown investment



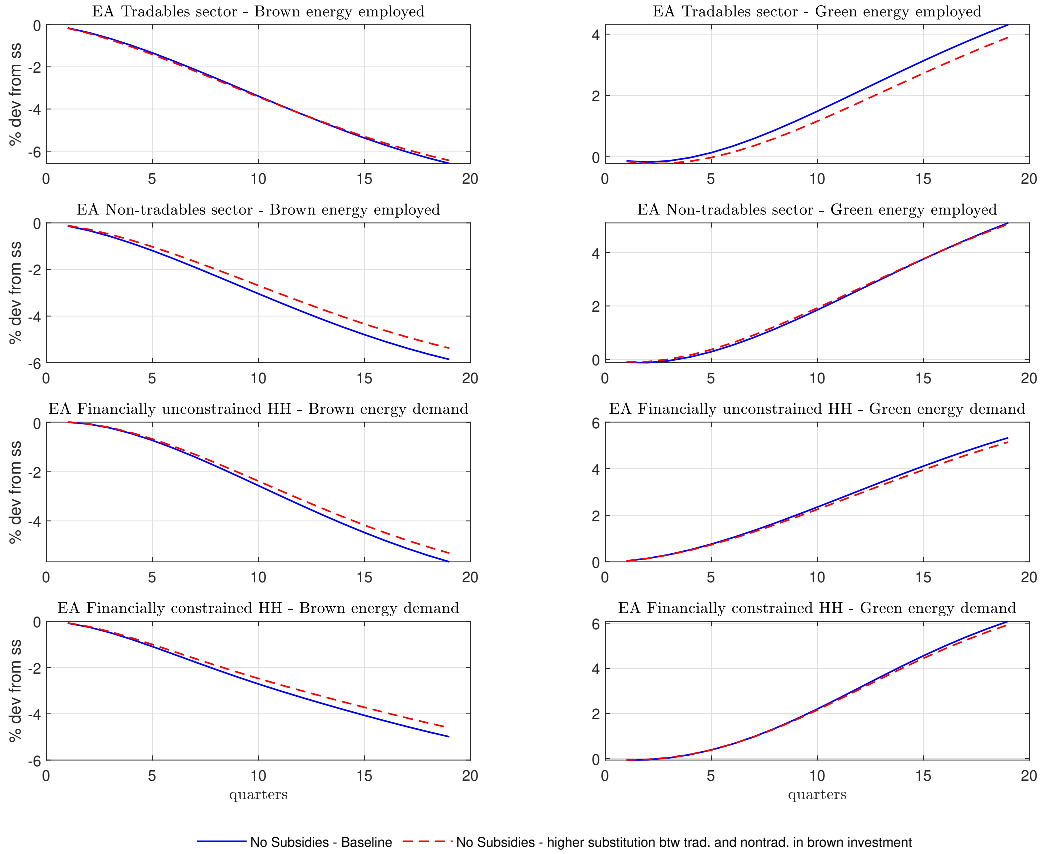
Notes: Impulse responses to a rise in tax on rental brown capital income in the EA. Horizontal axis: quarters. Vertical axis: percentage deviations from the baseline, except for inflation and interest rates (annualized percentage-point deviations), and the trade balance-to-GDP ratio (percentage-point deviations). GDP and its components are reported in real terms. Blue-solid lines represent impulse responses after a brown-capital rental income tax shock without subsidies in our baseline scenario ($\mu_{IB} = 0.5$). Red-dashed lines exhibit impulse responses after a brown-capital rental income tax shock without subsidies and with higher elasticity of substitution between tradables and non-tradables in production of the final brown investment good ($\mu_{IB} = 3$).

FIGURE D.18. Impulse Responses to a brown-capital rental income tax shock in the EA – Higher substitutability between tradables and non-tradables in final brown investment



Notes: Impulse responses to a rise in tax on rental brown capital income in the EA. Horizontal axis: quarters. Vertical axis: percentage deviations from the baseline, except for inflation and interest rates (annualized percentage-point deviations), and the trade balance-to-GDP ratio (percentage-point deviations). GDP and its components are reported in real terms. Blue-solid lines represent impulse responses after a brown-capital rental income tax shock without subsidies in our baseline scenario ($\mu_{IB} = 0.5$). Red-dashed lines exhibit impulse responses after a brown-capital rental income tax shock without subsidies and with higher elasticity of substitution between tradables and non-tradables in production of the final brown investment good ($\mu_{IB} = 3$).

FIGURE D.19. Impulse Responses to a brown-capital rental income tax shock in the EA – Higher substitutability between tradables and non-tradables in final brown investment



Notes: Impulse responses to a rise in tax on rental brown capital income in the EA. Horizontal axis: quarters. Vertical axis: percentage deviations from the baseline, except for inflation and interest rates (annualized percentage-point deviations), and the trade balance-to-GDP ratio (percentage-point deviations). GDP and its components are reported in real terms. Blue-solid lines represent impulse responses after a brown-capital rental income tax shock without subsidies in our baseline scenario ($\mu_{IB} = 0.5$). Red-dashed lines exhibit impulse responses after a brown-capital rental income tax shock without subsidies and with higher elasticity of substitution between tradables and non-tradables in production of the final brown investment good ($\mu_{IB} = 3$).

BANCO DE ESPAÑA PUBLICATIONS

WORKING PAPERS

2420 FRANCISCO GONZÁLEZ, JOSÉ E. GUTIÉRREZ and JOSÉ MARÍA SERENA: Shadow seniority? Lending relationships and borrowers' selective default.

2421 ROBERTO BLANCO, MIGUEL GARCÍA-POSADA, SERGIO MAYORDOMO and MARÍA RODRÍGUEZ-MORENO: Access to credit and firm survival during a crisis: the case of zero-bank-debt firms.

2422 FERNANDO CEREZO, PABLO GIRÓN, MARÍA T. GONZÁLEZ-PÉREZ and ROBERTO PASCUAL: The impact of sovereign debt purchase programmes. A case study: the Spanish-to-Portuguese bond yield spread.

2423 EDGAR SILGADO-GÓMEZ: Sovereign uncertainty.

2424 CLODOMIRO FERREIRA, JULIO GÁLVEZ and MYROSLAV PIDKUYKO: Housing tenure, consumption and household debt: life-cycle dynamics during a housing bust in Spain.

2425 RUBÉN DOMÍNGUEZ-DÍAZ and SAMUEL HURTADO: Green energy transition and vulnerability to external shocks.

2426 JOSEP GISBERT and JOSÉ E. GUTIÉRREZ: Bridging the gap? Fintech and financial inclusion.

2427 RODOLFO G. CAMPOS, MARIO LARCH, JACOPO TIMINI, ELENA VIDAL and YOTO V. YOTOV: Does the WTO Promote Trade? A Meta-analysis.

2428 SONER BASKAYA, JOSÉ E. GUTIÉRREZ, JOSÉ MARÍA SERENA and SERAFEIM TSOUKAS: Bank supervision and non-performing loan cleansing.

2429 TODD E. CLARK, GERGELY GANICS, and ELMAR MERTENS: Constructing fan charts from the ragged edge of SPF forecasts.

2430 MIGUEL GARCÍA-POSADA and PETER PAZ: The transmission of monetary policy to credit supply in the euro area.

2431 KLODIANA ISTREFI, FLORENS ODENDAHL and GIULIA SESTIERI: ECB communication and its impact on financial markets.

2432 FRUCTUOSO BORRALLO, LUCÍA CUADRO-SÁEZ, CORINNA GHIRELLI and JAVIER J. PÉREZ: "El Niño" and "La Niña": Revisiting the impact on food commodity prices and euro area consumer prices.

2433 VÍCTOR CABALLERO, CORINNA GHIRELLI, ÁNGEL LUIS GÓMEZ and JAVIER J. PÉREZ: The public-private wage GAP in the euro area a decade after the sovereign debt crisis.

2434 LIDIA CRUCES, ISABEL MICÓ-MILLÁN and SUSANA PÁRRAGA: Female financial portfolio choices and marital property regimes.

2435 RODOLFO G. CAMPOS, ANA-SIMONA MANU, LUIS MOLINA and MARTA SUÁREZ-VARELA: China's financial spillovers to emerging markets.

2436 LUDOVIC PANON, LAURA LEBASTARD, MICHELE MANCINI, ALESSANDRO BORIN, PEONARE CAKA, GIANMARCO CARIOLA, DENNIS ESSERS, ELENA GENTILI, ANDREA LINARELLO, TULLIA PADELLINI, FRANCISCO REQUENA and JACOPO TIMINI: Inputs in Distress: Geoeconomic Fragmentation and Firms' Sourcing.

2437 DANIEL DEJUAN-BITRIA, WAYNE R. LANDSMAN, SERGIO MAYORDOMO and IRENE ROIBÁS: How do changes in financial reporting standards affect relationship lending?

2438 ALICIA AGUILAR and RICARDO GIMENO: Discrete Probability Forecasts: What to expect when you are expecting a monetary policy decision.

2439 RODOLFO G. CAMPOS, JESÚS FERNÁNDEZ-VILLAVERDE, GALO NUÑO and PETER PAZ: Navigating by Falling Stars: Monetary Policy with Fiscally Driven Natural Rates.

2440 ALEJANDRO CASADO and DAVID MARTÍNEZ-MIERA: Local lending specialization and monetary policy.

2441 JORGE ABAD, DAVID MARTÍNEZ-MIERA and JAVIER SUÁREZ: A macroeconomic model of banks' systemic risk taking.

2442 JOSEP PIJOAN-MAS and PAU ROLDAN-BLANCO: Dual labor markets and the equilibrium distribution of firms.

2443 OLYMPIA BOVER, LAURA HOSPIDO and ANA LAMO: Gender and Career Progression: Evidence from the Banco de España.

2444 JESÚS FERNÁNDEZ-VILLAVERDE, GALO NUÑO and JESSE PERLA: Taming the curse of dimensionality: quantitative economics with deep learning.

2445 CLODOMIRO FERREIRA and STEFANO PICA: Households' subjective expectations: disagreement, common drivers and reaction to monetary policy.

2446 ISABEL MICÓ-MILLÁN: Inheritance Tax Avoidance Through the Family Firm.

2447 MIKEL BEDAYO, EVA VALDEOLIVAS and CARLOS PÉREZ: The stabilizing role of local claims in local currency on the variation of foreign claims.

2501 HENRIQUE S. BASSO, MYROSLAV PIDKUYKO and OMAR RACHEDI: Opening the black box: aggregate implications of public investment heterogeneity.

2502 MARCO BARDOSCIA, ADRIAN CARRO, MARC HINTERSCHWEIGER, MAURO NAPOLETANO, LILIT POPOYAN, ANDREA ROVENTINI and ARZU ULUC: The impact of prudential regulations on the UK housing market and economy: insights from an agent-based model.

2503 IRINA BALTEANU, KATJA SCHMIDT and FRANCESCA VIANI: Sourcing all the eggs from one basket: trade dependencies and import prices.

2504 RUBÉN VEIGA DUARTE, SAMUEL HURTADO, PABLO A. AGUILAR GARCÍA, JAVIER QUINTANA GONZÁLEZ and CAROLINA MENÉNDEZ ÁLVAREZ: CATALIST: A new, bigger, better model for evaluating climate change transition risks at Banco de España.

2505 PILAR GARCÍA and DIEGO TORRES: Perceiving central bank communications through press coverage.

2506 MAR DELGADO-TÉLLEZ, JAVIER QUINTANA and DANIEL SANTABÁRBARA: Carbon pricing, border adjustment and renewable energy investment: a network approach.

2507 MARTA GARCÍA RODRÍGUEZ: The role of wage expectations in the labor market.

2508 REBECA ANGUREN, GABRIEL JIMÉNEZ and JOSÉ-LUIS PEYDRÓ: Bank capital requirements and risk-taking: evidence from Basel III.

2509 JORGE E. GALÁN: Macroprudential policy and the tail risk of credit growth.

2510 PETER KARADI, ANTON NAKOV, GALO NUÑO, ERNESTO PASTÉN and DOMINIK THALER: Strike while the Iron is Hot: Optimal Monetary Policy with a Nonlinear Phillips Curve.

2511 MATTEO MOGLIANI and FLORENS ODENDAHL: Density forecast transformations.

2512 LUCÍA LÓPEZ, FLORENS ODENDAHL, SUSANA PÁRRAGA and EDGAR SILGADO-GÓMEZ: The pass-through to inflation of gas price shocks.

2513 CARMEN BROTO and OLIVIER HUBERT: Desertification in Spain: Is there any impact on credit to firms?

2514 ANDRÉS ALONSO-ROBISCO, JOSÉ MANUEL CARBÓ, PEDRO JESÚS CUADROS-SOLAS and JARA QUINTANERO: The effects of open banking on fintech providers: evidence using microdata from Spain.

2515 RODOLFO G. CAMPOS and JACOPO TIMINI: Trade bloc enlargement when many countries join at once.

2516 CORINNA GHIRELLI, JAVIER J. PÉREZ and DANIEL SANTABÁRBARA: Inflation and growth forecast errors and the sacrifice ratio of monetary policy in the euro area.

2517 KOSUKE AOKI, ENRIC MARTORELL and KALIN NIKOLOV: Monetary policy, bank leverage and systemic risk-taking.

2518 RICARDO BARAHONA: Index fund flows and fund distribution channels.

2519 ALVARO FERNÁNDEZ-GALLARDO, SIMON LLOYD and ED MANUEL: The Transmission of Macroprudential Policy in the Tails: Evidence from a Narrative Approach.

2520 ALICIA AGUILAR: Beyond fragmentation: unraveling the drivers of yield divergence in the euro area.

2521 RUBÉN DOMÍNGUEZ-DÍAZ and DONGHAI ZHANG: The macroeconomic effects of unemployment insurance extensions: A policy rule-based identification approach.

2522 IRMA ALONSO-ALVAREZ, MARINA DIAKONOVA and JAVIER J. PÉREZ: Rethinking GPR: The sources of geopolitical risk.

2523 ALBERTO MARTÍN, SERGIO MAYORDOMO and VICTORIA VANASCO: Banks vs. Firms: Who Benefits from Credit Guarantees?

2524 SUMIT AGARWAL, SERGIO MAYORDOMO, MARÍA RODRÍGUEZ-MORENO and EMANUELE TARANTINO: Household Heterogeneity and the Lending Channel of Monetary Policy.

2525 DIEGO BONELLI, BERARDINO PALAZZO, and RAM YAMARTHY: Good inflation, bad inflation: implications for risky asset prices.

2526 STÉPHANE BONHOMME and ANGELA DENIS: Fixed Effects and Beyond. Bias Reduction, Groups, Shrinkage and Factors in Panel Data.

2527 ÁLVARO FERNÁNDEZ-GALLARDO and IVÁN PAYÁ: Public debt burden and crisis severity.

2528 GALO NUÑO: Three Theories of Natural Rate Dynamics.

2529 GALO NUÑO, PHILIPP RENNER and SIMON SCHEIDEGGER: Monetary policy with persistent supply shocks.

2530 MIGUEL ACOSTA-HENAO, MARÍA ALEJANDRA AMADO, MONTSERRAT MARTÍ and DAVID PÉREZ-REYNA: Heterogeneous UIPDs across Firms: Spillovers from U.S. Monetary Policy Shocks.

2531 LUIS HERRERA and JESÚS VÁZQUEZ: Learning from news.

2532 MORTEZA GHOMI, JOCHEN MANKART, RIGAS OIKONOMOU and ROMANOS PRIFTIS: Debt maturity and government spending multipliers.

2533 MARINA DIAKONOVA, CORINNA GHIRELLI and JAVIER J. PÉREZ: Political polarization in Europe.

2534 NICOLÁS FORTEZA and SERGIO PUENTE: Measuring non-workers' labor market attachment with machine learning.

2535 GERGELY GANICS and LLUC PUIG CODINA: Simple Tests for the Correct Specification of Conditional Predictive Densities.

2536 HENRIQUE S. BASSO and OMAR RACHEDI: Robot adoption and inflation dynamics.

2537 PABLO GARCIA, PASCAL JACQUINOT, ČRT LENARČIČ, KOSTAS MAVROMATIS, NIKI PAPADOPOULOU and EDGAR SILGADO-GÓMEZ: Green transition in the Euro area: domestic and global factors.