EUROPEAN CENTRAL BANK
EUROSYSTEM

Working Paper Series

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Tariffs across the supply chain

No 3081

Abstract

What are the macroeconomic impacts of tariffs on final goods versus intermediate inputs? We set up a two-region, multi-sector model with production networks, sticky prices and wages, and trade in consumption, investment, and intermediate goods. We show that import tariffs on final goods have a smaller negative impact on GDP compared to tariffs on intermediate inputs, as final goods can be more readily substituted with domestic alternatives. In contrast, tariffs on intermediate inputs lead to larger GDP losses, given the limited substitutability of foreign inputs and their role in global supply chains. Moreover, inflation persistence is lower under tariffs on final goods, whereas tariffs on intermediate goods amplify cost pressures through production linkages. The results imply that a revenue-equivalent approach to import tariffs, targeting only final goods, can cushion the adverse effects of trade wars.

Keywords: Tariffs, Production Networks, Inflation.

JEL Classification: E31, E32, F12, F13, F41.

Non-technical summary

In the context of rising trade tensions and increasing recourse to protectionist policies, this paper studies how the structure of tariffs influences their macroeconomic effects. Specifically, it asks whether the economic consequences of import tariffs differ depending on whether they target final goods consumed by households or intermediate goods used as inputs in production. Using a novel multi-sector model with two regions—representing the European Union and the rest of the world—we show that the location of tariffs along the supply chain has significant implications for both GDP and inflation dynamics.

This paper builds on a rich body of literature on international production networks and New Keynesian macroeconomics, but introduces a novel focus on how tariffs propagate through global supply chains. We begin by developing a simplified analytical model that illustrates the core mechanisms at play. In this setting, tariffs on final goods raise consumer prices temporarily but have a limited impact on output, as households can substitute foreign goods with domestic alternatives. In contrast, tariffs on intermediate goods—such as imported components or raw materials—directly increase firms' production costs. Because such inputs are typically harder to substitute, the effects are more persistent and disruptive, leading to deeper GDP contractions and longer-lasting inflationary pressures.

These insights are then tested and expanded in a fully-fledged quantitative model. The model incorporates multiple sectors, sticky wages and prices, investment frictions, and realistic input-output linkages across countries and sectors. It is carefully calibrated to match data for the EU and the rest of the world, drawing from sources such as the WIOD input-output tables and existing empirical estimates for elasticities of substitution, markups, and other structural parameters. A key feature of the model is its ability to capture the amplification of shocks through production networks, which allows us to assess how tariff-induced cost increases ripple through the economy.

The quantitative results corroborate the analytical intuition. Tariffs on intermediate goods cause more persistent inflation and larger GDP losses than tariffs on final goods. When households face tariffs on consumer imports, they are often able to shift their consumption toward domestic products, mitigating the impact on output. The inflationary effects, in this case, are short-lived and stem directly from the higher prices of imported goods. However, when firms face tariffs on inputs that are essential for production, the cost pressures are passed on throughout the supply

chain. This raises prices more broadly and affects firms' pricing decisions, leading to a longer and more severe economic adjustment.

This paper also explores the implications of these findings for trade policy design, particularly in the context of retaliation. When the EU faces higher export tariffs imposed by foreign partners, it can respond by imposing tariffs on imports. We consider three scenarios: no retaliation, full retaliation (on both final and intermediate goods), and a revenue-equivalent retaliation that targets only final goods. The simulations show that full retaliation leads to the largest drop in GDP and the most persistent rise in inflation, due to the compounding effects of input cost shocks. In contrast, a retaliation strategy focused solely on final goods achieves much milder effects on inflation and output. This is because such a strategy avoids placing additional burdens on domestic producers that rely on imported inputs.

Overall, when engaging in trade disputes or designing tariff policies, it is essential to consider not only the magnitude of tariffs but also their position in the supply chain. Targeting final goods allows for a more contained macroeconomic impact, while tariffs on intermediate goods risk disrupting production networks and generating inflationary pressures that are difficult to control. These findings suggest that retaliatory measures in trade conflicts should be carefully designed to minimize unintended domestic costs.

1 Introduction

How does the structure of tariffs impact their transmission to key macroeconomic variables? Tariffs disrupt trade flows and influence prices, production costs, and economic activity in both the imposing and retaliating economies. As trade tensions escalate and countries impose additional import restrictions, the impact will crucially depend on the structure of these measures and the type of goods that are targeted. This paper explores the potential consequences of tariffs by focusing on two key questions: does it make a difference whether tariffs are imposed on final or intermediate goods? How does the degree of substitutability between domestic and imported goods play a role in this context?

Tariffs on final goods may directly raise consumer prices, reducing demand for imports and potentially shifting consumption toward domestic alternatives. In contrast, tariffs on intermediate inputs affect production costs for firms that rely on these goods, influencing their pricing decisions, competitiveness, and overall economic activity. When tariffs target intermediate goods that are essential for production (such as semiconductors), they may lead to more persistent cost-push driven inflation and disrupt supply chains, affecting output and employment more broadly. This is especially the case for economies that are highly open and deeply integrated in global value chains. The extent to which tariffs alter trade patterns and pricing also depends on the substitutability of affected goods. If tariffed products have close alternatives — either from domestic producers or third-country suppliers — the impact on prices and activity may be mitigated as buyers shift away from tariffed goods. However, if tariffed products are differentiated and less easily replaced, then their demand is more rigid.

To investigate these issues, we develop a two-region, multi-sector model with international production networks and a full input-output structure, and examine the transmission channels of a differentiated tariff shock on final or intermediate goods. The model builds on Bouakez et al. (2023) and Hinterlang et al. (2023), and includes sticky wages and prices, investment adjustment costs, and cross-border tariff shocks, and is calibrated on the European Union and the Rest of the World.

To gather some intuition, we first show analytically, in a simplified setting, how import tariffs levied either on final goods or intermediate inputs have radically different economic implications. Households can more easily substitute foreign goods with domestic counterparts, limiting the impact on GDP of tariffs imposed on final goods, only at the cost of a temporary surge in inflation, which is entirely due to the direct impact of the tariff change. This spike in prices, indeed, does not influence the price-setting behaviour of domestic producers, which leave their prices unchanged. By contrast, import tariffs on foreign inputs increase production costs, giving rise to persistent pressures on the price of domestically-produced goods. Given that foreign inputs are more difficult to substitute domestically compared to final goods, the drop in GDP is more severe.

In the full quantitative model, these results are further compounded and amplified by the presence of a rich input-output structure, as tariff shocks to inputs are propagated through the production network. Indeed, when tariffs are imposed on intermediate goods, there is a direct effect on production costs and prices. Due to the interaction with price stickiness, this effect is further compounded and propagated over time through input-output linkages.[1]

In our full quantitative application we investigate the potential impact of alternative retaliatory strategies in response to export tariffs faced by the EU. We find that a broad retaliation scenario, targeting both final and intermediate goods, results in a more pronounced contraction in EU GDP and more persistent inflation, compared to a revenue-equivalent retaliation scenario targeting only final goods. Indeed, the latter approach mitigates the economic fallout by avoiding persistent cost pressures on domestic production, amplified via the production network.

Related Literature. This paper is related to three main strands of the literature. First, it contributes to a rapidly growing literature studying the role of production networks in propagating the effects of shocks in multi-sector models with nominal rigidities. From this perspective, we relate to studies highlighting the role of sectoral heterogeneity and production linkages in amplifying the effects of monetary policy shocks (Pasten et al., 2020; Ghassibe, 2021; Rubbo, 2023), government spending (Bouakez et al., 2023), and the transmission of sectoral shocks to aggregate variables (Afrouzi and Bhattarai, 2023). Our paper makes use of a similar framework as Bouakez et al. (2023), but we extend the analysis to an open-economy framework, to shed light on the implications of production linkages in propagating the effect of tariff shocks.

Our paper also relates to open-economy, multi-sector New Keynesian models with international production networks (Devereux et al., 2023; Hinterlang et al., 2023; Kalemli-Özcan et al., 2025). Particularly, closest to our approach, a recent contribution by Kalemli-Özcan et al. (2025) also

[1]See, e.g., Afrouzi and Bhattarai (2023), who show analytically how production linkages amplify the persistence of inflation and GDP responses to sectoral shocks.

investigates the impact of tariffs in a multi-country multi-sector model with sticky prices and international production networks, showing how the inflationary effects of tariffs are amplified. Compared to them, we adopt a two-region model with a richer quantitative setting, including capital and both sticky prices and wages, and we focus on the specific question of how tariffs exert a different impact depending on the stage at which they are levied on the supply chain.

Third, and prominently, we contribute to the emerging interest in investigating the short-run macroeconomic impact of trade fragmentation in the context of rising global trade tensions (Bergin and Corsetti, 2023; Ambrosino et al., 2024; Moro and Nispi Landi, 2024; Auclert et al., 2025; Auray et al., 2025a; Monacelli, 2025). Particularly, Bergin and Corsetti (2023) using a New Keynesian model with global value chains show that the optimal monetary policy response to tariffs is expansionary. Other contributions typically consider tariffs affecting only either an imported final good (see, for instance, Monacelli, 2025) or an imported input (Auclert et al., 2025). While Auray et al. (2025a) consider tariffs affecting both, they do not investigate their potential different impacts as we do. To our knowledge, our paper is among the first to investigate both in a simple analytical framework as well as in a rich quantitative setting the different implications of tariffs levied at different stages of the supply chain, distinguishing between the different impact of tariffs levied on final goods as opposed to intermediate inputs.

Roadmap. The remainder of this paper is structured as follows. Section 3 provides some preliminary intuition on the basis of a simplified framework. Section 2 describes the full model, and Section 4 deals with quantitative analysis. Section 5 concludes.

2 A Simplified Example

In this section we rely on a simplified version of the model presented in Section 3 to provide some preliminary intuition on the mechanisms underlying the different impact of tariffs on final as opposed to intermediate goods. Specifically, along the lines of Auray et al. (2025b) and Monacelli (2025), we assume that the domestic country is a small open economy, while the rest of the world behaves as a closed economy and is unaffected by tariff shocks — an assumption that we will relax later in the full quantitative application. Compared to the aforementioned papers, we allow for foreign input sourcing (as also done, e.g., by Auclert et al., 2025) and for import tariffs impacting both final goods and production inputs.

As will be later explored in detail in the quantitative application of the full model in Section 4, the effects of tariffs will be further compounded and amplified by the presence of a richer (domestic and global) production network structure.

2.1 The Example Model

2.1.1 Households

Domestic households consume home goods, $C_{h,t}$, and foreign goods, $C_{f,t}$, and invest in domestic nominal bonds B_t (yielding net return i_t), and foreign nominal bonds B_t^* (with yield i^*).[2] Preferences over domestic and foreign consumption are given by

$$C_t = \left[\eta^{1/\lambda_C} C_{h,t}^{1-1/\lambda_C} + (1-\eta)^{1/\lambda_C} C_{f,t}^{1-1/\lambda_C}\right]^{\frac{\lambda_C}{\lambda_C - 1}} \tag{1}$$

where C_t denotes aggregate consumption, $\eta \in (0.5, 1)$ is the home bias in consumption and $\lambda_C > 0$ is the elasticity of substitution between domestic and foreign consumption. Household utility is given by

$$\mathbb{E}_t \sum_{j=0}^{\infty} \beta^j \left\{\ln(C_{t+j}) - N_{t+j}\right\} \tag{2}$$

where $\beta \in (0, 1)$ denotes the discount factor and N_t hours worked. The budget constraint is

$$P_{h,t} C_{h,t} + P_{f,t} C_{f,t} + B_t + \mathcal{E}_t B_t^* = W_t N_t + (1 + i_{t-1}) B_{t-1} + \mathcal{E}_t (1 + i^*) B_{t-1}^* + T_t + D_t \tag{3}$$

where W_t is the nominal wage rate, $\mathcal{E}_t$ denotes the nominal exchange rate (with a higher value corresponding to depreciation of the domestic currency), T_t denotes lump-sum transfers from the government, and D_t are dividends collected from producers. The price of the foreign good (in units of domestic currency) is given by

$$P_{f,t} = (1 + \tau_{c,t}) \mathcal{E}_t \tag{4}$$

where the foreign price P_t^* is normalized to 1, and $\tau_{c,t}$ is an import tariff imposed on the foreign consumption good.

[2] In line with the small open economy paradigm, we take all rest-of-the-world aggregates to be constant in this simplified framework. The quantitative analysis in Section 4 will, instead, consider the more general case where rest-of-the-world aggregates are also impacted by bilateral tariffs.

Optimal household choices give the labor supply condition

$$C_t^{-1}\,\frac{W_t}{P_t} = 1\,, \tag{5}$$

demand schedules for domestic and foreign consumption,

$$C_{h,t} = \eta\left(\frac{P_{h,t}}{P_t}\right)^{-\lambda_C} C_t\,, \tag{6}$$

$$C_{f,t} = (1-\eta)\left(\frac{P_{f,t}}{P_t}\right)^{-\lambda_C} C_t\,, \tag{7}$$

and Euler equations associated with domestic and foreign bonds,

$$1 = \beta\,\mathbb{E}_t\left[\frac{C_t}{C_{t+1}}\left(\frac{1+i_t}{1+\pi_{t+1}}\right)\right]\,, \tag{8}$$

$$1 = \beta\,\mathbb{E}_t\left[\frac{C_t}{C_{t+1}}\left(\frac{1+i^*}{1+\pi_{t+1}}\right)\frac{\mathcal{E}_{t+1}}{\mathcal{E}_t}\right]\,, \tag{9}$$

where $P_t = \left[\eta\,P_{h,t}^{1-\lambda_C} + (1-\eta)\,P_{f,t}^{1-\lambda_C}\right]^{\frac{1}{1-\lambda_C}}$ and $\pi_t = P_t/P_{t-1} - 1$ denotes CPI inflation.

As rest-of-the-world aggregates are taken to be constant, no arbitrage implies the following international risk-sharing condition:

$$C_t = \mathcal{E}_t\,\frac{1}{P_t}\,. \tag{10}$$

2.1.2 Firms

Domestic supply of the consumption good results from a composite of differentiated varieties, aggregated under a constant elasticity of substitution technology

$$Y_t = \left(\int_0^1 Y_t(z)^{\frac{\varepsilon-1}{\varepsilon}}dz\right)^{\frac{\varepsilon}{\varepsilon-1}} \tag{11}$$

with $\varepsilon > 1$. Demand for variety z is given by

$$Y_t(z) = \left(\frac{P_{h,t}(z)}{P_{h,t}}\right)^{-\varepsilon} Y_t \tag{12}$$

where $P_{h,t} = \left[P_{h,t}(z)^{1-\varepsilon}dz\right]^{\frac{1}{1-\varepsilon}}$.

Each firm is a monopolistic supplier of a single variety z, produced using (domestic) labor and an imported input according to the following production function

$$Y_t(z) = \left[\eta^{1/\lambda_M}\, N_t(z)^{1-1/\lambda_M} + (1-\eta)^{1/\lambda_M}\, M_t(z)^{1-1/\lambda_M}\right]^{\frac{\lambda_M}{\lambda_M - 1}} \tag{13}$$

where $\lambda_M > 0$ is the elasticity of substitution between domestic and foreign inputs and η is the relative factor intensity of the domestic input, assumed for simplicity to be equal to the home bias in consumption.

Cost minimization gives the following demand schedules for hours and the foreign input

$$N_t(z) = \eta \left(\frac{W_t}{MC_t}\right)^{-\lambda_M} Y_t(z)\,, \tag{14}$$

$$M_t(z) = (1-\eta) \left(\frac{P_{m,t}}{MC_t}\right)^{-\lambda_M} Y_t(z)\,, \tag{15}$$

where

$$MC_t = \left[\eta\, W_t^{1-\lambda_M} + (1-\eta)\, P_{m,t}^{1-\lambda_M}\right]^{\frac{1}{1-\lambda_M}} \tag{16}$$

is the nominal marginal cost and

$$P_{m,t} = (1+\tau_{m,t})\,\mathcal{E}_t \tag{17}$$

is the price of the foreign input (in units of domestic currency), with $\tau_{m,t}$ representing an import tariff imposed on the foreign input.

Wholesalers face quadratic adjustment costs from changing prices, solving

$$\max_{Y_v(z), P_{h,v}(z)} \mathbb{E}_t \sum_{v=t}^{\infty} \Lambda_{t,v} \left\{ \left[(1+\tau_p)\, P_{h,v}(z) - MC_v(z)\right] Y_v(z) - \frac{\psi}{2}\left(\frac{P_{h,v}(z)}{P_{h,v-1}(z)} - 1\right)^2 P_{h,v}\, Y_v \right\} \tag{18}$$

subject to (12), where $\Lambda_{t,v} = \beta\,\frac{P_t\,C_t}{P_v\,C_v}$ is the stochastic discount factor for nominal payoffs, and $\tau_p = \frac{1}{1-\varepsilon}$ is a production subsidy aimed at offsetting the steady-state markup. Optimality conditions and symmetry yield the usual NK Phillips curve

$$\pi_{h,t}\,(1+\pi_{h,t}) = \frac{\varepsilon}{\psi}\left(\frac{MC_t}{P_{h,t}} - 1\right) + \mathbb{E}_t\left[\Lambda_{t,t+1}\,\pi_{h,t+1}\,(1+\pi_{h,t+1})\,\frac{Y_{t+1}}{Y_t}\right] \tag{19}$$

where $\pi_{h,t} = P_{h,t}/P_{h,t-1} - 1$ is the inflation rate of domestically produced goods, which we refer as PPI inflation. Dividends are

$$D_t = [(1+\tau_p)\, P_{h,t} - MC_t]\; Y_t - \frac{\psi}{2}\pi_{h,t}^2 P_{h,t}\, Y_t \,. \tag{20}$$

2.1.3 Government

The proceeds from tariff revenues and the taxes levied to finance production subsidies are assumed to accrue to households in lump-sum form

$$T_t = \tau_{c,t}\, \mathcal{E}_t\, C_{f,t} + \tau_{m,t}\, \mathcal{E}_t\, M_t - \tau_p\, P_{h,t}\, Y_t \,. \tag{21}$$

2.1.4 Monetary Policy

In standard small open economy New Keynesian models —where the prices of domestically produced goods are typically sticky in terms of the domestic currency— monetary policy is generally prescribed to target PPI inflation, while looking through fluctuations in the foreign component of CPI inflation (see, e.g., Clarida et al., 2002). Accordingly, we assume the following PPI-targeting rule for monetary policy

$$1 + i_t = \frac{1}{\beta}\, (1 + \pi_{h,t})^{\phi} \,. \tag{22}$$

2.1.5 Equilibrium

The equilibrium of the simplified model is characterized by the household optimality conditions in (5) to (9), the risk sharing condition in (10), firm optimal input demands in (14) and (15), the optimal pricing condition posed by the NKPC in (19), the monetary policy rule in (22) and, finally, by market clearing in the bond and goods market. In this latter respect, the domestic bond is in zero net supply ($B_t = 0$ at every t), while market clearing for goods implies

$$Y_t = C_{h,t} + X_t + \frac{\psi}{2}\, \pi_{h,t}^2\, Y_t \tag{23}$$

where we assume the following demand for exports

$$X_t = (1-\eta)\left(\frac{P_{h,t}}{\mathcal{E}_t}\right)^{-\delta} \tag{24}$$

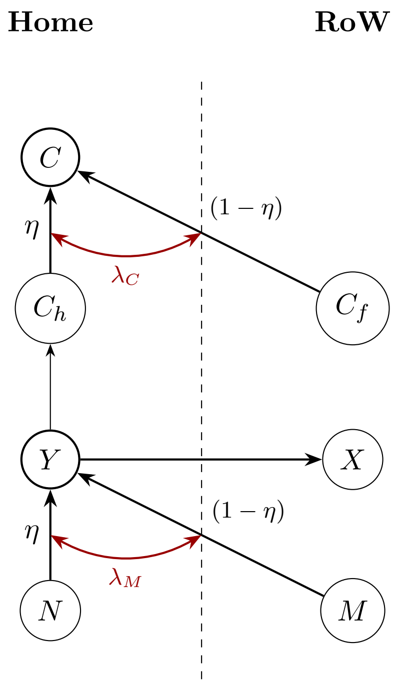

Figure 1: Summary of the simplified model.

with $\delta > 0$ representing the price elasticity of foreign demand.

Given that labor is the only primary source of domestic income in this simplified economy, real GDP coincides with real labor income

$$GDP_t = \frac{W_t}{P_t} N_t \,. \tag{25}$$

The structure of the simple model is summarized in Figure 1.

2.2 The Impact of Tariffs

Letting hats denote proportional (or percentage-point) deviations from the zero-inflation steady state, the first-order approximate dynamics of the simplified model are described by the following set of equations

$$\widehat{c}_{h,t} = -\lambda_C \left(\widehat{p}_{h,t} - \widehat{p}_t\right) + \widehat{c}_t \tag{26}$$

$$\widehat{c}_{f,t} = -\lambda_C \left(\widehat{\tau}_{c,t} + \widehat{\mathcal{E}}_t - \widehat{p}_t\right) + \widehat{c}_t \tag{27}$$

$$\widehat{c}_t = \widehat{w}_t - \widehat{p}_t \tag{28}$$

$$i_t - \mathbb{E}_t(\pi_{t+1}) = \mathbb{E}_t(\widehat{c}_{t+1} - \widehat{c}_t) \tag{29}$$

$$\widehat{p}_t = \eta\, \widehat{p}_{h,t} + (1-\eta)\,(\widehat{\tau}_{c,t} + \widehat{\mathcal{E}}_t) \tag{30}$$

$$\pi_t = \eta\, \pi_{h,t} + (1-\eta)\,(\Delta\widehat{\tau}_{c,t} + \Delta\widehat{\mathcal{E}}_t) \tag{31}$$

$$\widehat{c}_t = \widehat{\mathcal{E}}_t - \widehat{p}_t \tag{32}$$

$$\pi_{h,t} = \beta\, \mathbb{E}_t\,(\pi_{h,t+1}) + \kappa\,(\widehat{mc}_t - \widehat{p}_{h,t}) \tag{33}$$

$$\widehat{mc}_t = \eta\, \widehat{w}_t + (1-\eta)\,(\widehat{\tau}_{m,t} + \widehat{\mathcal{E}}_t) \tag{34}$$

$$\widehat{n}_t = -\lambda_M\,(\widehat{w}_t - \widehat{mc}_t) + \widehat{y}_t \tag{35}$$

$$\widehat{m}_t = -\lambda_M\,(\widehat{\tau}_{m,t} + \widehat{\mathcal{E}}_t - \widehat{mc}_t) + \widehat{y}_t \tag{36}$$

$$\widehat{x}_t = -\delta\,(\widehat{p}_{h,t} + \widehat{\tau}_{x,t} - \widehat{\mathcal{E}}_t) \tag{37}$$

$$\widehat{y}_t = \eta\, \widehat{c}_{h,t} + (1-\eta)\, \widehat{x}_t \tag{38}$$

$$\widehat{gdp}_t = (\widehat{w}_t - \widehat{p}_t) + \widehat{n}_t \tag{39}$$

$$i_t = \phi\, \pi_{h,t} \tag{40}$$

where $\kappa = \varepsilon/\psi$.

We are now interested in analyzing how the model behaves in response to AR(1) tariff shocks to imports of final as opposed to intermediate goods,

$$\widehat{\tau}_{g,t} = \rho\, \widehat{\tau}_{g,t-1} + \sigma_{g,t} \tag{41}$$

with $g \in \{c, m\}$ and $\rho \in [0, 1)$. The main results are summarised in the following propositions.

Proposition 1. *The responses of GDP, PPI inflation, and CPI inflation to tariff shocks on imported consumption goods are*

$$\widehat{gdp}_t = -(1-\eta)\,[1 - \eta\,(\lambda_C - 1)]\,\widehat{\tau}_{c,t} \tag{42}$$

$$\pi_{h,t} = 0 \tag{43}$$

$$\pi_t = (1-\eta)\,\Delta\widehat{\tau}_{c,t} \tag{44}$$

Proposition 2. *The responses of GDP, PPI inflation, and CPI inflation to tariff shocks on imported production inputs are*

$$\widehat{gdp}_t = -(1-\eta)\,\left\{\frac{\kappa\,(\phi-\rho)\,[\eta\,(1+\eta) + (1-\eta)\,(\eta\,\lambda_C + \delta)]}{\kappa\,(\phi-\rho) + (1-\rho)\,(1-\beta\,\rho)} - \lambda_M\right\}\,\widehat{\tau}_{m,t} \tag{45}$$

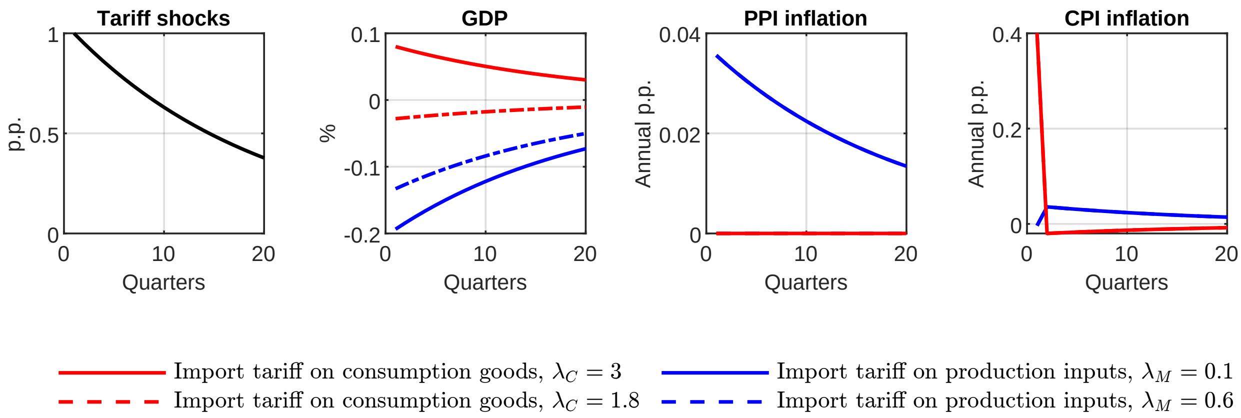

Figure 2: Impact of import tariffs. *Note*: $\eta = 0.9$, $\rho = 0.95$, $\beta = 0.99$, $\phi = 1.5$, $\kappa = 0.1$, $\delta = 1$. $\lambda_C = 3$ and $\lambda_M = 0.1$, unless otherwise noted.

$$\pi_{h,t} = \frac{\kappa\,(1-\rho)\,(1-\eta)}{\kappa\,(\phi-\rho) + (1-\rho)\,(1-\beta\,\rho)}\,\widehat{\tau}_{m,t} \tag{46}$$

$$\pi_t = \frac{\kappa\,(1-\eta)}{\kappa\,(\phi-\rho) + (1-\rho)\,(1-\beta\,\rho)}\,[(1-\rho)\,\widehat{\tau}_{m,t} - (1-\eta)\,(\phi-\rho)\,\Delta\widehat{\tau}_{m,t}] \tag{47}$$

Proposition 1 shows that when tariffs are imposed on consumption goods, GDP decreases depending on whether the elasticity of substitution between domestic and foreign consumption is not excessively large. Namely, GDP declines in response to an increase in tariffs on imported consumption goods provided that

$$\lambda_C < \frac{1}{\eta} + 1 \tag{48}$$

By contrast, as shown in Proposition 2, GDP decreases when tariffs are imposed on intermediate goods if the elasticity of substitution between domestic and foreign inputs is sufficiently small. Namely, GDP declines in response to an increase in tariffs on imported production inputs provided that

$$\lambda_M < \frac{\kappa\,(\phi-\rho)\,[\eta\,(1+\eta) + (1-\eta)\,(\eta\,\lambda_C + \delta)]}{\kappa\,(\phi-\rho) + (1-\rho)\,(1-\beta\,\rho)} \tag{49}$$

In practice, final goods are typically gross substitutes (with $\lambda_C > 1$), while production inputs are typically gross complements (with λ_M close to zero), implying a larger negative impact on GDP from imports tariffs on intermediate inputs compared to import tariffs on final goods. These results are illustrated in Figure 2.

Moreover, as shown in the two propositions and illustrated in Figure 2, import tariffs on consumption goods are transitorily inflationary, and due only to their direct effect on the domestic CPI. By contrast, the rise in inflation induced by import tariffs on intermediate inputs is smaller on impact, but persistent. Importantly, only tariffs on intermediate inputs affect the price-setting behavior of firms and the subsequent losses arising from quadratic price-adjustment costs. Therefore, while monetary policy should react to the persistent rise in PPI inflation induced by intermediate input tariffs, it can instead fully look through the temporary fluctuations in CPI inflation induced by final good tariffs, that leave PPI inflation unaffected. This simple insight will be further corroborated in the quantitative application of the full model in Section 4.

3 The Full Model

The basic structure of the full model is akin to Bouakez et al. (2023) and Hinterlang et al. (2023). We focus on a two-region specification — capturing a domestic economy and the rest of the world — enriched by including wage and price stickiness in domestic currency, investment adjustment costs, and cross-border tariff shocks. Each economy comprises S sectors, interconnected through input-output linkages both within and between regions. The two regions, $i \in \{h, f\}$, have relative size ω_h and $\omega_f = 1 - \omega_h$, and engage in international trade in intermediate, investment and final goods. We also allow the representative household in each region to invest in an internationally-traded asset. The model will be used to analyse the effects of tariff shocks, modelled as cross-border taxes on imports in each region.

3.1 Household

A representative household in each region i chooses aggregate consumption, $C_{i,t}$, labour supply, $N_{i,t}$, a basket of investment goods, $I_{i,t}$, and holdings of domestic bonds, $B_{i,t}$, as well as internationally-traded assets, $A_{ij,t}$, which are potentially denominated in the other region's currency. Expected lifetime utility is

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{(C_{i,t} - \gamma\, C_{i,t-1})^{1-\sigma}}{1-\sigma} - \chi_i \, \frac{N_{i,t}^{1+\varphi}}{1+\varphi} \right], \tag{50}$$

where $\beta \in (0,1)$ is the discount factor, σ is the inverse elasticity of intertemporal substitution, $\gamma \geq 0$ captures habit persistence in consumption, φ is the inverse Frisch elasticity of labour supply, and χ_i captures the region-specific relative disutility of labour and consumption. The household budget constraint, with nominal prices and quantities denominated in domestic currency, is

$$P^C_{i,t}\, C_{i,t} + P^I_{i,t}\, I_{i,t} + B_{i,t} + A_{ij,t}\, \mathcal{E}_{i,t} + \frac{\zeta}{2}\left(\frac{A_{ij,t}\, \mathcal{E}_{i,t}}{P^C_{i,t}} - \frac{A_{ij}\, \mathcal{E}_i}{P^C_i}\right)^2 P^C_{i,t}$$
$$\leq W^c_{i,t}\, N_{i,t} + R^K_{i,t}\, K_{i,t-1} + R_{i,t-1}\, B_{i,t-1} + R^a_{t-1}\, A_{ij,t-1}\, \mathcal{E}_{i,t} + TR_{i,t} + D_{i,t} \quad (51)$$

where $P^C_{i,t}$ denotes the consumer price index (CPI), $P^I_{i,t}$ is the price of the investment goods basket, $W^c_{i,t}$ is the wage earned by the household, $R^K_{i,t}$ denotes the nominal rental rate of capital, and $R_{i,t-1}$ is the gross nominal return on domestic bonds. The accumulation of physical capital, $K_{i,t}$, is subject to convex adjustment costs

$$K_{i,t} = (1-\delta)\, K_{i,t-1} + I_{i,t}\left[1 - \frac{\xi}{2}\left(\frac{I_{i,t}}{I_{i,t-1}} - 1\right)^2\right], \quad (52)$$

where $\delta \in (0,1)$ is the depreciation rate and $\xi \geq 0$ governs the magnitude of the adjustment costs. Internationally-traded assets pay a return $R^a_{i,t-1}$ between $t-1$ and t, and are subject to quadratic portfolio adjustment costs, whose magnitude is governed by $\zeta > 0$.[3] $\mathcal{E}_{i,t}$ denotes the bilateral exchange rate between i and j, with $\mathcal{E}_{i,t} = 1/\mathcal{E}_{j,t}$ and a higher value of $\mathcal{E}_{i,t}$ corresponding to a depreciation of i's currency. We assume, without loss of generality, that the internationally-traded asset is denominated in f's currency.[4] Finally, $TR_{i,t}$ and $D_{i,t}$ denote, respectively, net lump-sum transfers from the government and dividends collected from producers.

Household optimal decisions give the following first-order conditions regarding labour supply,

$$\chi_i\, N^{\varphi}_{i,t} = \mu_{i,t}\, \frac{W_{i,t}}{P^C_{i,t}}\,, \quad (53)$$

investment and capital accumulation choices

$$\frac{P^I_{i,t}}{P^C_{i,t}} = q_{i,t}\left[1 - \frac{\xi}{2}\left(\frac{I_{i,t}}{I_{i,t-1}} - 1\right)\left(3\,\frac{I_{i,t}}{I_{i,t-1}} - 1\right)\right] + \xi\,\beta\,\mathbb{E}\left[\frac{\mu_{i,t+1}}{\mu_{i,t}}\, q_{i,t+1}\left(\frac{I_{i,t}}{I_{i,t-1}} - 1\right)\left(\frac{I_{i,t}}{I_{i,t-1}}\right)^2\right], \quad (54)$$

$$q_{i,t} = \beta\,\mathbb{E}_t\left\{\frac{\mu_{i,t+1}}{\mu_{i,t}}\left[\frac{R^K_{i,t}}{P^C_{i,t}} + (1-\delta)\, q_{i,t+1}\right]\right\}, \quad (55)$$

[3] These adjustment costs are typically calibrated to a small amount and are introduced to pin down the international asset position following transitory shocks (see Schmitt-Grohé and Uribe, 2003).

[4] In other words, in the budget constraint in (51), when $i = h$ and $j = f$, $A_{ij,t}\,\mathcal{E}_{i,t} = A_{hf,t}\,\mathcal{E}_{h,t}$, while $A_{ij,t}\,\mathcal{E}_{i,t}$ is replaced by $A_{fh,t}$ when $i = f$ and $j = h$.

and domestic bond and foreign asset holdings

$$1 = \beta\, \mathbb{E}_t \left[\frac{\mu_{i,t+1}}{\mu_{i,t}} \frac{R_{i,t}}{\Pi^{CPI}_{i,t+1}} \right], \tag{56}$$

$$1 = \beta\, \mathbb{E}_t \left\{ \frac{\mu_{i,t+1}}{\mu_{i,t}} \frac{\mathcal{E}_{i,t+1}}{\mathcal{E}_{i,t}} \frac{R^a_t}{\Pi^{CPI}_{i,t+1} \left[1 + \zeta\,(a_{ij,t} - a_{ij})\right]} \right\}, \tag{57}$$

where $\mu_{i,t} = (C_{i,t} - \gamma\, C_{i,t-1})^{-\sigma} - \gamma\, \beta\, \mathbb{E}_t[(C_{i,t+1} - \gamma\, C_{i,t})^{-\sigma}]$ is the marginal utility of current consumption, $q_{i,t}$ is the marginal value of capital, and $\Pi^{CPI}_{i,t} = P^C_{i,t}/P^C_{i,t-1}$ denotes the gross CPI inflation rate in region i. Given the presence of portfolio adjustment costs, the return on internationally-traded assets includes a risk premium, $[1 + \zeta\,(a_{ij,t} - a_{ij})]^{-1}$, where $a_{ij,t} := A_{ij,t}\, \mathcal{E}_i / P^C_{i,t}$.

The total amount of labour supplied by the household in each region i is a constant-elasticity-of-substitution (CES) aggregator of the labour supplied to each sector, $N_{i,s,t}$:

$$N_{i,t} = \left(\sum_{s=1}^{S} \omega_{N,i,s}^{-1/\nu_N}\, {N_{i,s,t}}^{1+1/\nu_N} \right)^{\frac{\nu_N}{1+\nu_N}}, \tag{58}$$

where $\omega_{N,i,s}$ is the weight attached to sector s in region i, and $\nu_N > 0$ denotes the elasticity of substitution of labour supply across domestic sectors. In other words, labour is assumed to be (imperfectly) mobile domestically across sectors, but not across regions. Given the CES structure, sectoral labor supply is given by

$$N_{i,s,t} = \omega_{N,i,s} \left(\frac{W^c_{i,s,t}}{W^c_{i,t}} \right)^{\nu_N} N_{i,t} \tag{59}$$

where

$$W^c_{i,t} = \left[\sum_{s=1}^{S} \omega_{N,i,s}\, {W^c_{i,s,t}}^{(1+\nu_N)} \right]^{\frac{1}{1+\nu_N}} \tag{60}$$

and $W^c_{i,s,t}$ is the wage earned in sector s.

Similarly, aggregate capital supplied by the household bundles sectoral capital services, $K_{i,s,t}$, by means of the following CES aggregator

$$K_{i,t} = \left(\sum_{s=1}^{S} \omega_{K,i,s}^{-1/\nu_K}\, {K_{i,s,t}}^{1+1/\nu_K} \right)^{\frac{\nu_K}{1+\nu_K}}, \tag{61}$$

where $\omega_{K,i,s}$ denotes the weight attached to capital supplied to sector s in region i, and $\nu_K > 0$ is the elasticity of substitution of capital supply across domestic sectors. Sectoral capital supply is given by

$$K_{i,s,t} = \omega_{K,i,s} \left(\frac{R^K_{i,s,t}}{R^K_{i,t}} \right)^{\nu_K} K_{i,t} \tag{62}$$

where

$$R^k_{i,t} = \left[\sum_{s=1}^{S} \omega_{K,i,s} \, R^K_{i,s,t}{}^{(1+\nu_K)} \right]^{\frac{1}{1+\nu_K}} \tag{63}$$

and $R^K_{i,s,t}$ is the rental rate of capital in sector s.

3.2 Labour Unions

We introduce nominal wage rigidity following Devereux et al. (2023). We posit that there are monopolistically competitive labour unions operating in each different sector and region. These unions transform homogeneous labour services from the household into different varieties $L_{i,s,t}(l)$, which are then converted into a final labour composite $L_{i,s,t}$ that is sold to sectoral producers. The labour aggregators have the following CES structure

$$L_{i,s,t} = \left(\int_0^1 L_{i,s,t}(l)^{1-1/\varepsilon^w_{i,s}} \, dl \right)^{\frac{\varepsilon^w_{i,s}}{\varepsilon^w_{i,s}-1}}, \tag{64}$$

where $\varepsilon^w_{i,s}$ is the elasticity of substitution among different labour services within each region and sector. Cost minimisation yields the following demand curves for each variety

$$L_{i,s,t}\,(l) = \left(\frac{W_{i,s,t}(l)}{W_{i,s,t}} \right)^{-\varepsilon^w_{i,s}} L_{i,s,t} \tag{65}$$

where the nominal wage paid by producers in each sector is given by

$$W_{i,s,t} = \left(\int_0^1 W_{i,s,t}(l)^{1-\varepsilon^w_{i,s}} \, dl \right)^{\frac{1}{1-\varepsilon^w_{i,s}}}. \tag{66}$$

The unions set the wages for the varieties of labour services, $W_{i,s,t}\,(l)$, subject to (65) and facing quadratic adjustment costs à la Rotemberg. Unions' period profits are

$$D^w_{i,t}(l) = [W_{i,s,t}(l) - W^c_{i,s,t}]\, L_{i,s,t}\,(l) - \frac{\psi^w_{i,s}}{2} \left(\frac{W_{i,s,t}(l)}{W_{i,s,t-1}(l)} - 1 \right)^2 W_{i,s,t} \tag{67}$$

where $\psi^w_{i,s}$ governs the size of wage adjustment costs. Union l operating in sector s of region i solves

$$\max_{\{W_{i,s,t}(l),L_{i,s,t}(l)\}} \mathbb{E}_t \sum_{v=t}^{\infty} \beta^v \frac{P^C_{i,t}}{P^C_{i,v}} D^w_{i,v}(l) \tag{68}$$

subject to (65). Given symmetry, the optimality condition for the union problem gives

$$\Pi^w_{i,s,t}\left(\Pi^w_{i,s,t}-1\right) = \frac{\varepsilon^w_{i,s}}{\psi^w_{i,s}} \left(\frac{W^c_{i,s,t}}{W_{i,s,t}} - \frac{1}{\mathcal{M}^w_{i,s}}\right) L_{i,s,t} + \beta\,\mathbb{E}_t \left[\Pi^w_{i,s,t+1}\left(\Pi^w_{i,s,t+1}-1\right)\frac{\Pi^w_{i,s,t+1}}{\Pi^{CPI}_{i,t+1}}\right] \tag{69}$$

where $\mathcal{M}^w_{i,s} = \varepsilon^w_{i,s}/(1-\varepsilon^w_{i,s})$ is the steady-state wage markup, and $\Pi^w_{i,s,t} = W_{i,s,t}/W_{i,s,t-1}$ denotes gross sectoral wage inflation.

3.3 Firms

3.3.1 Domestic Retailers

In each region i, a perfectly competitive representative retailer purchases sectoral consumption goods $C_{i,s,t}$ from sectoral retailers, which are then bundled into final consumption, $C_{i,t}$, using the following CES technology

$$C_{i,t} = \left[\sum_{s=1}^{S} \omega_{C,i,s}^{1/\sigma_c} C_{i,s,t}^{1-1/\sigma_c}\right]^{\frac{\sigma_c}{\sigma_c-1}} \tag{70}$$

where $\omega_{C,i,s}$ is the weight of sector s in the consumption bundle in region i, and σ_c denotes the elasticity of substitution of consumption across sectors. Given the CES structure, the demand schedules for sectoral consumption goods are

$$C_{i,s,t} = \omega_{C,i,s}\left(\frac{P^C_{i,s,t}}{P^C_{i,t}}\right)^{-\sigma_c} C_{i,t} \tag{71}$$

where

$$P^C_{i,t} = \left[\sum_{s=1}^{S} \omega_{C,i,s} P^C_{i,s,t}{}^{(1-\sigma_c)}\right]^{\frac{1}{1-\sigma_c}} \tag{72}$$

and $P^C_{i,s,t}$ is the sectoral price of consumption goods.

Similarly, a perfectly competitive representative retailer assembles the final investment good according to the following CES technology

$$I_{i,t} = \left[\sum_{s=1}^{S} \omega_{I,i,s}^{1/\sigma_I} \, I_{i,s,t}^{1-1/\sigma_I} \right]^{\frac{\sigma_I}{\sigma_I - 1}} \tag{73}$$

where $I_{i,s,t}$ denotes sectoral demand for investment goods, $\omega_{I,i,s}$ is the weight attached to each sector s in the investment bundle in region i, and σ_I denotes the elasticity of substitution of investment across domestic sectors. The demand schedules for sectoral investment goods are

$$I_{i,s,t} = \omega_{I,i,s} \left(\frac{P^I_{i,s,t}}{P^I_{i,t}} \right)^{-\sigma_I} I_{i,t} \tag{74}$$

where

$$P^I_{i,t} = \left[\sum_{s=1}^{S} \omega_{I,i,s} \, {P^I_{i,s,t}}^{(1-\sigma_I)} \right]^{\frac{1}{(1-\sigma_I)}} \tag{75}$$

and $P^I_{i,s,t}$ is the price of sectoral investment goods.

Finally, in each sector s of region i, there is a perfectly competitive retailer that aggregates sectoral intermediate inputs $M_{i,s,x,t}$ into an intermediate-input bundle $M_{i,s,t}$ using the following CES technology

$$M_{i,s,t} = \left[\sum_{x=1}^{S} \omega_{M,i,s,x}^{1/\sigma_M} \, M_{i,s,x,t}^{1-1/\sigma_M} \right]^{\frac{\sigma_M}{\sigma_M - 1}}$$

where $M_{i,s,x,t}$ denotes the amount of intermediate goods purchased from sector x, whose weight in the overall bundle is governed by $\omega_{M,i,s,x}$; σ_M is the elasticity of substitution of intermediate inputs across sectors within each region. The demand schedules for sectoral intermediate goods are

$$M_{i,s,x,t} = \omega_{M,i,s,x} \left(\frac{P^M_{i,s,x,t}}{P^M_{i,s,t}} \right)^{-\sigma_M} M_{i,s,t} \, , \tag{76}$$

where

$$P^M_{i,s,t} = \left[\sum_{x=1}^{S} \omega_{M,i,s,x} \, {P^M_{i,s,x,t}}^{(1-\sigma_M)} \right]^{\frac{1}{(1-\sigma_M)}} \tag{77}$$

and $P_{i,s,x,t}$ is the price paid by producers in sector s to purchase intermediate goods from producers in sector x.

Importantly, sectoral consumption, investment and intermediate good prices and quantities will be influenced by domestic as well as by foreign dynamics. These mechanisms, which play a pivotal role in our framework, are now discussed in detail.

3.3.2 International Retailers

The two regions are interconnected also through trade in goods. Specifically, we assume that in each sector s and region i, competitive international retailers bundle consumption, investment and intermediate goods combining domestic and foreign goods. We introduce tariffs as exogenous cross-border taxes on imports, assumed to be rebated to households in a lump-sum manner through transfers T_t. Moreover, we differentiate between tariffs on consumption and intermediate goods.

The CES bundle for a perfectly competitive international consumption goods retailer operating in sector s of region i is

$$C_{i,s,t} = \left[\eta_{C,i,s}^{1/\lambda_{C,i,s}} \, C_{ii,s,t}^{1-1/\lambda_{C,i,s}} + (1-\eta_{C,i,s})^{1/\lambda_{C,i,s}} \, C_{ij,s,t}^{1-1/\lambda_{C,i,s}}\right]^{\frac{\lambda_{C,i,s}}{\lambda_{C,i,s}-1}} , \tag{78}$$

where $C_{ii,s,t}$ denotes consumption goods produced domestically; $C_{ij,s,t}$ denotes consumption goods produced abroad, in region $j \neq i$; $\eta_{C,i,s}$ is the sectoral preference bias of region i towards goods produced domestically, which pins down the share of imports of consumption goods, and $\lambda_{C,i,s}$ is the elasticity of substitution between domestic and foreign consumption goods. The demand schedules for domestic and foreign consumption goods in region i are

$$C_{ii,s,t} = \eta_{C,i,s} \left(\frac{P_{i,s,t}}{P_{i,s,t}^C}\right)^{-\lambda_{C,i,s}} C_{i,s,t} \, , \tag{79}$$

$$C_{ij,s,t} = (1-\eta_{C,i,s}) \left[\frac{(1+\tau_{C,i,s,t}) \, P_{j,s,t} \, \mathcal{E}_{i,t}}{P_{i,s,t}^C}\right]^{-\lambda_{C,i,s}} C_{i,s,t} \, , \tag{80}$$

where

$$P_{i,s,t}^C = \left\{\eta_{C,i,s} \, P_{i,s,t}^{1-\lambda_{C,i,s}} + (1-\eta_{C,i,s}) \, \left[(1+\tau_{C,i,s,t}) \, P_{j,s,t} \, \mathcal{E}_{i,t}\right]^{1-\lambda_{C,i,s}}\right\}^{\frac{1}{1-\lambda_{C,i,s}}} , \tag{81}$$

$P_{i,s,t}$ is the producer price of region i, $P_{j,s,t}$ is the producer price of region j, converted in domestic currency through the nominal exchange rate $\mathcal{E}_{i,t}$, and $\tau_{C,i,s,t}$ is a tariff on consumption goods of sector s imported from region j. These tariffs are assumed to follow an exogenous AR(1) process.

Similarly, the CES bundle for investment goods of sector s in region i is

$$I_{i,s,t} = \left[\eta_{I,i,s}^{1/\lambda_{I,i,s}} \, I_{ii,s,t}^{1-1/\lambda_{I,i,s}} + (1-\eta_{I,i,s})^{1/\lambda_{I,i,s}} \, I_{ij,s,t}^{1-1/\lambda_{I,i,s}}\right]^{\frac{\lambda_{I,i,s}}{\lambda_{I,i,s}-1}} , \tag{82}$$

where $I_{ii,s,t}$ denotes investment goods produced domestically; $I_{ij,s,t}$ denotes investment goods produced abroad, in region $j \neq i$; $\eta_{I,i,s}$ is the home bias of region i for investment goods of sector s, and $\lambda_{I,i,s}$ is the elasticity of substitution between domestic and foreign investment goods. The demand schedules for domestic and foreign investment goods in region i are

$$I_{ii,s,t} = \eta_{I,i,s} \left(\frac{P_{i,s,t}}{P^{I}_{i,s,t}}\right)^{-\lambda_{I,i,s}} I_{i,s,t} \, , \tag{83}$$

$$I_{ij,s,t} = (1-\eta_{I,i,s}) \left(\frac{P_{j,s,t}\,\mathcal{E}_{i,t}}{P^{I}_{i,s,t}}\right)^{-\lambda_{I,i,s}} I_{i,s,t} \, , \tag{84}$$

where

$$P^{I}_{i,s,t} = \left\{\eta_{I,i,s}\, P_{i,s,t}^{1-\lambda_{I,i,s}} + (1-\eta_{I,i,s})\, (P_{j,s,t}\,\mathcal{E}_{i,t})^{1-\lambda_{I,i,s}}\right\}^{\frac{1}{1-\lambda_{I,i,s}}} . \tag{85}$$

Lastly, the CES aggregator bundling domestic and foreign intermediate goods used by sector s and sourced from sector x is

$$M_{i,s,x,t} = \left[\eta_{M,i,s,x}^{1/\lambda_{M,i,s}} \, M_{ii,s,x,t}^{1-1/\lambda_{M,i,s}} + (1-\eta_{M,i,s,x})^{1/\lambda_{M,i,s}} \, M_{ij,s,x,t}^{1-1/\lambda_{M,i,s}}\right]^{\frac{\lambda_{M,i,s}}{\lambda_{M,i,s}-1}} \tag{86}$$

where $M_{ii,s,x,t}$ denotes intermediate goods used in sector s of region i and produced in sector x of region i; $M_{ij,s,x,t}$ denotes intermediate goods used in sector s of region i and produced in sector x of region $j \neq i$; $\eta_{M,i,s,x}$ is the home bias of region i for intermediate inputs, and $\lambda_{M,i,s,x}$ is the elasticity of substitution between domestic and foreign intermediate goods. The demand schedules for domestic and foreign intermediate goods in region i are

$$M_{ii,s,x,t} = \eta_{M,i,s,x} \left(\frac{P_{i,x,t}}{P^{M}_{i,s,x,t}}\right)^{-\lambda_{M,i,s}} M_{i,s,x,t} \, , \tag{87}$$

$$M_{ij,s,x,t} = (1-\eta_{M,i,s,x}) \left[\frac{(1+\tau_{M,i,x,t})\; P_{j,x,t}\,\mathcal{E}_{i,t}}{P^{M}_{i,s,x,t}}\right]^{-\lambda_{M,i,s,x}} M_{i,s,x,t} \, , \tag{88}$$

where

$$P^M_{i,s,x,t} = \left\{\eta_{M,i,s,x}\, P_{i,x,t}^{1-\lambda_{M,i,s,x}} + (1-\eta_{M,i,s,x})\left[(1+\tau_{M,i,x,t})\; P_{j,x,t}\,\mathcal{E}_{i,t}\right]^{1-\lambda_{M,i,s,x}}\right\}^{\frac{1}{1-\lambda_{M,i,s,x}}} \tag{89}$$

and imports of intermediate goods of region i are subject to sector-specific, exogenous tariff shocks $\tau_{M,i,x,t}$.

3.3.3 Producers

In each sector s in region i, there is a continuum of monopolistically competitive firms producing differentiated varieties indexed by $z \in [0,1]$. These varieties are aggregated into a single sectoral good with the following CES technology:

$$y_{i,s,t} = \left[\int_0^1 y_{i,s,t}\,(z)^{1-1/\varepsilon^P_{i,s}}\right]^{\frac{\varepsilon^P_{i,s}}{\varepsilon^P_{i,s}-1}} \tag{90}$$

where $\varepsilon^P_{i,s} > 1$ represents the elasticity of substitution across varieties within each sector in region i. The implied demand curve for each variety is

$$y_{i,s,t}\,(z) = \left(\frac{P_{i,s,t}\,(z)}{P_{i,s,t}}\right)^{-\varepsilon^P_{i,s}} y_{i,s,t} \tag{91}$$

where $P_{i,s,t} = \left[P_{i,s,t}(z)^{1-\varepsilon^P_{i,s}} dz\right]^{\frac{1}{1-\varepsilon^P_{i,s}}}$ and $P_{i,s,t}\,(z)$ denotes the price of variety z.

Each variety z is supplied by a single monopolistic producer using the following technology

$$y_{i,s,t}\,(z) = \left[K_{i,s,t-1}\,(z)^{1-\alpha_{L,i,s}}\; L_{i,s,t}\,(z)^{\alpha_{L,i,s}}\right]^{\alpha_{M,i,s}}\; M_{i,s,t}\,(z)^{1-\alpha_{M,i,s}}\;. \tag{92}$$

Cost minimization gives the following input demands

$$K_{i,s,t-1}(z) = \alpha_{M,i,s}\,(1-\alpha_{L,i,s})\,\frac{MC_{i,s,t}}{R^K_{i,s,t}}\,y_{i,s,t}\,(z)\;, \tag{93}$$

$$L_{i,s,t}(z) = \alpha_{M,i,s}\,\alpha_{L,i,s}\,\frac{MC_{i,s,t}}{W_{i,s,t}}\,y_{i,s,t}\,(z)\;, \tag{94}$$

$$M_{i,s,t}(z) = (1-\alpha_{M,i,s})\,\frac{MC_{i,s,t}}{P^M_{i,s,t}}\,y_{i,s,t}\,(z)\;, \tag{95}$$

where

$$MC_{i,s,t} = \left[\left(\frac{1}{\alpha_{M,i,s}} \right) \left(\frac{R^K_{i,s,t}}{1-\alpha_{L,i,s}} \right)^{1-\alpha_{L,i,s}} \left(\frac{W_{i,s,t}}{\alpha_{L,i,s}} \right)^{\alpha_{L,i,s}} \right]^{\alpha_{M,i,s}} \left(\frac{P^M_{i,s,t}}{1-\alpha_{M,i,s}} \right)^{1-\alpha_{M,i,s}} \tag{96}$$

is the nominal marginal cost.

Producers set nominal prices $P_{i,s,t}(z)$ in domestic currency, subject to quadratic adjustment costs à la Rotemberg. Period-t profits are

$$D_{i,t}(z) = P_{i,s,t}(z)\, y_{i,s,t}(z) - MC_{i,s,t}\, y_{i,s,t}(z) - \frac{\psi^P_{i,s}}{2} \left(\frac{P_{i,s,t}(z)}{P_{i,s,t-1}(z)} - 1 \right)^2 P_{i,s,t}\, y_{i,s,t}, \tag{97}$$

where $\psi^P_{i,s}$ is the sector- and region-specific parameter governing the size of price adjustment costs. Producers choose $P_{i,s,t}(z)$ and $y_{i,s,t}(z)$ to maximise their expected discounted stream of profits,

$$\max_{\{P_{i,s,t}(z), y_{i,s,t}(z)\}} \mathbb{E}_t \sum_{v=t}^{\infty} \beta^v \frac{\mu_{i,v}}{\mu_{i,t}} \frac{P^C_{i,t}}{P^C_{i,v}} D_{i,v}(z) \tag{98}$$

subject to (91). Given symmetry, the solution to the price-setting problem gives the following region- and sector-specific New Keynesian Phillips curve:

$$\left(\Pi^{PPI}_{i,s,t} - 1\right) \Pi^{PPI}_{i,s,t} = \frac{\varepsilon^P_{i,s}}{\psi^P_{i,s}} \left(\frac{MC_{i,s,t}}{P_{i,s,t}} - \frac{1}{\mathcal{M}^P_{i,s}} \right) + \beta\, \mathbb{E}_t \left[\frac{\mu_{i,t+1}}{\mu_{i,t}} \left(\Pi^{PPI}_{i,s,t+1} - 1\right) \frac{\left(\Pi^{PPI}_{i,s,t+1}\right)^2}{\Pi^{CPI}_{i,t+1}} \frac{y_{i,s,t+1}}{y_{i,s,t}} \right] \tag{99}$$

where $\mathcal{M}^P_{i,s} = \varepsilon^P_{i,s}/(\varepsilon^P_{i,s} - 1)$ is the steady-state price markup, and $\Pi^{PPI}_{i,s,t} = P_{i,s,t}/P_{i,s,t-1}$ denotes the gross PPI inflation rate in sector s of region i.

3.4 Monetary Policy

Monetary policy is assumed to follow a Taylor rule of the form

$$\frac{R_{i,t}}{R_i} = \left(\frac{R_{i,t-1}}{R_i} \right)^{\rho_R} \left[\left(\frac{\Pi_{i,t}}{\Pi_i} \right)^{\phi_\pi} \left(\frac{Y^{VA}_{i,t}}{Y^{VA}_i} \right)^{\phi_y} \right]^{1-\rho_R} \tag{100}$$

where $\rho_R \in [0, 1)$ is a smoothing parameter, Π_i is the target inflation rate in region i, and the parameters ϕ_π and ϕ_y capture the responsiveness of the nominal interest rate to deviations of inflation and GDP from their steady-state values.

3.5 Market clearing

Market clearing in the labour market requires, for each sector and region,

$$N_{i,s,t} = L_{i,s,t} \tag{101}$$

Goods' market clearing requires

$$P_{i,s,t}\, y_{i,s,t} = P^C_{i,s,t}\, C_{i,s,t} + P^I_{i,s,t}\, I_{i,s,t} + \sum_{x=1}^{S} P^M_{i,x,s,t}\, M_{i,x,s,t} + TB_{i,s,t} + \frac{\psi^P_{i,s}}{2}\left(\Pi^{PPI}_{i,s,t} - 1\right)^2 P_{i,s,t}\, y_{i,s,t} \tag{102}$$

where sectoral trade balances are defined as

$$TB_{i,s,t} = \frac{P_{i,s,t}}{\omega_i}\,\omega_j \left(C_{ji,s,t} + I_{ji,s,t} + \sum_{x=1}^{S} M_{ji,s,x,t}\right) - P_{j,s,t}\,\mathcal{E}_{i,t}\left(C_{ij,s,t} + I_{ij,s,t} + \sum_{x=1}^{S} M_{ij,s,x,t}\right). \tag{103}$$

The aggregate trade balance of region i is, then, given by $TB_{i,t} = \sum_{s=1}^{S} TB_{i,s,t}$.

At the aggregate level,

$$Y^{VA}_{i,t} = C_{i,t} + \frac{P^I_{i,t}}{P^C_{i,t}}\, I_{i,t} + \frac{TB_{i,t}}{P^C_{i,t}}\,. \tag{104}$$

Both domestic and internationally-traded assets are in zero net supply. Therefore,

$$B_{i,t} = 0 \tag{105}$$

and, since the internationally-traded asset is denominated in f's currency,

$$\omega_h\, A_{hf,t} + \omega_f\, A_{fh,t} = 0\,. \tag{106}$$

Furthermore, the equilibrium and market clearing conditions imply that the evolution of internationally-traded assets obeys

$$A_{fh,t} = R^a_{t-1}\, A_{fh,t-1} + TB_{f,t}. \tag{107}$$

4 Quantitative Analysis

4.1 Calibration

We calibrate the model at quarterly frequency and to two regions, the EU and the rest of the world. The relative size of the two regions is set according to the share of the EU in global GDP at purchasing power parity, i.e. $\omega_{EU} = 0.15$ and $\omega_{RoW} = 1 - \omega_{EU}$.

We first discuss aggregate parameters, that are common across the two regions, to then turn to choices regarding sector-specific parametrizations. The calibration is summarized in Table 1.

Aggregate Economy. The discount factor β is set to 0.998, reflecting a 1% annual interest rate, while the inverse intertemporal elasticity of substitution is set to $\sigma = 1$, in line with Coenen et al. (2013). Also in line with the latter study, habit persistence is set to $\gamma = 0.6$, and the Frisch elasticity of labor supply to 0.5 (hence, $\varphi = 2$). The capital depreciation rate is targeted to be 10% per year (i.e., $\delta = 0.025$), and the investment adjustment cost parameter is set to $\xi = 5$.

Sector-Specific Parameters. We consider 10 sectors, specified along the NACE Rev. 2 classification: agriculture (A); mining and quarrying (B); manufacturing (C); electricity and gas (D); water supply and waste management (E); construction (F); wholesale and retail trade, transportation, accommodation and food services (G-I); information and communication (J); professional, scientific, technical, administration and support services (M-N); other services (R-S).

A first dimension across which we allow for sectoral heterogeneity entails the elasticity of substitution across varieties, $\varepsilon^P_{i,s}$, which is calibrated to target the implied steady-state sectoral price markups. In line with evidence from Christopoulou and Vermeulen (2012) for the euro area, markups range between 18% in manufacturing and 86% in information and communication services. The elasticity of substitution among differentiated labour services, ε^w, is taken to be common across sectors and reflecting an implied steady-state wage markdown of 30% (Coenen et al., 2013). As for price stickiness, we calibrate $\psi^P_{i,s}$ to reflect the frequency of price adjustment that would be implied in a Calvo model, matching the evidence reported in Dhyne et al. (2006) and Gautier et al. (2024).[5] The resulting $\psi^P_{i,s}$'s range between 0.05 for energy (sector D) and 136 for sector E in the EU. As for wage stickiness, we set ψ^w to 75, in line with Born and Pfeifer (2020).

[5]This amounts to setting $\psi^P_{i,s} = (\varepsilon^P_{i,s} - 1)\,\frac{\theta^P_{i,s}}{(1-\theta^P_{i,s})\,(1-\beta\,\theta^P_{i,s})}$, where $\theta^P_{i,s}$ is the fraction of unadjusted prices in a quarter.

Table 1: Calibration.

Parameter	Description	Value	Target/Source
A. Aggregate economy			
$\omega_{EU}, \omega_{RoW}$	Relative size	0.15, 0.85	Share of global GDP at PPP
β	Discount factor	0.998	1% annual interest rate
σ	Inverse EIS	1	Coenen et al. (2013)
φ	Inverse Frisch elasticity	2	Coenen et al. (2013)
δ	Depreciation rate of capital	0.025	10% per year
ξ	Investment adjustment costs	5	Coenen et al. (2013)
γ	Habit persistence	0.6	Coenen et al. (2013)
ζ	Portfolio adjustment costs	0.001	Schmitt-Grohé and Uribe (2003)
B. Sector-specific parameters			
$\mathcal{M}^P_{i,s}$	Price markups	$1.18 - 1.86$	Christopoulou and Vermeulen (2012)
$\mathcal{M}^w$	Wage markdown	1.3	Coenen et al. (2013)
$\psi^P_{i,s}$	Price adjustment costs	$0.05 - 136$	Dhyne et al. (2006); Gautier et al. (2024)
ψ^w	Wage adjustment costs	75	Born and Pfeifer (2020)
C. Elasticites of substitution			
σ_C	Across sectoral consumption	2	Bouakez et al. (2023)
σ_I	Across sectoral investment	2	Bouakez et al. (2023)
σ_M	Across sectoral inputs	0.1	Bouakez et al. (2023)
ν_N	Across sectoral labour supply	1	Bouakez et al. (2023)
ν_K	Across sectoral capital supply	1	Bouakez et al. (2023)
λ_C	Between foreign and domestic consumption	3	Bajzik et al. (2020)
λ_M	Between foreign and domestic inputs	0.1	Boehm et al. (2019)
D. Input-Output linkages			
$\alpha_{M,i,s}, \alpha_{L,i,s}$	Factor intensities		WIOD socio-economic accounts
$\omega_{N,i,s}, \omega_{K,i,s}$	Sectoral labour and capital weights		WIOD socio-economic accounts
$\omega_{C,i,s}, \omega_{I,i,s}$	Sectoral consumption and investment weights		WIOD national accounts
$\omega_{M,i,s,x}$	Sectoral intermediate input weights		WIOD Input-Output tables
$\eta_{C,i,s}, \eta_{I,i,s}$	Home bias in consumption and investment		WIOD Input-Output tables
$\eta_{M,i,j,s,x}$	Home bias in intermediate input use		WIOD Input-Output tables
E. Monetary Policy			
ρ_R	Inertia in the Taylor rule	0.85	Coenen et al. (2013)
ϕ_π	Weight on CPI inflation in Taylor rule	1.9	Coenen et al. (2013)
ϕ_y	Weight on GDP in the Taylor rule	0.1	Christiano et al. (2005)

A second set of parameters pertains to input-output linkages. We rely on the calibration toolkit provided by Hinterlang et al. (2023) and compute intermediate use coefficients, factor intensities, sectoral contributions to final demand and home bias parameters from WIOD input-output tables. Sectoral weights for consumption ($\omega_{C,i,s}$) and investment ($\omega_{I,i,s}$) are computed from WIOD national accounts data, while sectoral weights for the capital stock ($\omega_{K,i,s}$) and employment ($\omega_{N,i,s}$) are based on WIOD socioeconomic accounts data. The same data allows to impute factor intensities, $\alpha_{M,i,s}$ and $\alpha_{N,i,s}$, and the weight of each sector in the input-output network (reflected in the $\omega_{M,i,s,x}$ weights). Factor intensities of intermediate inputs are computed by dividing the values of intermediate inputs by gross output per industry. Similarly, the factor intensities of labour are computed using the share of labour compensation in gross output per industry. The home bias parameters, $\eta_{C,i,s}$, $\eta_{I,i,s}$, $\eta_{M,i,s,x}$, are also imputed in a similar way from WIOD input-output tables.

Following Bouakez et al. (2023), we set the elasticities of substitution across sectoral consumption and investment (σ_c and σ_I) to 2, and the elasticity of substitution across sectoral inputs to $\sigma_M = 0.1$. The latter choice implies strong complementarity of intermediate inputs across industries, as is standard in the literature and consistent with the estimates of Atalay (2017) and Miranda-Pinto (2021). As in Bouakez et al. (2023), the elasticities of substitution of labour and capital supply, ν_N and ν_K, are both set to 1.

Armington Elasticities. Crucial parameter choices regard the elasticities of substitution between domestic and foreign goods, also known as Armington elasticities.[6] We set the elasticity of substitution between domestic and foreign final goods to 3, consistent with the median value reported in the meta-analysis by Bajzik et al. (2020) based on the approach of Feenstra et al. (2018).[7] In counterfactual simulations, we instead use a value at the lower bound of the 95% confidence intervals reported in the same study and set the Armington elasticity for final goods to 1.8.

As for the investment basket, empirical evidence on the Armington elasticity is limited. Therefore, we set it to 0.75, as the cross-sector elasticity of substitution of investment within each region.

[6]The elasticity of substitution between domestic and foreign goods is commonly called the Armington elasticity in honor of Armington (1969), who first formulated a theoretical model featuring goods distinguished by their place of origin.

[7]Structural models that focus on the long run, such Caliendo and Parro (2015), typically assume higher values (around 5).

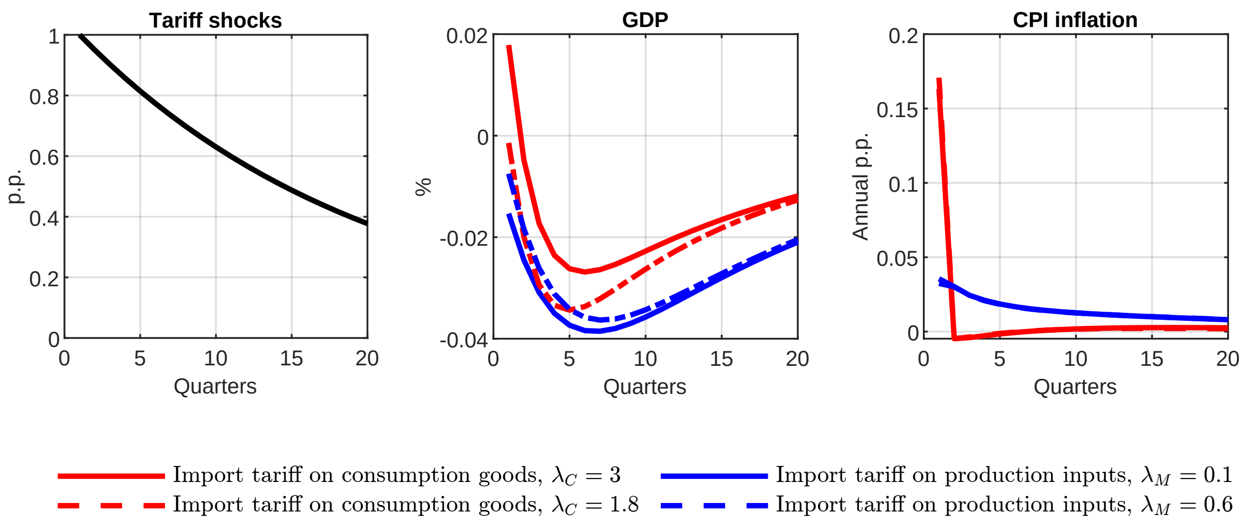

Figure 3: Impact of import tariffs in the full model. *Note:* $\lambda_C = 3$ and $\lambda_M = 0.1$, unless otherwise noted.

In contrast, we assume a very low elasticity of substitution between domestic and foreign intermediate inputs, equal to 0.1, consistent with the short-run focus of the model. This parameter choice is in line with estimates of Boehm et al. (2019), who provide evidence of strong complementarities, with an estimated Armington elasticity near zero.[8] In counterfactual simulations, we set the Armington elasticity for intermediate inputs to 0.6, which aligns with the value chosen by Kalemli-Özcan et al. (2025).

Monetary Policy. As for the Taylor rule coefficients, we set $\phi_y = 0.1$ as in Christiano et al. (2005) and, given our focus on the euro area, $\phi_\pi = 1.9$ and $\rho_R = 0.85$, in line with Coenen et al (2013).

4.2 Results

4.2.1 Impact of Import Tariffs

Corroborating the insights from the simplified model, the level of substitutability between domestic and foreign goods plays a crucial role also in the full quantitative model. When final goods are less substitutable, the (impact) effect on economic activity of import tariffs on final goods is reversed: as can be seen in Figure 3, it is positive for $\lambda_C = 3$ but becomes negative for

[8]In a companion paper, Boehm et al. (2014) show that this choice also helps to bring international co-movement of the variables in the model closer to what it is observed in the data, corroborating the insight of Heathcote and Perri (2002), that first proposed values below 1 for this parameter (notwithstanding difficulties in its empirical estimation at the time, which traditionally led to considerable uncertainty in calibration procedures for this parameter).

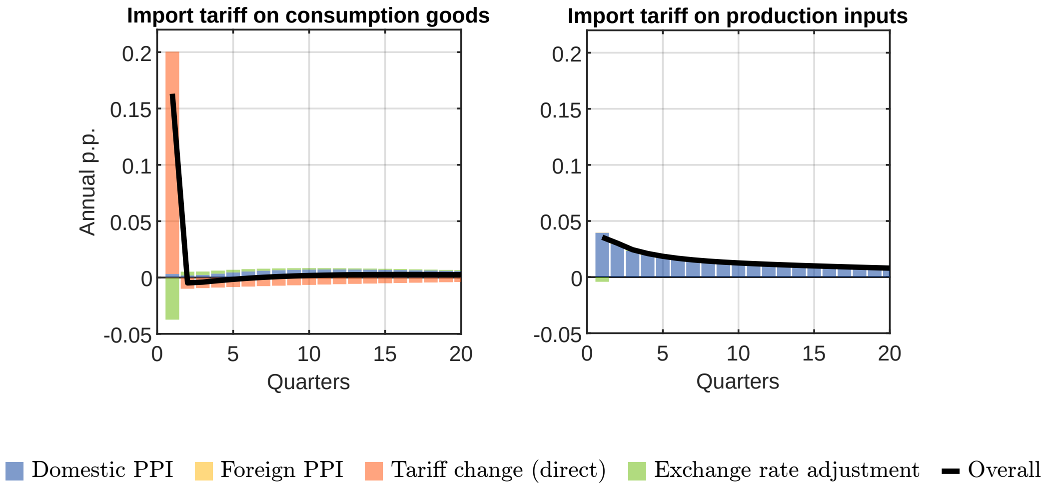

Figure 4: Decomposition of the effect of import tariffs on domestic CPI inflation.

$\lambda_C = 1.8$. In both cases, in the full model import tariffs depress capital accumulation, implying that the response of GDP is hump-shaped and becomes negative even when λ_C is relatively high. Conversely, higher substitutability of intermediate goods can mitigate the GDP decline when import tariffs affect these inputs. However, inflation dynamics remain unaffected by changes in the substitution elasticity between domestic and foreign inputs, with ripple effects through production networks giving rise to inflation persistence.

Figure 4 decomposes the impact of import tariffs on CPI inflation. The basic insights from the simplified setting are again confirmed: while tariffs levied at the final stage of the supply chain have only a temporary effect on inflation, tariffs levied more upstream, at the intermediate input stage, have persistent effects on production costs and inflation. Moreover, these effects are now further compounded and amplified by the presence of a rich input-output structure, as tariff shocks to inputs are propagated through the production network.

4.2.2 Export Tariffs and Import Retaliation

We now perform a quantitative assessment of the impact of potential retaliatory measures by the EU against rising tariffs on its exports. We consider three main scenarios: (i) impact of tariffs levied by the rest of the world (RoW) on both final and intermediate goods imports from the EU, with no retaliation from the EU; (ii) full retaliation by the EU, taxing both final and intermediate goods imports; and (iii) EU tariff retaliation only on its imports of final goods. The baseline scenario in (i) is modelled as an unexpected 1 percentage-point increase in cross-border taxes on EU exports, specifically affecting agriculture and manufacturing—two sectors deeply integrated into global value chains and commonly targeted by trade restrictions. Since the third scenario would involve retaliation on a smaller subset of imports, it is calibrated in such a way that the ex-ante (steady-state) revenue from the tariff is equivalent to that under the second scenario. Such revenue-equivalent tariff on final goods is 85 per cent higher than the across-the-board tariff on both final and intermediate goods considered in the second scenario, e.g., an across-the-board tariff increase of 1 p.p. on both final and intermediate goods is equivalent to a tariff increase of 1.85 p.p. on final goods only, in terms of steady-state revenue.

As shown in Figure 5, a persistent increase in export tariffs in the baseline scenario acts like a tax on trade that cools down overall economic activity while nudging up consumer prices right away. GDP dips modestly and inflation jumps a little on impact before returning to target. The temporary increase in consumer prices comes mainly from the fact that the real exchange rate depreciates to offset the loss in export competitiveness, while making imports (including those of intermediate inputs) more expensive.

If the EU strikes back by matching tariffs on both final and intermediate imports ("full retaliation"), the hit to output is larger: GDP falls by around twice as much than under no retaliation. Inflation climbs on impact due to the direct impact of the change in tariffs, but also stays persistently positive thereafter, due to sticky prices and the way higher input costs ripple through production networks.

In the third scenario, where the EU instead targets only final goods with its counter-tariffs, the fallout is milder. Consumers can more easily swap foreign finished products for domestic alternatives (which is, instead, more challenging for intermediate inputs used in production), and the network effects are milder, so GDP shrinks less than under full retaliation. Although inflation initially ticks up, it soon falls back to target. Imports of final goods plunge more than in the full-retaliation case, pushing the real exchange rate up further. Producers dodge the worst of input-cost shocks, and the stronger currency helps offset the price of imported materials.

5 Conclusions

The strategy in imposing or retaliating against foreign trade restrictions has significant consequences for economic activity, inflation, and trade dynamics. In this paper, we show that the impact crucially depends on whether import tariffs target final or intermediate goods and on the substitutability between domestic and imported goods. Focusing on final goods, as the EU has

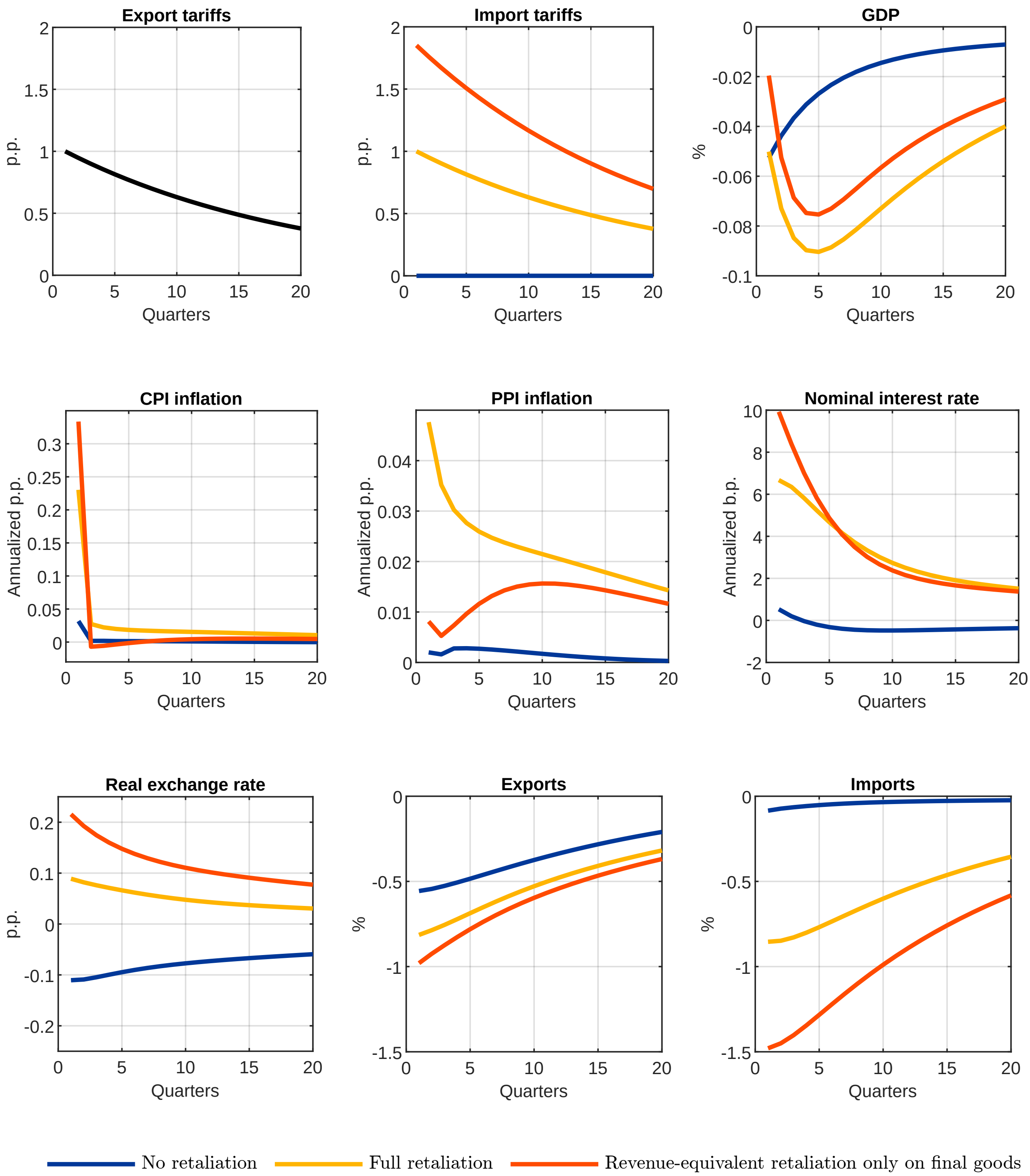

Figure 5: Impact of export tariffs and alternative retaliatory measures.

done in the past in its limited countermeasures to US actions, tends to raise consumer prices only temporarily but has a limited effect on production costs. However, expanding retaliation to include intermediate goods could increase production costs for sectors reliant on foreign inputs, leading to broader economic disruptions and more persistent inflationary pressures. Our results suggest that full retaliation, involving import tariffs on both final and intermediate goods, results in more sustained inflation and a more pronounced economic contraction compared to targeting only final goods.

While the EU's retaliatory measures against the United States could have inflationary impacts, US tariffs on China may result in disinflationary pressures, as low-cost Chinese exports may be redirected towards the EU, contributing to downward pressure on prices. In this respect, extending our analysis to a setting with more than two regions constitutes an interesting avenue for further research.

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Acknowledgements

We are grateful to Óscar Arce, Günter Coenen, Aurélien Eyquem, Vanessa Gunnella, David Lodge, Philip R. Lane, Tommaso Monacelli, Tobias Schuler, and to seminar participants at the ECB for insightful comments and suggestions.
All errors are our own. The views expressed here are those of the authors. They do not necessarily reflect those of the ECB or the Eurosystem and should not be reported as such.

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PDF ISBN 978-92-899-7388-5 ISSN 1725-2806 doi:10.2866/8048766 QB-01-25-163-EN-N