The Macroeconomic Stabilization of Tariff Shocks: What is the Optimal Monetary Response?

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Abstract

In the wake of Brexit and Trump trade war, central banks face the need to reconsider the role of monetary policy in managing the inflationary-recessionary effects of hikes in tariffs. Using a New Keynesian model enriched with elements from the trade literature, including global value chains, firm dynamics, and comparative advantage, we show that the optimal monetary response is expansionary. It supports activity and producer prices at the expense of aggravating short-run headline inflation---contrary to the prescription of the standard Taylor rule. This holds all the more when the home currency is dominant in pricing of international trade.

Keywords: tariff shock, tariff war, optimal monetary policy, comparative advantage, production chains
JEL classification: F4

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1. Introduction

Brexit and the Trump trade wars ignited a debate over the economic effects of tariffs, and the appropriate monetary policy response to the economic slowdown potentially induced by these shocks. U.S. tariffs on Chinese exports rose seven-fold from 2018 to 2020, with little sign of any policy reversal since.[1] During the four years after the Brexit referendum in the absence of a trade agreement, uncertainty over trade relations with Europe dampened investment and production in the U.K.; even in the wake of an agreement implemented in 2021 trade remained hampered by increased regulatory requirements. More to the point, these notable recent trade disputes could signify a weakening of global consensus regarding free trade, and may herald a changed environment, in which central banks will again face this new type of shock.

While these events have motivated a recent swell in research on the macroeconomic effects of trade policy, this nascent literature has not focused on the monetary dimension. Research has been conducted mostly in the context of real trade models, or monetary models with a stylized monetary side (see the foundational work of Barattieri, et al. (2021), among others).[2] In recent theoretical research on the macroeconomics of tariff shocks, monetary policy is modelled in terms of Taylor rules, without however deriving them from an optimal policy exercise. This approach is tantamount to assuming that tariffs are akin to supply shocks, either productivity or markup supply disturbances, so that the best monetary response consists of countering their inflationary effects with a contraction. (See Barattieri et al. (2021), Caldara et al. (2020), and Linde and Pescatori (2019) for examples.) But the question central banks have been facing is how to respond efficiently to surprise shifts in trade policy. This calls for a welfare-based analysis of the optimal policy, capable of providing economic insight into how to redress the macroeconomic impact of a tariff shock. This paper is the first we know of to conduct such an analysis.

We study the Ramsey optimal monetary policy response to tariff shocks in a New Keynesian model that is enriched, incrementally, with features we deem particularly relevant

[1] In 2021 they remained more than six times their 2018 levels. From Brown (2021).
[2] See also, for example Bloom, et al. (2019), Born et al. (2019), Breinlich et al. (2017), Caliendo et al. (2017), Davies and Studnicka (2018), Dhingra et al. (2017), Sampson (2017), Steinberg (2019), and Van Reenen (2016). Some recent contributions use monetary models with standard monetary policy rules in the background, but these do not derive optimal policy or focus on the monetary response. Important examples are Linde and Pescatori (2019), Erceg et al. (2018) and Caldara et al. (2020). Barattieri et al. (2021) goes on to consider two alternative monetary regimes of a zero lower bound and a fixed exchange rate. Earlier work inspired by previous episodes of trade war include Crucini and Kahn (1996).

for understanding the effects of tariffs. First, in line with recent open economy macro, our model features (if only in a stylized way) value chains in production, in which imported goods are used in the production of exports. This implies that tariff protection of domestic exporters also raises the cost of production for domestic firms. Second, drawing on the trade literature, the model features two traded sectors, one consisting of monopolistically competitive differentiated goods, characterized by sticky prices and sunk entry cost, and the other perfectly competitive non-differentiated goods. Hence, a country's comparative advantage is endogenous, with shocks causing reallocation of production across countries and sectors as well as changes in the composition of international trade. Third, we allow for asymmetries in exchange rate pass-through, as well as a distribution sector that drives a wedge between border and consumer prices, reducing the pass through of tariffs.[3]

We show that the Ramsey optimal response to a tariff war is broadly expansionary across a range of economic environments—the opposite of the optimal response to adverse productivity or markup shocks, which is generally anti-inflationary. Although like these shocks tariffs cause a hike in inflation accompanied by a fall in output, the combination of demand and supply effects brought about by a tariff hike is distinctly different. On one hand, tariffs translate into a cost-push factor via the cost of intermediates and imported consumption goods, which would motivate a rise in nominal wages. On the other hand, because of their direct effect on consumer prices, they translate into a fall in demand for goods, depressing wages. Except for the case of economies where the share of intermediates in production is very high, the demand effects prevail---causing (ex-tariff) inflation to fall in a persistent way. Hence the optimal monetary policy response is expansionary.

The economics of this result is best illustrated through a comparative analysis of tariffs with other shocks. In contrast to a standard productivity shock, the contraction and reallocation of production between countries and sectors caused by trade policy is not driven by a shift in fundamental economic costs of production. Rather, it is a cost artificially created by policy, which is distortionary even if the revenue is rebated back to consumers. We show that monetary policy can play a key role in mitigating this first-order distortion.

While markup shocks, like tariffs, are distortionary, tariffs differ in key dimensions: they apply selectively to export sales rather than all sales of a firm, the revenues accrue to the

[3] The trade-motivated features of our model do not drive the sign and the "economics" of the optimal monetary response to tariffs. However, they do impinge on its intensity and transmission, and magnify the welfare costs of suboptimal policies.

importing country rather than the exporting firm, and, most crucially, tariff duties are imposed directly on the importer rather than part of the price set by exporters. Because of this last point, a tariff shock drives a wedge between the prices at the border and at consumer level, and this wedge translates into a fall in the demand faced by firms. As producers respond by setting lower (border) prices, the shock produces persistent and inefficient (ex-tariff) PPI deflation. Thus, monetary policy optimally leans against the fall in (sticky, ex-tariff) prices. We show that the Ramsey optimal monetary policy response to a tariff, a monetary expansion, is indeed the opposite of the optimal response to a comparable mark-up shock raising prices.

The logic of the result applies to both the case of tariff wars, and to the case of tariffs imposed asymmetrically by one country. With asymmetric tariffs, however, exchange rate misalignment raises an additional trade off, that the Ramsey (cooperative) optimal policy redresses by prescribing a monetary expansion in the country whose exports are targeted by the foreign trade policy, and a contraction in the country imposing the tariff. The combined, home and foreign, monetary stance causes the home currency to depreciate, so as to mitigate the distortionary effects of a tariff on international relative prices. This result suggests that a policy of currency depreciation in response to imposition of (one-sided) tariffs could be justified on the grounds of reducing distortions and promoting global welfare.

Moving beyond the standard macro analysis, we assess the benefits of efficient monetary stabilization in a richer environment where, realistically, tradable goods are produced in multiple sectors, subject to asymmetric tariff rates. Inter-sectoral adjustment may moderate the aggregate impact of the tariff on output and activity, which per se reduces the need for monetary stimulus. Yet, the tariff-induced distortions on comparative advantage bring forward additional policy trade-offs for monetary authorities, that can be quite consequential in terms of both societal welfare and policy design (but are missed in standard monetary analysis). Namely, without loss of generality, we focus our analysis on tariffs imposed on the differentiated (manufacturing) good sector, which the incidence of nominal rigidities makes more sensitive to monetary policy stabilization. We show that the welfare benefits from sustaining entry and production in this sector motivate a monetary stimulus well beyond the one required to support the (distorted) natural rate. We also clarify that the monetary trade-off between activity, inflation and comparative advantage across multiple tradable goods is distinct from the one associated with the coexistence of tradables and non-tradables. The classical model relying on this distinction misses the need for stabilization to address distortions affecting the composition of exports.

We generalize our results allowing for incomplete or asymmetric exchange rate pass through and/or to a muted tariff pass through from border to consumer prices. We establish that in a world of Dominant Currency Pricing (DCP), where one country issues a dominant currency, the different incidence of price stickiness on exporters induces a strong asymmetry in both the transmission of tariff shocks and the optimal policy response. Even in a retaliatory, symmetric tariff war, the optimal monetary stance differs across borders. It is expansionary in the dominant currency country, since PCP price stickiness among domestic producers of differentiated tradables makes it possible to redress the tariff distortion on domestic production via internal demand and currency depreciation, while a weaker currency has a muted effect on imported inflation. The optimal stance is instead contractionary in the other country, since LCP price stickiness among foreign exporters insulates export prices from currency movements, while import prices remain highly sensitive to the exchange rate. As a result, although activity contracts in both countries, it falls by less in the country issuing the dominant currency. Most strikingly, implementing a monetary expansion allows the issuer of the dominant currency to redress the effects of the symmetric tariff on the differentiated goods sector. Although the tariff war is symmetric, this country actually gains comparative advantage in the production and export of these goods.

In line with recent empirical evidence (Flaaen et al. 2020 and Cavallo et al. 2019), a high degree of tariff pass through at border prices may correspond to a very low degree of pass through at consumer prices [4]. We show that an extension of the model including a distribution sector (after Corsetti and Dedola 2005) can match the evidence, allowing us to refine our qualitative and quantitative results.

Our work is related to a number of recent papers studying the macroeconomic effects of trade policies in dynamic stochastic general equilibrium models. The seminal work in Barattieri et al. (2021) and Erceg et al. (2018) study whether trade policies can potentially serve as effective tools of macroeconomic stimulus in environments with nominal frictions. Caldara et al. (2018) investigates the macroeconomic implications of trade policy uncertainty. Linde and Pescatori (2019) study the degree to which endogenous exchange rate movements work to offset the macroeconomic effects of tariffs and export subsidies. These papers share with our

[4] In our model, for the PCP baseline, under the suboptimal policy the price-setting response of exporters accounts for a degree of incomplete pass-through of tariffs to border prices---these fall in line with a lower demand for foreign goods. Under the optimal policy, instead, the efficient home expansion causes ex-tariff border prices to rise.

work the specification of a monetary economy, but focus on the effects and/or design of tariff policies in a macroeconomic environment where monetary policy operates according to a standard Taylor rule in the background. In contrast, we focus on the design of the welfare-optimizing monetary policy response of a central bank faced by exogenous tariff shocks.

Closely related to us is the recent work by Auray et al. (2021), which shares our focus on the interaction of tariff policy with alternative monetary policies, including cooperative optimal policy. Specifically, they address the question of how alternative monetary policies affect an endogenous, strategic tariff policy. This runs in the opposite direction of our question, the choice of optimal monetary policy in the face of an exogenous tariff policy. As already mentioned, the question we ask is directly motivated by the need to design an effective monetary response to trade policy initiatives best viewed as exogenous shocks, either imposed by a foreign country over which central banks have no control, or reflecting an unexpected shift in the political agenda of the domestic government. Further, the economic environments of our models differ. Auray et al. (2021) specify a standard New Keynesian DSGE model, whereas we consider a model with economic features found important in the trade literature, such as international production chains and multiple traded sectors with the resulting shifts in comparative advantage.

The paper proceeds as follows. The next section describes the model environment and calibration that we use to study the optimal stabilization of a symmetric tariff war and a unilateral foreign tariff. To fully appreciate the novel features of our model, in Section 3, we start by analyzing the optimal policy response to a trade war in a one-tradable sector only version of the model—the standard workhorse model in open macro—assuming complete exchange rate pass-through. Section 4 repeats the analysis for the case of a unilateral hike in tariffs. In Section 5, we revisit our exercises allowing for two sectors, thus including macroeconomic issues raised by the distortionary effect of tariffs on comparative advantage. In section 6 and 7 we verify the robustness of our results when either exchange rate or tariff pass-through is incomplete, and study the implications of one currency being dominant in the invoicing of international trade. Section 8 summarizes conclusions and policy implications.

2. Model

The theoretical framework builds upon the monetary comparative advantage model developed in Bergin and Corsetti (2020), as it combines macroeconomic elements important for studying monetary policy, such as sticky prices and endogenous labor supply, with features of trade models, such as firm entry dynamics and endogenous comparative advantage among multiple traded sectors, which are important for studying trade policies. To address the issue at hand, we augment this framework, foremost, with ad-valorem tariffs imposed on imported goods.

The model features two countries, home and foreign, each of which produce two types of tradable goods. The first type of good comes in differentiated varieties produced under monopolistic competition, where firm entry requires a sunk investment, and prices are subject to nominal rigidities. The second type of good is modeled according to the standard specification in real business cycle models, assuming perfect substitutability among producers within a country, but imperfect substitutability across countries. In the text to follow, we present the households' and firms' problems as well as the monetary and fiscal policy rules from the vantage point of the home economy, with the understanding that similar expressions and considerations apply to the foreign economy—foreign variables are denoted with a "*".

2.1. Goods consumption demand and price indexes

In the benchmark version of the model, households consume goods produced in both sectors, and of both domestic and foreign origin. The differentiated goods come in many varieties, produced by a time-varying number of monopolistically competitive firms in the home and foreign country, n_t and n_t* respectively, each producing a single variety. Each variety is an imperfect substitute for any other variety in this sector, either of home or foreign origin, with elasticity ϕ. The non-differentiated goods come in a home and foreign version, which are imperfect substitutes with elasticity η. However, within each country, all goods in this sector are perfectly substitutable with each other, and are produced in a perfectly competitive environment. We will refer to the differentiated sector as "manufacturing," and denote this sector with a D; we will denote the non-differentiated sector with a N.

Tariffs are specified as ad-valorem duties imposed at the dock. They directly enter the relative prices observed by consumers, and which enter the demand equations. Tariff revenue is collected by the government of the importing country and rebated to domestic consumers, thus canceling out in the consolidated national budget constraint.

The overall consumption index is specified as follows:

$$C_t \equiv \left(\theta^{\frac{1}{\xi}} C_{D,t}^{\frac{\xi-1}{\xi}} + (1-\theta)^{\frac{1}{\xi}} C_{N,t}^{\frac{\xi-1}{\xi}} \right)^{\frac{\xi}{\xi-1}},$$

where $$C_{D,t} \equiv \left(\int_0^{n_t} c_t(h)^{\frac{\phi-1}{\phi}} dh + \int_0^{n_t^*} c_t(f)^{\frac{\phi-1}{\phi}} df \right)^{\frac{\phi}{\phi-1}}$$

is the index over the endogenous number of home and foreign varieties of the differentiated manufacturing good, $c_t(h)$ and $c_t(f)$, and

$$C_{N,t} \equiv \left(\nu^{\frac{1}{\eta}} C_{H,t}^{\frac{\eta-1}{\eta}} + (1-\nu)^{\frac{1}{\eta}} C_{F,t}^{\frac{\eta-1}{\eta}} \right)^{\frac{\eta}{\eta-1}}$$

is the index over goods differentiated only by country of origin, $C_{H,t}$ and $C_{F,t}$ with $\nu \in [0,1]$ accounting for the weight on domestic goods. The corresponding welfare-based consumption price index is

$$P_t = \left(\theta P_{D,t}^{1-\xi} + (1-\theta)\left(P_{N,t}\right)^{1-\xi} \right)^{\frac{1}{1-\xi}}, \text{ where} \quad (1)$$

$$P_{D,t} = \left(n_t p_t(h)^{1-\phi} + n_t^* \left(p_t(f) T_{D,t} \right)^{1-\phi} \right)^{\frac{1}{1-\phi}} \quad (2)$$

is the index over the prices of all varieties of home and foreign manufacturing goods, $p_t(h)$ and $p_t(f)$, and

$$P_{N,t} = \left(\nu P_{H,t}^{1-\eta} + (1-\nu)\left(P_{F,t} T_{N,t} \right)^{1-\eta} \right)^{\frac{1}{1-\eta}} \quad (3)$$

is the index over the prices of home and foreign non-differentiated goods. In these indexes, $T_{D,t}$ represents the quantity of 1 plus the ad valorem tariff rate imposed by the home country on imports of foreign differentiated goods, and $T_{N,t}$ represents the quantity of 1 plus the ad-valorem tariff rate imposed by the home country on imports of foreign non-differentiated goods. In reporting results, we will distinguish between the "ex-tariff" price determined by an exporter, $p_t(f)$, and the "tariff-inclusive" price, $p_t(f) T_{D,t}$, paid by an importer.

The relative demand functions for domestic residents implied from our specification of preferences are listed below:

$$C_{D,t} = \theta \left(P_{D,t} / P_t \right)^{-\xi} C_t \quad (4)$$

$$C_{N,t} = C_{D,t} = (1-\theta)\left(P_{N,t} / P_t \right)^{-\xi} C_t \quad (5)$$

$$c_t(h) = \left(p_t(h) / P_{D,t} \right)^{-\phi} C_{D,t} \quad (6)$$

$$c_t(f) = \left(p_t(f) T_{D,t} / P_{D,t} \right)^{-\phi} C_{D,t} \quad (7)$$

$$C_{H,t} = \nu\left(P_{H,t} / P_{N,t}\right)^{-\eta} C_{N,t} \tag{8}$$

$$C_{F,t} = (1-\nu)\left(P_{F,t}T_{N,t} / P_{N,t}\right)^{-\eta} C_{N,t} \tag{9}$$

Note that demand functions for imports (Eqs. (7) and (9)) depend on the tariff-inclusive price.

2.2 Home households' problem

The representative home household derives utility from consumption (C_t), and from holding real money balances (M_t/P_t); it suffers disutility from labor (l_t). The household budget consists of labor income from working at the nominal wage rate W_t; profits rebated from home firms denoted with (Π_t) in real terms and defined below, as well as interest income on bonds in home currency ($i_{t-1}B_{H,t-1}$) and foreign currency ($i_{t-1}^{*}B_{F,t-1}$), where e_t is the nominal exchange rate in units of home currency per foreign. Income also includes lump-sum government transfers (T_t), used for monetary injections and to rebate tariff revenue. It is assumed that consumers do not internalize the effects of their consumption decisions on government tariff rebates.

Household optimization for the home country may be written:

$$\max E_0 \sum_{t=0}^{\infty} \beta^t U\left(C_t, l_t, \frac{M_t}{P_t}\right)$$

where utility is defined by

$$U_t = \frac{1}{1-\sigma} C_t^{1-\sigma} + \ln \frac{M_t}{P_t} - \frac{1}{1+\psi} l_t^{1+\psi} ,$$

subject to the budget constraint:

$$P_t C_t + \left(M_t - M_{t-1}\right) + \left(B_{Ht} - B_{Ht-1}\right) + e_t\left(B_{Ft} - B_{Ft-1}\right) = W_t l_t + \Pi_t + i_{t-1} B_{Ht-1} + i_{t-1}^{*} B_{Ft-1} - P_t AC_{Bt} + T_t .$$

In the utility function, the parameter σ denotes risk aversion and ψ is the inverse of the Frisch elasticity. The constraint includes a small cost to holding foreign bonds

$$AC_{Bt} = \frac{\psi_B\left(e_t B_{Ft}\right)^2}{2 P_t p_{Ht} y_{Ht}} ,$$

scaled by ψ_B, which is a common device to assure long run stationarity in the net foreign asset position, and resolve indeterminacy in the composition of the home bond portfolio. The bond adjustment cost is a composite of goods that mirrors the consumption index, with analogous demand conditions to Eqs. (4)-(9).

Household optimization implies an intertemporal Euler equation:

$$\frac{1}{P_t C_t^{\sigma}} = \beta(1+i_t) E_t\left[\frac{1}{P_{t+1} C_{t+1}^{\sigma}}\right] \tag{10}$$

a labor supply condition:

$$W_t / P_t = l_t^{\psi} C_t^{\sigma} \tag{11}$$

a money demand condition:

$$M_t = P_t C_t^{\sigma}\left(\frac{1+i_t}{i_t}\right), \tag{12}$$

and a home interest rate parity condition:

$$\mathrm{E}_t\left[\frac{P_t C_t^{\sigma}}{P_{t+1} C_{t+1}^{\sigma}} \frac{e_{t+1}}{e_t}\left(1+i_t^*\right)\left(1+\psi_B\left(\frac{e_t B_{ft}}{p_{Ht} y_{Ht}}\right)\right)\right] = \mathrm{E}_t\left[\frac{P_t C_t^{\sigma}}{P_{t+1} C_{t+1}^{\sigma}}\left(1+i_t\right)\right]. \tag{13}$$

The problem and first order conditions for the foreign household are analogous.

2.3 Home firm problem and entry condition in the differentiated goods sector

In the manufacturing sector, the production of each differentiated variety follows

$$y_t(h) = \alpha_{D,t}\left[G_t(h)\right]^{\zeta}\left[l_t(h)\right]^{1-\zeta}, \tag{14}$$

where $\alpha_{D,t}$ is a productivity shock specific to the production of differentiated goods but common to all firms within that sector, $l_t(h)$ is the labor employed by firm h, and $G_t(h)$ is a composite of differentiated goods used by firm h as an intermediate input. $G_t(h)$ is specified as an index of home and foreign differentiated varieties that mirrors the consumption index specific to differentiated goods ($C_{D,t}$). If we sum across firms, $G_t = n_t G_t(h)$ represents economy-wide demand for differentiated goods as intermediate inputs. Given that the index is the same as for consumption, this implies demands for differentiated goods varieties, $d_{G,t}(h)$ and $d_{G,t}(f)$, analogous to Eqs. (6)–(7).[5]

Differentiated goods firms set prices $p_t(h)$ subject to an adjustment cost:

$$AC_{P,t}(h) = \frac{\psi_P}{2}\left(\frac{p_t(h)}{p_{t-1}(h)} - 1\right)^2 \frac{p_t(h) y_t(h)}{P_t}, \tag{15}$$

[5] See section 1 of the online appendix for the demand equations not listed here.

where ψ_P is a calibrated parameter governing the degree of price stickiness. For the sake of tractability, we follow Bilbiie et al. (2008) in assuming that new entrants inherit from the price history of incumbents the same price adjustment cost, and so make the same price setting decision.[6]

There is free entry in the sector, but, once active, firms are subject to an exogenous death shock. Since all differentiated goods producers operating at any given time face the same exogenous probability of exit δ, a fraction δ of them exogenously stop operating each period. The number of firms active in the differentiated sector, n_t, at the beginning of each period evolves according to:

$$n_{t+1} = (1-\delta)(n_t + ne_t), \tag{16}$$

where ne_t denotes new entrants.

To set up a firm, managers incur a one-time sunk cost, K_t, and production starts with a one-period lag. This cost is not constant but varies reflecting an entry congestion externality, represented as an adjustment cost that is a function of the number of new firms:

$$K_t = \left(\frac{ne_t}{ne_{t-1}}\right)^{\lambda} \overline{K}, \tag{17}$$

where $\overline{K}$ indicates the steady state level of entry cost, and the parameter λ indicates how much the entry cost rises with an increase in entry activity. The congestion externality plays a similar role as the adjustment cost for capital standard in business cycle models, which moderates the response of investment to match dynamics in data. In a similar vein, we calibrate the adjustment cost parameter, λ, to match data on the dynamics of new firm entry.[7] The demands for varieties for use as entry investment, $d_{K,t}(h)$ and $d_{K,t}(f)$, are determined analogously to demands for consumption of differentiated goods.

We now can specify total demand facing a domestic differentiated goods firm:

$$d_t(h) = c_t(h) + d_{G,t}(h) + d_{K,t}(h) + d_{AC,P,t}(h) + d_{AC,B,t}(h) \tag{18}$$

which includes the demand for consumption ($c_t(h)$) by households, and the demand by firms for intermediate inputs ($d_{G,t}(h)$), investment (the sunk entry costs) ($d_{K,t}(h)$), and goods

[6] The price index for adjustment cost is identical to the overall consumption price index, implying demands analogous to those for consumption in Eqs. (4)-(9). See section 1 of the online appendix for the demand equations not listed here.

[7] The value of steady state entry cost $\overline{K}$ has no effect on the dynamics of the model, and so will be normalized to unity.

absorbed as adjustment costs for prices ($d_{AC,P,t}(h)$) and bonds holding costs ($d_{AC,B,t}(h)$). There is an analogous demand from abroad $d_t^*(h)$. We assume iceberg trade costs τ_D for exports, so that market clearing for a firm's variety is:

$$y_t(h) = d_t(h) + (1+\tau_D) d_t^*(h), \tag{19}$$

We follow Corsetti, et al. (2010) in specifying markup shocks in the form of a tax imposed on firms, rebated in lump sum back to owners of firm (in our case, households). In order to imply a firm markup of $\frac{\phi}{(\phi-1)T_{MU,t}}$ where $T_{MU,t}$ is subject to stochastic shocks, we specify a tax of $(1-T_{MU,t})$ paid by the firm on each unit of revenue. So firm profits are computed as:

$$\pi_t(h) = \left[p_t(h) d_t(h) + e_t p_t^*(h) d_t^*(h)\right] T_{MU,t} - mc_t y_t(h) - P_t AC_{p,t}(h). \tag{20}$$

where $mc_t = \zeta^{-\zeta}(1-\zeta)^{\zeta-1} P_{D,t}{}^{\zeta} W_t^{1-\zeta} / \alpha_{D,t}$ is marginal cost.

Thus the value function of firms that enter the market in period *t* may be represented as the discounted sum of profits of domestic sales and export sales:

$$v_t(h) = E_t\left\{\sum_{s=0}^{\infty} \left(\beta(1-\delta)\right)^s \frac{\mu_{t+s}}{\mu_t} \pi_{t+s}(h)\right\},$$

where we assume firms use the discount factor of the representative household, who owns the firm, to value future profits. With free entry, new producers will invest until the point that a firm's value equals the entry sunk cost:

$$v_t(h) = P_{D,t} K_t. \tag{21}$$

By solving for cost minimization we can express the relative demand for labor and intermediates as a function of their relative costs:

$$\frac{P_{D,t} G_t(h)}{W_t l_t(h)} = \frac{\zeta}{1-\zeta}. \tag{22}$$

Managers optimally set prices by maximizing the firm value subject to all the constraints specified above. The price setting equation:

$$\begin{aligned} p_t(h) = {} & \frac{\phi}{(\phi-1)T_{MU,t}} mc_t + \frac{\psi_P}{2}\left(\frac{p_t(h)}{p_{t-1}(h)} - 1\right)^2 p_t(h) - \psi_P \frac{1}{\phi-1}\left(\frac{p_t(h)}{p_{t-1}(h)} - 1\right)\frac{p_t(h)^2}{p_{t-1}(h)} \\ & + \frac{\psi_P}{\phi-1} E_t\left[\beta \frac{\Omega_{t+1}}{\Omega_t}\left(\frac{p_{t+1}(h)}{p_t(h)} - 1\right)\frac{p_{t+1}(h)^2}{p_t(h)}\right] \end{aligned} \tag{23}$$

expresses the optimal pricing as a function of the stochastically discounted demand faced by producers of domestic differentiated goods,

$$\Omega_t = \left[\left(\frac{p_t(h)}{P_{D,t}} \right)^{-\phi} \left(C_{D,t} + G_t + ne_t (1-\theta_K) K_t + AC_{P,D,t} + AC_{B,D,t} \right) \right.$$

$$\left. + \left(\frac{(1+\tau_D) T^*_{D,t} p_t(h)}{e_t P^*_{D,t}} \right)^{-\phi} (1+\tau_D) \left(C^*_{D,t} + G^*_t + ne^*_t (1-\theta_K) K^*_t + AC^*_{P,D,t} + AC^*_{B,D,t} \right) \right] \Big/ \mu_t .$$

This sums the demand arising from consumption, use as intermediate inputs, sunk entry cost, price adjustment costs, and bond holding costs.

Under the assumption that firms preset prices in own currency, i.e., assuming producer currency pricing, the good price in foreign currency moves one-to-one with the exchange rate, net of trade costs:

$$p^*_t(h) = (1+\tau_D) p_t(h) / e_t , \tag{24}$$

where recall the nominal exchange rate, e, measures home currency units per foreign.

Note that, since households own firms, they receive firm profits but also finance the creation of new firms. In the household budget, the net income from firms may be written:

$$\Pi_t = n_t \pi_t(h) - ne_t v_t(h) .$$

In reporting our quantitative results, we will refer to the overall home gross production of differentiated goods defined as: $y_{D,t} = n_t y_t(h)$.

2.4 Home firm problem in the undifferentiated goods sector

In the second sector firms are assumed to be perfectly competitive in producing a good differentiated only by country of origin. The production function for the home non-differentiated good is linear in labor:

$$y_{H,t} = \alpha_{N,t} l_{H,t} , \tag{25}$$

where $\alpha_{N,t}$ is stochastic productivity specific to this country and sector. It follows that the price of the homogeneous goods in the home market is equal to marginal costs:

$$p_{H,t} = W_t / \alpha_{N,t} . \tag{26}$$

An iceberg trade cost specific to the non-differentiated sector implies prices of the home good abroad are

$$p^*_{H,t} = p_{H,t} (1+\tau_N) / e_t . \tag{27}$$

Analogous conditions apply to the foreign non-differentiated sector.

2.5 Monetary policy

To compute the Ramsey allocation, we posit that the monetary authority maximizes aggregate welfare of both countries:

$$\max E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{1}{2}\left(\frac{1}{1-\sigma} C_t^{1-\sigma} - \frac{1}{1+\psi} l_t^{1+\psi} \right) + \frac{1}{2}\left(\frac{1}{1-\sigma} C_t^{*1-\sigma} - \frac{1}{1+\psi} l_t^{*1+\psi} \right) \right)$$

under the constraints of the economy defined above. As common in the literature, we write the Ramsey problem by introducing additional co-state variables, which track the value of the planner committing to a policy plan. [8] We assume full commitment, and we adopt a timeless perspective.

For comparison, we also study three alternative nominal specifications. In the first one, we assume flexible prices and wages, so to characterize the natural allocation. In the second, we model monetary policy positing a constant money growth rule:

$$\frac{M_t}{M_{t-1}} = \upsilon , \tag{28}$$

which we label the 'no (stabilization) policy' case. In the last one, with replace the above with a Taylor rule of the form

$$1 + i_t = \left(1 + i_{t-1}\right)^{\gamma_i} \left[\left(1 + \bar{i}\right) \left(\frac{p_t(h)}{p_{t-1}(h)} \right)^{\gamma_p} \left(\frac{Y_t}{\bar{Y}} \right)^{\gamma_Y} \right]^{1-\gamma_i} , \tag{29}$$

where terms with overbars are steady-state values. In this rule, inflation is defined in terms of differentiated goods producer prices, while Y_t is a measure of GDP defined net of intermediates as:[9]

$$Y_t = \left((1 + n_t)^{(-1/(1-\sigma))} \int_0^{n_t} p_t(h) y_t(h) dh - P_{D,t} G_t + p_{H,t} y_{H,t} \right) / P_t , \tag{30}$$

Across these different specifications of monetary policy, we will abstract from public consumption expenditure, so that the government uses seigniorage revenues and taxes to finance transfers, assumed to be lump sum. Government transfers are also used to rebate to consumers the tariff duties paid to the government by consumers and firms on imported goods, and the revenue from the tax on firms used to model markup shocks. The government budget constraint thus is specified as follows:

[8] To compute the Ramsey allocation, we adopt the methodology created by Giovanni Lombardo and used in Coenen et al. (2010), available from https://www.dropbox.com/s/q0e9i0fw6uziz8b/OPDSGE.zip?dl=0.
[9] For computational simplicity, the Taylor rule is specified in terms of deviations of GDP from its steady state value, which is distinct from the output gap.

$$
\begin{aligned}
T_t &= \left(M_t - M_{t-1}\right) + \left(T_{D,t} - 1\right) n^*_{t-1} d_t(f) + \left(1 - T_{MU,t}\right)\left(n_{t-1} d_t(h) + n^*_{t-1} d_t(f)\right) \\
&+ \left(T_{N,t} - 1\right)\left(C_{F,t} + AC_{P,F,t} + AC_{B,F,t}\right)
\end{aligned} \quad . \tag{31}
$$

2.6 Shocks process and equilibrium definition

To conserve space, the market clearing conditions to close the model are reported in section 2 of the online appendix. A competitive equilibrium in our world economy is defined along the usual lines, as a set of processes for quantities and prices in the home and foreign country satisfying: (i) the household and firms optimality conditions; (ii) the market clearing conditions for each good and asset, including money; (iii) the resource constraints—whose specification can be easily derived from the above and is omitted to save space.

Shocks are normally distributed in logs. See Appendix section 2 for the usual details.

We report the effects on welfare of a given policy regime configuration relative to the Ramsey allocation. We follow the custom of computing the change in welfare in terms of steady state consumption units that households would be willing to forgo to continue under the Ramsey policy regime rather than adopt an alternative, suboptimal policy. Identical initial conditions are assumed across different monetary policy regimes, using the Ramsey allocation, and transition dynamics are included in the computation to avoid spurious welfare reversals.[10]

2.7 Model calibration and solution

Choice of parameter values for the numerical exercise largely follows that in Bergin and Corsetti (2020). See table 1 for a list of parameter values; see Appendix section 4 for a more detailed discussion of the parameterization. We focus here on the additional parameterization related to tariffs.

The process for tariff shocks is calibrated with a mean value of 1.02 (2 percentage point mean tariff rate) to match U.S. tariff data in Barattieri et al. (2021). The autoregressive parameter is set to 0.56, estimated from Barattieri et al. (2021).[11] The standard deviation of 6 percentage points is taken from Caldara et al. (2020), chosen to capture tariff increases that have been threatened on imports from China and on imports of autos and motor-vehicle parts in

[10] For welfare computation, we adopt the methodology created by Giovanni Lombardo and used in Coenen et al. (2010), available from https://www.dropbox.com/s/q0e9i0fw6uziz8b/OPDSGE.zip?dl=0.

[11] We do not adopt the standard deviation of shocks estimated in Barattieri et al (2021), as these estimates are based on a sample from normal times with low volatility in tariffs compared to the more recent period of Brexit and Trump tariffs.

2018-2019. Markup shocks are calibrated with the same parameters as tariff shocks, to facilitate comparison.

The model is solved as a second order approximation using perturbation methods.

3. Monetary stabilization with symmetric trade war

We state our main findings focusing initially on the one-sector version of the model, as this is sufficient to make our most basic points, and is close to the standard specification in the macroeconomic literature. Later sections will demonstrate robustness and amplification of the key results when the model environment is extended with additional features that have been viewed as important in the trade literature. In the one-sector environment, both countries produce just differentiated goods (the non-differentiated goods sector is shut down by setting $\theta = 1$).

Simulations are conducted for two types of tariff shocks. In this section, we study a symmetric rise in tariffs in both countries---the case of a trade war with full retaliation. In section 4 below, we will study a unilateral foreign tariff on home exports, which will allow us to gain insight into the response of the exchange rate and trade balance.[12] In all cases tariffs rise by one standard deviation, based on the calibration presented above.

The effects of an unexpected, symmetric rise in tariffs in both countries are shown in Figure 1a. This includes the macroeconomic response of selected variables under different assumption about policy regimes. The figure contrasts the Ramsey optimal policy (solid line) with the cases of "flexible prices" (dot-dash line), "Taylor rule" (dotted line), and "no-policy" (dashed line), where the latter is obtained by imposing a constant money growth rule. The figure reports impulse responses only for home variables, since the foreign counterparts are identical.

3.1 The transmission of symmetric tariff shocks under suboptimal policies

To isolate the transmission of tariff shocks to the economy, it is instructive to run the model under either a no-policy response or under familiar suboptimal rules stabilizing inflation. Consider first the absence of stabilization, captured by our constant money growth rule (dashed

[12] The case of a symmetric global shock is modeled by drawing a single shock and feeding it directly into the tariff processes for both home and foreign differentiated goods. This is equivalent to setting the four elements in the upper left quadrant of the covariance matrix for the joint shock process equal to a common variance, with all other elements zero. The autroregressive matrix is diagonal. The case of a unilateral shock is specified by setting just the second diagonal element of the covariance matrix as nonzero.

line in Figure 1a). In this case, a symmetric tariff shock induces a transitory rise in headline inflation and causes a recession---note that this response supports the interpretation of tariff shocks as an adverse supply shock typically put forward in the literature (especially Barattieri, et al. (2021). The consumer price index rises mainly because of the direct effect of the tariffs paid on imported consumption goods, since tariffs are added to the price at the border. As shown in the figure, the rise in price level is as persistent as the tariff shock, i.e., the rise in inflation is transitory. When the shock abates, in our baseline the economy actually experiences a deflation, with the price level gently returning to trend over time.[13]

As will be clear below, key to our argument is the result that, while headline CPI inflation is positive immediately following the tariff, the inflation rate in the prices set by firms (PPI inflation, which is ex-tariff) is negative. This is so despite the rise in the average price of composite material inputs, combining both domestic and imported goods, shown in the figure. A negative PPI response is indeed driven by the fall in wages the firm must pay, in turn resulting from the fall in labor demand due to the recessionary effects of the tariff. (See the response of the real wage in Figure 1a.)[14]

The relevance of demand effects of tariffs is apparent from the fall in GDP. Higher tariffs depress demand and output via different channels. The clearest and most powerful channel is the rise in the price of imported goods, used in both the round-about production structure and as consumer goods. In part, consumption demand falls sharply and persistently with the loss of real income due to higher prices (driving down real wages on impact). In part, households smooth spending intertemporally, acting on expectations that tariffs will abate in the future, bringing down consumption prices. Intertemporal substitution thus lowers current consumption on top and above current income effects (see Erceg et al., 2018 for a detailed discussion of this channel.) The combined effects cause a (temporary but) sharp fall in demand for traded goods worldwide. A different, complementary channel operates via the rise in entry costs, also reflecting higher prices of imported inputs. Higher entry costs are responsible for the sharp fall in firm entry (a fall in investment demand), and the progressive reduction in the

[13] Empirical evidence in Barattieri, et al. (2021) also suggests the effect on inflation is transitory. Impulse responses from empirical VARs in their Figures 2, 3 and 5 show the impact on inflation of imposing anti-dumping duties begins and then decays rather quickly after duties are actually imposed, allowing for a lag for the typical period of 4 months after initiation of an anti-dumping case for a determination to be reached duties to be imposed.

[14] We should note that, in equilibrium, higher prices of material inputs also motivate firms to substitute toward labor inputs, which is an additional force pushing production costs in an upward direction, since it dampens the fall in demand of labor and thus in wage.

number of firms, apparent from Figure 1a. Indirectly, a lower number of firms and product varieties also contributes to raising inflation, measured with the welfare-relevant price index. Observe that the drop in the number of firms is quite persistent, and this conveys a high degree of persistence to the fall in GDP.

By magnifying the effects of the tariff on demand, nominal rigidities amplify the macroeconomic transmission of the shock. Compare the impulse responses under flexible prices (dot-dash lines in Figure 1a) to the no-policy scenario (dashed line). The fall in GDP and the number of firms are smaller for the flexible price case for the first several quarters of the simulation. This difference mainly stems from the fact that, in the presence of nominal rigidities, firms are not able to fully pass through lower wage costs on to prices, which in our model environment would work to counteract the direct effect of the tariff. Note that, on impact, inflation is initially higher under sticky prices than under flexible prices.

In this context, a standard Taylor rule (dotted lines), i.e., responding to headline inflation, would be even less efficient than our no-policy regime. Policymakers would respond to tariffs by raising nominal rates, and thus exacerbate the fall in GDP and firm creation in the initial period. Note that, in light of our analysis, a better approach to stabilization via Taylor rules would call for a redefinition of the inflation target excluding the direct effects of the tariff, i.e., the Taylor rule should respond to PPI rather than CPI inflation. In the economy depicted in Figure 1a, applying this revised rule would flip the monetary stance from contractionary to expansionary. While suboptimal, the prescription from a Taylor rule targeting PPI inflation would be closer to the Ramsey solution we derive below (see Appendix Figure 1).

Using our model, we verify that the equilibrium fall in wages, leading to a fall production costs, dominates for a wide range of calibrations. This is a remarkable result, given that, as discussed above, tariffs raise the cost of imported materials, and hence affect the overall production costs and firm price setting. In light of this observation, however, we may expect that the transmission of a tariff shock will be specifically sensitivity to the share of material inputs in marginal costs, parameterized as ς. Based on sensitivity analysis with simulations of our model, we find that for a shares of ς=0.53 or greater, a tariff will raise PPI rather than lower it. This point will be discussed further below.

3.2 The optimal monetary response to the shock

We now come to our main question, concerning the optimal monetary policy response to a tariff-induced macroeconomic slowdown cum inflation. In Figure 1a, impulse responses for the cooperative Ramsey optimal policy are depicted as a solid line. In stark contrast to the standard Taylor rule, the optimal monetary policy response is expansionary: the nominal interest rate falls markedly in both countries. Compared to the no-policy case, the Ramsey policy response mitigates by half the fall in GDP, while it exacerbates slightly the rise in inflation in the initial period.

The overall expansionary monetary stance is seemingly at odds with an interpretation of the shock as akin to productivity or markup shocks. It is well known that the optimal monetary policy prescription in the presence of an inflationary supply shock involves monetary contraction, not an expansion. While this argument may have motivated the specification of Taylor rules in related literature (Erceg et al. (2018) and Barattieri et al. (2021)),[15] our result obviously calls for a thorough theoretical reconsideration.

The optimality of a monetary expansion is a result robust to a wide range of alternative environments, including the degree of price stickiness, the persistence of the tariff shock, and the degree of openness. As shown in Appendix Figure 2, (as expected) a lower price stickiness (ψ_P) diminishes the size of the interest rate cut. The figure shows that the magnitude of the interest rate cut also diminishes with a higher degree of persistence in the tariff (ρ_{TD}). But even if the tariff is permanent, a cut in interest rate remains the optimal monetary policy response. In addition, we verify sensitivity to international openness, by setting the trade cost $\tau_D = 0$. In our model this implies that imports of consumption goods and intermediates endogenously rise. Appendix Figure 2 verifies that a cut in interest rate remains the optimal monetary policy response in this case. Without drawing an additional figure for the no-policy case, we verify that PPI inflation following a tariff shock remains negative, even though imports now account for roughly half of all intermediates (hence material input costs are correspondingly higher). In fact, compared to the benchmark calibration, higher openness implies that GDP and hence wages fall even more in response to any given tariff shock, which reinforces the reduction in overall production costs and PPI.[16]

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[15] As a result, recent papers tend to ascribe to the monetary policy response a role in amplifying the effects of tariff shocks on macro aggregates.

[16] Our main conclusion is robust to alternative degrees of openness in the economy; while magnitudes vary, impulse responses are qualitatively all the same as the benchmark case. By way of example, if we set the trade cost parameter to 1.7 (from Epifani and Gancia, 2017), in our model the import share for

One parameter our result does depend on is the share of material inputs in marginal cost, parameterized by ς. As discussed earlier, a sufficiently high value for this share implies PPI inflation rather than deflation, due to the rising cost of imported intermediates. Figure 1b shows that progressively raising this share likewise implies a smaller interest rate cut, and potentially an optimal interest rate increase. Sensitivity analysis with model simulations indicates that a share of ς=0.57 or higher flips the optimal interest rate cut to an interest rate increase.[17] This is higher than our benchmark calibration, and somewhat higher than the range typical in the literature. Jones (2007) suggests a value of 0.434 for the overall U.S. economy, for example.[18]

We close this section highlighting the role of firm entry dynamics.[19] When we use a version of the model without firm entry dynamics (keeping n fixed at its steady state value from the benchmark simulation), the effects of the tariff on output and consumption are significantly less persistent. Nonetheless, the optimal policy still prescribes comparable interest rate cuts in response to the tariff shock.

3.3 The Macroeconomic effects of tariffs: insight from a comparative analysis with other supply shocks

To shed light on the macroeconomics of tariff shocks and the optimal policy response to them, it is instructive to compare them explicitly to other (standard) supply shocks studied in the literature. To this end, Figure 1c compares selected impulse responses for the tariff shocks in Column 1, with an adverse productivity shock in column (2), and a markup shock in column (3). All three shocks, on impact, generate a fall in output and rise in inflation. But, as discussed below, the tariff shock differs from the other two in key respects.

3.3.1 Productivity

The case of an adverse productivity shock is familiar from the literature and requires little discussion. But note in Figure 1c (column 2) that PPI and CPI inflation rise closely

---

intermediates is 0.12---a low degree of openness. The PPI deflation and optimal interest rate cut remain, but are proportionately scaled down in magnitude. See Appendix Figure 2.

[17] This is close to, but slightly higher than, the value of $\varsigma = 0.53$ that flips the sign of PPI changes from deflation to inflation. Figure 1c reports results for a calibration of $\varsigma = 0.6$, where both PPI and interest rate effects are inverted compared to the benchmark calibration.

[18] Epifani and Gancia (2017) adopt a value of 0.51, based on estimates specific to manufacturing.

[19] See Appendix Figure 4 for impulse responses.

together due to the rise in production costs; this contrasts with the tariff (column 1), in which CPI rises but firm pricing (ex-tariff) does not. In the case of the productivity shock, a monetary contraction that aggressively stabilizes inflation has the effect of bringing output close to the flexible price allocation. In this case, monetary tightening serves to redress the sticky price distortion, by bringing demand down to the level of GDP that would prevail under flexible prices and wages at the new, lower, level of productivity. In other words, a fall in demand and output is efficient when total factor productivity falls for exogenous reasons. The same logic does not apply to a tariff shock. The reason is straightforward: with tariffs in place, the flexible price allocation is distorted and hence inefficient. Note that there is a wider gap in impulse responses in the optimal policy and the flexible price allocations for the case of a tariff shock. Most definitely, the optimal policy is not aiming to replicate the flexible price allocation. To the contrary, policy aims to reduce the effects of the tariff on macro aggregates far more than required to compensate for nominal rigidities. Rather than eliminating the sticky-price distortion, monetary policy takes advantages of nominal rigidities in order to increase macro aggregates over the short run, and so improve social welfare. Policymakers tolerate a temporary burst of inflation above the long-run stability target.

Essential to understanding the motivation for the monetary policy expansion is the fact that the tariff distortion shifts expenditure away from imported goods toward domestic goods, thus sacrificing efficient gains from trade. The shortfall in production arises largely because of the price rise forced on producers, not warranted in terms of fundamental productivity or shipping technology---as already mentioned, the tariff moves the equilibrium away from an efficient allocation. Although tariff duties are rebated back to a country's residents, consumers and firms respond to the rise in the relative price of imports. The demand for imported goods is inefficiently low. But, while in the case of a symmetric tariff war monetary policy cannot directly redress relative price distortions, it can indirectly offset the distortion by pushing demand and overall production up, closer to their efficient, higher levels.

3.3.2 Markups

Like tariffs, also markup shocks impose a rise in price unwarranted by production costs. Since they introduce an artificial distortion in prices, the resulting allocation (the fall in output) is not efficient. As discussed extensively in the literature (see e.g., Clarida, Gali, and Gertler 1999 and Corsetti, et al. 2010), markup shocks fundamentally differ from productivity shocks in the way they raise a policy tradeoff between stabilizing output and inflation.

Despite these similarities, tariff shocks differ from standard markup shocks in at least three ways. First, a home tariff shock only affects prices of imported goods, while markup shocks are typically envisioned as affecting the prices of all home goods, both exported and sold domestically. Second, the revenue generated by a tariff shock accrues to the importing country, while the profits from higher markups go to firms in the exporting country. Third, tariffs are imposed directly on the buyer, thus added on top of the price set by the exporter. In the model specification in section 2 above, the markup shock (T_{MU}) appears explicitly inside the price setting rule for the firm (equation 23), while the tariff shocks (T_D) does not. Instead it appears directly in the demand function for imports (equation 7). An implication is that markups shocks are passed through onto prices only to the extent that firms raise prices in reaction to them; whereas tariff-shocks raise consumer prices one-to-one over whatever price is set by firms managers at the border. As shown above, it is indeed plausible that, facing a lower demand in the destination country due to higher cum-tariff consumer prices, exporters actually reduce their preset price at the border.

Figure 1c shows that the implications of markup shocks differ from the tariff shock. As with productivity shocks, the markup shock (column 3) implies that CPI and PPI rise closely together; whereas for a tariff shock CPI rises with the tariff, but the producer price (ex-tariff) does not. The other striking difference, of course, is that the optimal monetary policy response to the markup shock is a monetary contraction raising interest rate, in contrast with the interest rate cut in response to the tariff shock.

The difference in policy responses to the two shocks is driven primarily by the third of the three distinctions between shocks listed above. To bring the model to bear on this point, in the appendix, we include a figure (Appendix Figure 3) showing the impulse responses arising from markup shocks where we remove each of the three differences with the tariff shocks listed above. Namely, in turn, we assume that the shock only affects markups on prices for exports; we redistribute markup revenue across border through an international transfer; we add the markup on top of prices set by the firm.[20] The figure shows that the optimal policy response to a positive markup shock flips, from a rise to a cut in interest rates, only with the last change in shock specification---that placing markups outside of the firm price-setting function.[21]

[20] See Appendix section 5 for an explanation of model modifications required.

[21] Appendix Figure 3 further shows that if we just limit a markup shock to exports, but make no other alterations in the shock, the optimal rise in interest rate is smaller than in the benchmark case of the markup shock. This simply reflects the fact that the shock impacts a smaller share of the overall economy, so all impulse responses are scaled down proportionately. The figure shows that if we also introduce cross-

The economics underlying this result lay in the different interactions of the two shocks with price stickiness. In response to markup shocks, one the one hand, as shown in Figure 1c, the rise of inflation is dampened by the fact firms have sticky prices. On the other hand, nominal rigidities add persistence in the effect of the shock on prices, beyond the persistence of the shock itself. As explained in Clarida, Gali, and Gertler (1999) early on, the optimal monetary policy response to markup shocks is shaped by the persistence of inflation and expectations for future inflation. Given that markup shocks present policy makers with a tradeoff between stabilizing inflation and output, a more persistent rise in inflation places greater importance on fighting inflation in this tradeoff, leading to a greater tendency toward monetary contraction.

The tradeoff raised by tariff shocks differs in a key dimension. Because tariffs are added to the export price set by firms, the response of inflation at the consumer level is much higher on impact---and inflation falls much faster when the shock subsides. Since relative prices adjust strongly to the tariff, on impact, the tariff translates into a fall in the demand for exports---the demand contraction causes firms to optimally reduce border prices. Again, nominal rigidities mean that deflation (not inflation) in export border prices becomes persistent---weighing on the optimal monetary policy response. This becomes expansionary to prevent the persistent, costly, fall in prices.

3.4 Stochastic properties of the equilibrium allocation and welfare

Table 2 quantifies the effect of policies in terms of the standard deviations and means of endogenous variables. Relative to a Taylor rule, the optimal policy implies a lower volatility in the main macroeconomic aggregates of GDP, consumption, employment, and investment in firm entry, while it does imply slightly higher volatility in the rate of inflation. The table also reports unconditional means of variables, showing that the optimal policy implies a higher mean level of consumption together with a lower mean level of labor, a result made possible by a higher efficiency associated with a higher average number of active firms.

The table 2 also reports welfare conditional on a suboptimal policy (Taylor Rule), as a percentage of welfare under the Ramsey optimal policy. A Taylor rule policy lowers welfare relative to Ramsey by 0.082%---modest values are typical of business cycle analysis . As

country transfers of the revenue from the extra markup, this additional change in the shock specification has no effect on the optimal interest rate or impulse responses, as the cross-country transfers cancel out for a shock symmetric to both countries.

already mentioned, the optimal policy improves the allocation along many margins, including a higher average level and a lower volatility of consumption and leisure, and a higher number of product varieties produced by a larger number of active firms.

Roundabout production and firm entry are consequential for welfare. As shown in columns 2 and 3 of Table 2, the welfare loss of a Taylor rule relative to the Ramsey optimal policy falls from 0.082% in the benchmark model, to 0.057% if there is no roundabout production using material inputs ($\varsigma = 0$), and it falls to 0.024% if firm entry is also eliminated by holding the number of firms fixed.

To place our welfare results in perspective, we find it instructive to compare them with those obtained from simulating our model conditional on productivity shocks only (no tariff shock). To enhance comparability, we calibrate productivity shocks following the classic study by Backus et al. (1992), and set model parameters adopting standard value in the literature with no roundabout production or firm entry. In this standard setting, the welfare loss from pursuing a Taylor rule rather than following the Ramsey optimal policy is 0.110%, a similar (though slightly larger) loss than for the tariff shock. One may find this result surprising. The overall welfare implications of tariff shocks can be expected to be somewhat smaller compared to productivity shocks, given that trade is a modest fraction of GDP---less of the economy is directly affected by a tariff shock compared to aggregate productivity shocks. However, relative to Ramsey, a Taylor rule turns out to be much more inefficient in response to tariff shocks than in response to productivity fluctuations. In addition, we calibrate the model to recent tariff shocks, which are fairly large in magnitude. In our result, these factors seem to balance each other, resulting in comparable losses.

4. Optimal monetary stabilization of a unilateral tariff shock

We now move on from the symmetric equilibrium of a tariff war, to study the logical counterpart of an asymmetric scenario where one country (the foreign country in our case) imposes a tariff on home exports, while home tariffs are held constant. This asymmetric tariff scenario is of interest, as it permits us to study the implications of tariffs for key international variables like the exchange rate and the trade balance, where implications cancel out under symmetric shocks.

4.1 Transmission under suboptimal policy

For the no-policy case (dashed line in Figure 2a), our impulse responses resonate with the "headline case for protection" in policy debates. A foreign tariff results in a foreign trade surplus (home trade deficit). While the effect of the tariff on home GDP is distinctly contractionary, foreign GDP rises (by a smaller magnitude than the fall in home GDP). Looking deeper into the transmission of the tariff, however, the headline case for protection is not strong. As discussed by Erceg et al. (2018), the GDP in the country that imposes the tariff (the foreign country in our experiment) may rise or fall: the fall in consumption demand due to intertemporal incentives may be dominated by the rise in export demand due to the expenditure switching effect of relative prices. In our benchmark calibration the expenditure switching effect dominates, but the outcome may differ depending, e.g., on trade elasticities.[22] Moreover, the tariff also impinges on investment demand associated with the creation of new firms. The tariff has an undesired contractionary effect on firm entry in the Foreign economy, while it favors entry in the Home economy. The effects on inflation are also asymmetric across counties. Both CPI and PPI inflation rates fall at home in the initial period of the shock, while they rise in foreign.

In response to a unilateral tariff on home exports, the home exchange rate depreciates. Remarkably, holding policy rates constant, endogenous exchange rate movements offset about half of the effect of the tariff on the terms of trade.[23]

4.2 Efficient stabilization

An optimal cooperative response to a unilateral tariff shock highlights new channels and mechanisms. In Figure 2a, economic dynamics under the optimal policy are depicted with a solid line. In response to the shock, the optimal cooperative policy still prescribes substantial monetary expansion at home (lower home interest rates). The optimal response abroad, instead, is now a contraction. One reason is the asymmetric effect of the shock on PPI inflation, already highlighted in the analysis of the no-policy case: a home monetary expansion helps stabilize the negative PPI inflation at home, while a rise in foreign interest rate is required to help stabilize

[22] In our calibration the trade elasticity is somewhat higher than typical, since it is pinned down by the elasticity of substitution between any two varieties, be they home or foreign varieties. Experiments not pictured indicate that if we reduce this elasticity of substitution slightly, from 5.2 to 4, the expenditure switching effect abates enough that the response of the foreign GDP to the tariff is negative.

[23] It is worth noting that, in the no-policy scenario, the currency depreciation reflects exclusively the equilibrium response of the real (as opposed to nominal policy) rates across countries---hence the adjustment in consumption and thus in the stochastic discount factors.

the positive PPI inflation in the foreign country. Another reason is that, under cooperation, an asymmetric monetary stance redresses the impact of the tariff on the terms of trade via currency depreciation. In Figure 2a, the optimal policy significantly dampens the home terms of trade movements in the initial periods, compared to the no-policy case.

As for the symmetric tariff case, the optimal policy does not aim to bring the allocation close to the flexible price (natural rate) one.[24] On the contrary, it brings most macro aggregates to overshoot their flex-price levels (dot-dash lines in the figure). By way of example, in the flex-price allocation, the home country experiences a large GDP contraction on impact: the optimal policy almost fully reverses the negative effect of the tariff on activity. Most strikingly, the optimal policy prevents the sharp rise in Foreign GDP that would materialize in the no-policy case. The Foreign GDP actually falls into negative territory, below the flexible price level. As already noted, it is efficient for monetary authorities to take advantage of sticky prices to manipulate relative prices and offset the distinct distortion created by the foreign tariff.

As in the symmetric tariff case, the optimal policy response is at odds with strict CPI inflation targeting or a Taylor rule with a large weight on CPI inflation. To engineer the optimal currency adjustment, the optimal monetary stance actually exacerbates home inflation. The optimal policy prescribes a cut in interest rates that is an order of magnitude larger than the one implemented under a Taylor rule (dotted line in Figure 2a): the implied currency depreciation is about twice the size. A Taylor rule does little to dampen the effects of the shock on the terms of trade, the trade balance, and home GDP---these variables remain quite close to the no-policy case in Figure 2a.[25]

4.3 Tariff vs. supply shocks: comparative analysis

Again, it is instructive to explore the economics of our results by comparing tariff shocks to other supply shocks. We now consider asymmetric tariff, productivity and markup shocks, paying special attention to implications for the exchange rate (which did not enter our

[24] The global monetary stance cannot exactly replicate the pre-tariff allocation, i.e. a home currency depreciation that offsets the terms of trade response to a tariff does not undo the trade distortion. On the one hand, the optimal rate of currency depreciation is not sufficient to fully restore home GDP to the pre-tariff level, especially over time (more so, if the persistence of the tariff shock exceeds that of price stickiness). On the other hand, the implied cut in home interest rate tends to over-stimulate home consumption---causing a significant aggravation of overall inflation in the home country.

[25] Appendix Figure 5 considers the case where the social planner puts nearly all weight on the foreign country welfare rather than home country welfare. Strikingly, it is still optimal for monetary policy of the two countries to engineer a home country currency depreciation.

discussion for symmetric shocks earlier). As shown in Figure 2b, all these shocks cause a (protracted) fall in home GDP and an impact rise in foreign inflation, but the optimal policy differs in the case of tariff shocks. Relative to our previous analysis, however, the figure highlights the dynamic of the exchange rate.

As is familiar from the literature, in response to an adverse home productivity shock, a home currency appreciation raising the relative price of home exports helps bring home GDP closer to the level implied by the flexible price allocation, which is efficient. An appreciation is also optimal in response to a markup shock, reflecting the optimal anti-inflationary stance of the monetary authorities. In either case, the home currency moves opposite to the case of the optimal stabilization of a tariff shock.[26]

The reason has already been discussed in the previous section. With the tariff added to the price set by firms, the shock ends up affecting optimal pricing primarily through the contraction in demand for exports caused by a sharp rise in their prices at the consumer level. Hence the shock brings about a persistent deflationary pressure on sticky price setting. The cooperative monetary stance, on both sides of the border, aims at reducing this pressure, redressing in part the distortions due to nominal rigidities.

4.4 Welfare

To compute welfare implications under asymmetric tariff shocks, we simulate the model with home and foreign tariffs uncorrelated. The welfare computations are shown in Table 2. (Given that both countries are equally likely to experience a unilateral tariff shock, the benefits of optimal policy are symmetric across countries.) Relative to the optimal policy, the welfare loss under a Taylor rule, while still modest, is larger in the case of unilateral shocks than in symmetric tariff war: 0.25% (column 4) as opposed to 0.082%. The loss in welfare is associated with a particularly large fall in the mean level of firm entry, as well as with a fall in mean consumption and a rise in labor effort. Key features of our model contribute to these

[26] Appendix Figure 6 reports impulse responses to modifications of the markup shock. In the context of asymmetric shocks, two features are quantitatively important for explaining the different optimal policy responses to markup shocks versus tariff shocks. A markup shock modified to affect only exports and not domestic sales flips the optimal exchange rate response from appreciation to depreciation, though the home interest rate still rises somewhat. A markup shock further modified to be outside of the sticky price setting rule of firms fully replicates the dynamics and optimal policy prescription for a tariff shock, calling for both a home interest rate cut and a home currency depreciation. Introducing cross-country transfers of the revenue from markup shocks has quantitatively small effects on optimal policy or impulse responses.

results. The welfare loss is reduced by half when roundabout production is excluded from the model (column 5), and further reduced when the number of firms is held constant (column 6).[27]

5. Accounting for the effects of tariffs on comparative advantage

Tariffs and trade war can affect the composition of output and exports of a country---hence they can impinge on comparative advantage. We now bring our analysis to bear on optimal monetary policy in a model environment that incorporates a broader set of features, viewed as important by the trade literature and relevant to an assessment of the policy trade-offs raised by a new welfare relevant margin. In particular, we consider the model with two tradable sectors, which permits study of the effect of tariffs and monetary policy on comparative advantage. We will show that the intuition for the main findings from the simplified one-sector model carries through in this enriched version of the model. We demonstrate that the motivation for and the effects of an optimal expansion are actually stronger than suggested by the standard workhorse model.

In our calibration, the share of differentiated goods in the final goods bundle is $\theta = 0.61$.[28] As our baseline we assume that tariffs are raised on the differentiated goods sector---we will discuss briefly below the case of a tariff shock to the other sector. To highlight the most novel results in the richer version of our model, we begin our discussion with the case of an asymmetric shock to the tariff on home exports, reversing the order of the previous section.

5.1 Unilateral tariff shocks

As shown in Figure 3, the effects of a foreign tariff on home comparative advantage are significant. Relative to the one-sector model (compare Figures 2 and 3), the fall in Home GDP

[27] For the sake of completeness, we also report welfare analysis for an asymmetric case with just shocks to foreign tariffs on home exports, and no shocks to home tariffs. Results in Appendix Table 1 show that even in this asymmetric case, home and foreign countries benefit nearly equally from the cooperative optimal monetary policy response to counter foreign tariffs. In fact, the foreign country improvement in welfare (0.125%) is slightly higher than that for the home country (0.124%)---while the cooperative monetary policy response to foreign tariffs lowers foreign GDP relative to the Taylor rule, it raises welfare due to higher consumption.

[28] The trade literature tends to distinguish among tradable sectors varying their exposure to trade. We elaborate on this distinction, by assuming that sectors differ in terms of their exposure to the effects of monetary policy: Firms in the non-differentiated good sector are perfectly competitive and operate under flexible prices. Firms in the other sector operate as specified in section 2 and 3 of the paper. As typical in the trade literature, we continue to specify the tariff as imposed on the differentiated goods sector. Results for tariffs imposed on the non-differentiated sector are presented in the appendix (see Appendix Figures 6-7), and are discussed more below.

is smaller overall, but the muted effect on activity at the aggregate level corresponds to a large sectoral reallocation. In the no-policy scenario, for instance, the percentage fall in the production of differentiated goods in the home country is three times the percentage fall in GDP. This sectoral contraction is matched by a rise in home production of non-differentiated goods of a similar magnitude. In the foreign country, sectoral productions mirror this adjustment, moving in the opposite direction.

Comparative advantage is an important transmission channel, missed by the standard one-sector model. Namely, in response to a targeted tariff on home differentiated goods, the foreign country gains by specializing in the production of differentiated goods, the Home country loses out as it ends up producing a larger share of non-differentiated goods. In the model, this normative result reflects the welfare gains from a rise in the share of good varieties produced in a country, that residents can enjoy without paying transportation costs---according to the “home market effect” widely discussed in the literature after Krugman (1980). In the trade literature, similar shifts in comparative advantage have been associated with a reconsideration of the “optimal tariff argument” by Ossa 2007, stressing distinct benefits from specializing in the differentiated goods sector (see Corsetti et al., 2007 and Bergin and Corsetti, 2020, for a discussion).

In spite of this important difference, in our exercises the optimal monetary policy is qualitatively similar to that in the one-sector model---the interest rate movements and currency depreciation are slightly smaller in magnitude. Key to our analysis is that the degree of price stickiness is different across sectors—as a simplification, we assume that prices are sticky only in the differentiated good sector. A monetary policy expansion has the potential to manipulate two relative prices. The first is the relative price between the home and the foreign differentiated goods; the second is the relative price between differentiated goods, which have sticky prices, and non-differentiated goods, which have flexible prices. Balancing different margins, the home optimal monetary policy again calls for a deeper interest rate cut than implied by the Taylor rule, so to reduce the tariff-induced loss in both comparative advantage and aggregate production.

In our baseline, the welfare loss from following a Taylor rule instead of the optimal policy appears to be smaller in the two-sector than in the one-sector model, as shown in Table 2 (see column 8).[29] This is because (a) the differentiated goods sector accounts only for a limited share of the aggregate economy and (b) monetary stabilization is not consequential for the stabilization of the non-differentiated sector, which has flexible prices. The magnitude of the welfare losses is however sensitive to the degree of substitutability between the goods produced in the two sectors, as this crucially impinges on the extent to which a tariff shock (and the policy response to it) can drive a shift in comparative advantage. For example, if the two goods are assumed substitutes, with an elasticity of ξ=1.5 instead of 1.0 in the benchmark case, the welfare loss in the two-sector model becomes larger than that in the one-sector model (see column 8 in Table 2).

5.2 Symmetric tariff wars

In a symmetric tariff war targeting differentiated goods, the aggregate economic dynamics in the two-sector model are seemingly close to the case of the one-sector model (compare Figure 1a with Figure 4). For instance, output falls markedly in either model specification. But this aggregate result masks an important difference: the contraction in activity in the two-sector model is largely driven by the fall in differentiated goods production worldwide (similar to one experience by the home country in Figure 3). The production of non-differentiated goods actually rises. In a symmetric tariff war, there is no shift in comparative advantage across countries---rather, the tariff distortions result in a shift in the sectoral composition of output at a global level.

The optimal stance is expansionary in both countries, despite the inflationary impact of the tariff, hence once again at odds with the Taylor rule mandating a contraction. Given that a symmetric tariff war cannot be remedied by a currency depreciation, the optimal policy aims at resolving the distortion created by the tariff between differentiated and non-differentiated prices within each country. An expansionary monetary stance mitigates the contraction in the differentiated good sector, driving up overall aggregate demand as well as the prices of non-differentiated goods, which are flexible. Because of these contrasting effects, the welfare implications of the tariff shock, in terms of welfare losses from implementing a Taylor-rule policy relative to the optimal rules, again appear to be smaller in the two-sector than in the one-sector model, as reported in Table 2 (see column 7).

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[29] For purposes of stochastic simulation, we allow tariffs to both differentiated and non-differentiated goods, specifying that shocks are independent across the two sectors.

5.3 Inspecting the mechanism: sectoral reallocation

The literature that studies inter-sectoral reallocation from tariffs typically assumes that the second sector produces goods that are not internationally traded---a recent instance is Caliendo et al. (2017). For comparison, we modify our model by assuming that the non-differentiated sector produces non-tradables ($\nu = 1$). Simulation results indicate that the implications of tariff shocks for the production of differentiated goods are similar to those in Figure 3.[30] The economic transmission is however profoundly different: there is no shift in comparative advantage. The effect on the non-differentiated sector is an order of magnitude smaller if these are not traded internationally.

In the appendix, we also consider the case of a foreign tariff shock targeted to home exports of the non-differentiated goods.[31] Given that this sector has flexible prices, it is not surprising that the impulse responses are much more similar across alternative monetary policies, than for tariff shocks hitting the differentiated sector with sticky prices. The choice of monetary policy is less consequential in dealing with tariff shocks targeting a sector subject to small or no nominal price distortions.

6. Tariff wars with dominant currencies

In this section we reconsider our results moving away from the assumption of producer currency pricing, implying complete exchange rate pass-through. Proceeding in steps, we first assume that export prices are symmetrically sticky in local currencies, as may be the case for trade across, say, US and the EU; next, we will discuss the case of one dominant currency. The analysis will provide key insight on the role of exchange rate devaluation to compensate for the price distortions of a tariff.

6.1 The stabilization of tariff shocks when export prices are sticky in local currency

We first consider a specification in which prices are sticky in the local currency of the buyer (LCP), which contrasts with the assumption of producer currency pricing (PCP) in the baseline model. See section 3 of the online appendix for the modified price-setting equations, counterparts to Eqns. (23) and (24).

[30] See Appendix Figure 7.
[31] See Appendix Figures 8 and 9.

Relative to the baseline, LCP does not significantly alter the transmission of a tariff to prices or macroeconomic aggregates. By way of example, consider the scenario of a unilateral foreign tariff in the two-sector model with constant money growth policy, depicted for the LCP case in Figure 5.[32] Comparing the corresponding PCP case in Figure 3 discussed earlier, the dynamics of the terms of trade under the no-policy scenario (dashed line) are nearly identical, as are the dynamics of GDP. This suggests a first important result, which may be surprising in light of the fact that LCP price stickiness is known to dampen pass-through of exchange rate changes. Tariff shocks, however, are different from exchange rate shocks, in that tariffs are imposed directly on the importer, for any given price charged by the exporter. So even if the exporters ignore the tariff and do not change the price they charge at the dock, the importers still have to set prices after paying the full tariff increase.

Yet LCP has significant implications for the optimal policy, most apparent in the case of a unilateral tariff. Comparing the LCP case in Figure 5 with the baseline PCP case of Figure 3, the optimal monetary policy under LCP lowers the foreign interest rate instead of raising it---hence the monetary response to the tariff shock is symmetric. This significantly dampens the home currency depreciation relative to the PCP case---the exchange rate hardly moves. The GDP dynamics are correspondingly different. Under PCP, a monetary expansion can buffer the fall in home GDP by improving price competitiveness of Home products via currency depreciation. Under LCP, the optimal policy cannot rely on the exchange rate to contain the fall in economic activity and the shift in home comparative advantage between sectors.

6.2 Asymmetric effects of tariff wars under dominant currency pricing (DCP)

A specification of the model that recently has become standard in open macro literature has both Home and Foreign firms setting export prices in one dominant currency. We develop a dominant currency (DCP) version of our model by designating one country's currency as dominant and specifying that exporters in this country follow the PCP price setting equation, while those in the other country follow the LCP price setting equation.

Selected impulse responses for three different cases are summarized in Figure 6, with additional results reported in the appendix.[33] In column (1) of Figure 6, we assume that the foreign country imposes a tariff on home exports. If the home currency is dominant (i.e. home

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[32] Results for other scenarios of tariff shocks are to be found in Appendix Figures 10-12. Appendix Table 2 reports welfare analysis for the LCP model, showing similar welfare losses as for the PCP model.
[33] See Appendix Figures 13-15. Welfare implications are reported in Appendix Table 3.

exporters are subject to PCP stickiness while foreign exporters to LCP), the dynamics of macroeconomic variables closely resemble our earlier case of symmetric PCP. The optimal policy response calls for a significant cut in home interest rate, which substantially dampens home output fluctuations relative to the Taylor Rule. In column 2 of Figure 6, we assume instead that the dominant currency country is foreign (the home exporters are subject to LCP stickiness, while foreign exporters to PCP). The dynamics of response to a unilateral foreign tariff now resemble our earlier case where of symmetric LCP price stickiness. The optimal policy is closer to the Taylor rule, with a smaller cut in home interest rate and reduced stabilization of home output fluctuations.

The takeaway from Figure 6 is straightforward. Facing an asymmetric tariff shock, the dominant currency country (i.e., the U.S.) can rely to a much larger extent on monetary policy as a tool to redress the distortionary effects of the shock on output and employment, and on exchange rate movements to help absorb the shock---this is true even in a retaliatory tariff war. In a tariff war, indeed, even if the shock is symmetric, the optimal monetary stance is not. The optimal monetary response is expansionary in the dominant currency country (the home country in column (3) of Figure 6), contractionary in the other country. As a result, while GDP falls in both countries, it falls by less in the country issuing the dominant currency.

The dominant-currency country has a clear advantage since PCP price stickiness makes it possible to redress the tariff distortion via a monetary boost and currency depreciation. In the wake of a symmetric tariff shock on the differentiated good sector, the DCP country actually gains a comparative advantage in the production and export of this good.[34] In the simulation reported in column (3) of Figure 6, the home production rises relative to the pre-tariff equilibrium. [35]

7. Robustness to a low pass-through of tariffs to consumer prices

In this section we demonstrate that the main results of our analysis are robust to an environment with a low pass-through of tariffs from border to consumer prices. Recent empirical evidence in Cavallo et al. (2019) and Flaaen et al. (2020) suggests that the tariff pass

[34] As is well understood, in the case of dominant currency pricing, both the transmission of shocks across borders and policy stabilization are inherently asymmetric, even when shocks are symmetric. A point in case is the effect of a symmetric tariff war impinging on the exports of both countries.

[35] These results would be missed in exercises imposing a Taylor rule for monetary policy. In this case (as in the case of no-policy response) a dominant currency pricing would not alter a nearly symmetric transmission of the tariff shocks.

through to import prices at the dock, while not complete, is high. It is however much lower to retail prices, depending on the good.[36]

Our benchmark model with PCP correctly predicts high pass-through of tariffs to import prices at the dock. Because of a composition effect, nonetheless, the pass-through of the tariff to the sectoral consumer price index of differentiated goods in the foreign country (which includes both domestic and imported varieties) is a modest 24.3%, owing largely to home bias in this sector. This compares favorably with the pass-through to consumer prices Flaaen et al. (2020) estimate for 2016 China duties, but is smaller than the pass–through the same authors estimate for the 2018 tariffs. It is higher than the values (close to zero) estimated in Cavallo et al. (2019).

To account for a low degree of tariff pass-through at consumer level, we can model the incidence of local production inputs and/or distribution on the price of imports faced by consumers. We extend the model in the spirit of Corsetti and Dedola (2005), positing that, realistically, consumers do not purchase imported differentiated varieties directly from producers. Consumer goods combine imported goods with domestic labor and home differentiated domestic goods as inputs. Analytically, we now specify the consumption index without the direct inclusion of imported varieties: $C_{D,t} \equiv \left(\int_0^{n_t} c_t\left(h\right)^{\frac{\phi-1}{\phi}} dh \right)^{\frac{\phi}{\phi-1}}$, and correspondingly change in the consumer price indexes and demand equations.[37]

This version of the model is able to reconcile the empirical evidence of a near zero pass-through to consumers, with a near perfect pass-through at the dock. Pass-through at the dock is 99.0% for a given imported variety; pass-through to the consumer price index of differentiated goods is actually negative, and equal to -14.25%, in the initial period of the shock.[38]

Simulations indicate that even if the tariff does not impact consumer prices on a one-to-one basis, it still has large effects on GDP and other macroeconomic aggregates through the demand for imported intermediate goods by domestic producers. (See Appendix Figure 16 for a unilateral shock and Appendix Figure 17 for a symmetric shock). On impact, home GDP falls 1.45% in the low pass-through specification compared to 2.06% in the benchmark model. The

[36] See Appendix section 5.1 for a more detailed discussion of the empirical literature.
[37] See section 5.2 of the online appendix for the full list of modified equations.
[38] See section 5.2 of the online appendix for a more detailed discussion of simulation results.

optimal policy calls for a strong expansionary response to moderate the macroeconomic effects of the tariff, with a home interest rate cut (by 0.53 percentage points, compared to a cut of 0.54 percentage points in the benchmark model shown in Figure 3). We conclude that a low pass-through to consumer prices does not necessarily moderate the macroeconomic effects of tariff shocks, nor reduce the need for a thorough assessment of the correct monetary policy response.

8. Conclusion

This paper studies the optimal monetary policy response to tariff shocks in a New Keynesian model that includes elements from the trade literature, including global value chains in production and comparative advantage between two traded sectors. The most novel and consequential result from our analysis is that the optimal (cooperative) policy response to tariffs is generally expansionary, with the goal of stabilizing the output gap at the expense of further aggravating inflation.

A high degree of tolerance of short run inflation characterizes the optimal response to tariff shocks whether these are symmetric or asymmetric, i.e., tariffs are imposed by a trading partner. In the case of unilateral tariff shocks, however, the domestic and foreign monetary stance have opposite sign, to engineer a currency depreciation that helps offset the effects of tariffs on international relative prices. The optimal stabilization, however, can only imperfectly redress the distortions of the tariff on a broader set of macroeconomic aggregates.

These conclusions are largely robust to alternative economic environments with multiple traded sectors, alternative types of price stickiness, and low pass-through of tariffs to consumer prices. We find that an environment with multiple traded sectors may dampen the aggregate impact of a tariff---hence the optimal monetary expansion in response to a tariff is somewhat muted. The scope for monetary stabilization is also reduced under multiple layers of nominal rigidities, in particular under local currency price stickiness, as this is known to limit the role of the exchange rate in stabilizing the economy.

A second novel result from our analysis concerns the optimal stabilization of a tariff war in the presence of a dominant currency in trade. In response to a symmetric tariff war, the optimal stance is expansionary in the country issuing the dominant currency, because PCP price stickiness among its producers makes it possible to redress the tariff distortion. Somewhat surprisingly, but in line with standard policy prescriptions, the optimal monetary stance is contractionary in the other country. As a result, while GDP contracts in both countries, it falls by less in the country issuing the dominant currency. Although tariffs are symmetric, this country benefits from acquiring comparative advantage in differentiated goods.

We derive our results assuming monetary cooperation across borders, consistent, if only on logical grounds, with modelling tariffs as exogenous shocks. In a non-cooperative equilibrium, monetary policy fails to internalize spillovers and will generally act differently relative to our results. Because of the trade cost externality analyzed in our related work studying macro policy implications for comparative advantage (see Bergin and Corsetti, 2020), one may expect that policymakers will have a strong incentive to keep the production of a large number of varieties within their borders. The incentive to implement a monetary expansion in response to a tariff may be even stronger. We leave to future work an analysis of the strategic dimension of non-cooperative policy, and the strategic interactions between optimal monetary and trade policies.

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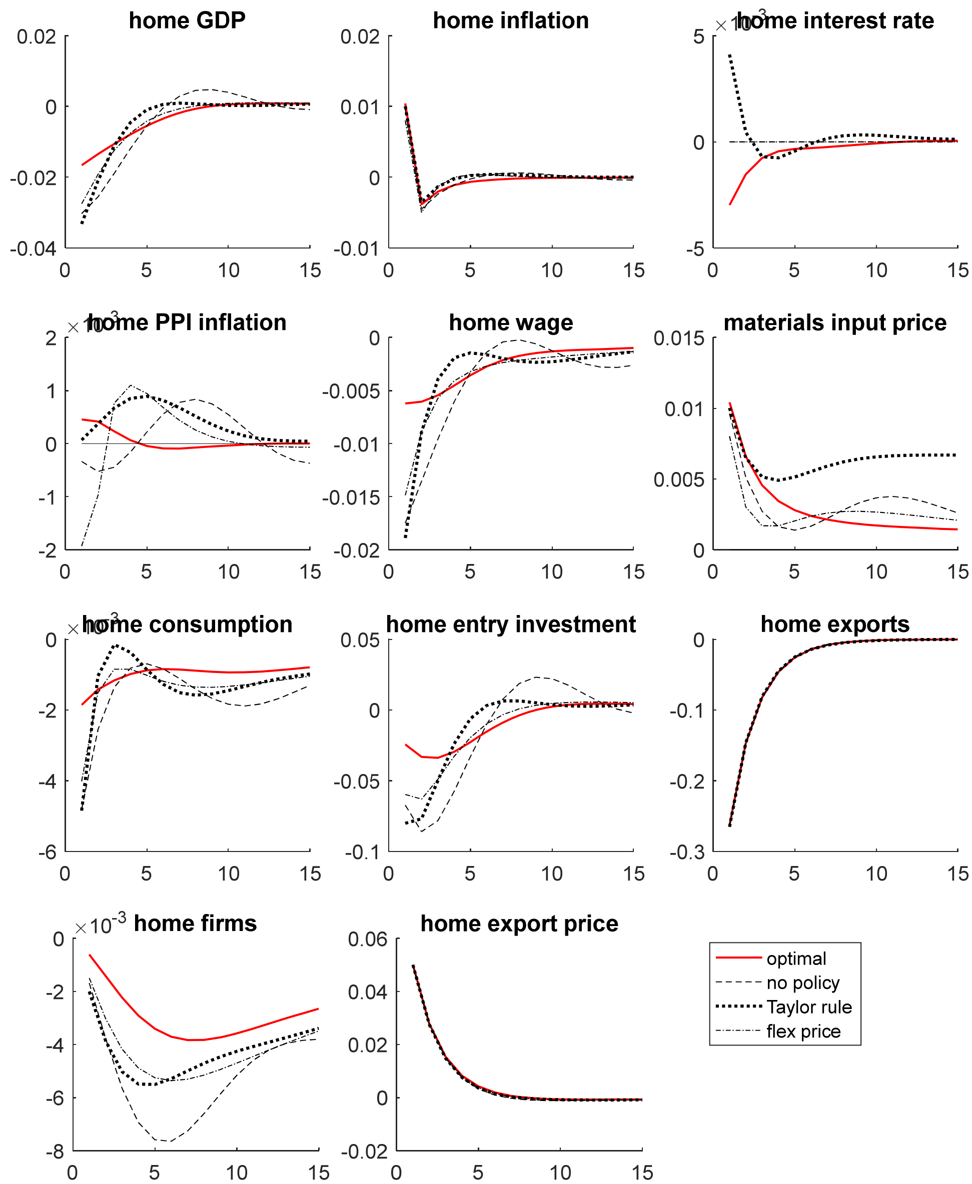
Table 1. Benchmark Parameter Values

Preferences	
Risk aversion	$\sigma = 2$
Time preference	$\beta = 0.99$
Labor supply elasticity	$1/\psi = 1.9$
Differentiated goods share	$\theta = 1, \quad 0.61$
Non-differentiated goods home bias	$\nu = 0.5$
Differentiated goods elasticity	$\phi = 5.2$
Non-differentiated goods elasticity	$\eta = 15.3$
Substitution between sectors	$\xi = 1$
Technology	
Firm death rate	$\delta = 0.1$
Price stickiness	$\psi_P = 49$
Intermediate input share	$\varsigma = 1/3$
Differentiated goods trade cost	$\tau_D = 0.44$
Non-differentiated goods trade cost	$\tau_N = 0$
Mean sunk entry cost	$\overline{K} = 1$
Firm entry adjustment cost	$\lambda = 0.10$
Bond holding cost	$\psi_B = 10^{-6}$
Tariff means	$\overline{T_D} = \overline{T_N} = 1.02$

Table 2. Moments of variables, and welfare:
Comparing Taylor Rule policy to Ramsey

	one-sector model						two-sector model		
	common shock			independent shock			common	independent	
	(1) benchmark	(2) no roundabout	(3) no firm entry or roundabout	(4) benchmark	(5) no roundabout	(6) no firm entry or roundabout	(7) benchmark	(8) benchmark	(9) Substitutes ($\xi=1.5$)
standard deviations in percent (difference from Ramsey case)									
GDP	1.50	1.35	0.15	2.38	2.26	1.80	0.70	-0.01	0.09
employment	1.13	1.27	0.17	2.57	2.64	2.16	0.47	-0.01	-0.36
consumption	0.25	0.33	0.19	-0.19	-0.14	-0.16	0.04	-0.26	0.57
firm entry investment	5.62	7.98	0.00	-6.80	-6.32	0.00	4.89	-8.13	26.39
number of firms	0.53	0.85	0.00	-1.02	-0.84	0.00	0.52	-3.17	25.68
inflation	-0.06	-0.10	-0.05	0.15	0.12	0.13	-0.28	-0.13	2.34
real exch. rate	0.00	0.00	0.00	-0.95	-0.83	-0.94	0.00	-0.72	0.12
unconditional means of variables (percent change from Ramsey case)									
GDP	0.041	0.027	0.012	0.055	0.061	0.070	0.016	0.091	0.808
employment	0.019	0.012	0.010	0.081	0.051	0.063	0.014	0.070	2.540
consumption	-0.012	-0.010	0.000	-0.078	-0.043	0.029	-0.010	-0.058	-2.883
firm entry investment	-0.052	-0.077	0.000	-0.688	-0.718	0.000	-0.086	-0.641	-15.662
number of firms	-0.052	-0.077	0.000	-0.688	-0.718	0.000	-0.086	-0.641	-15.662
Welfare (percent change from Ramsey case, conditional, in consumption units):									
	-0.082	-0.057	-0.024	-0.250	-0.149	-0.106	-0.053	-0.155	-0.293

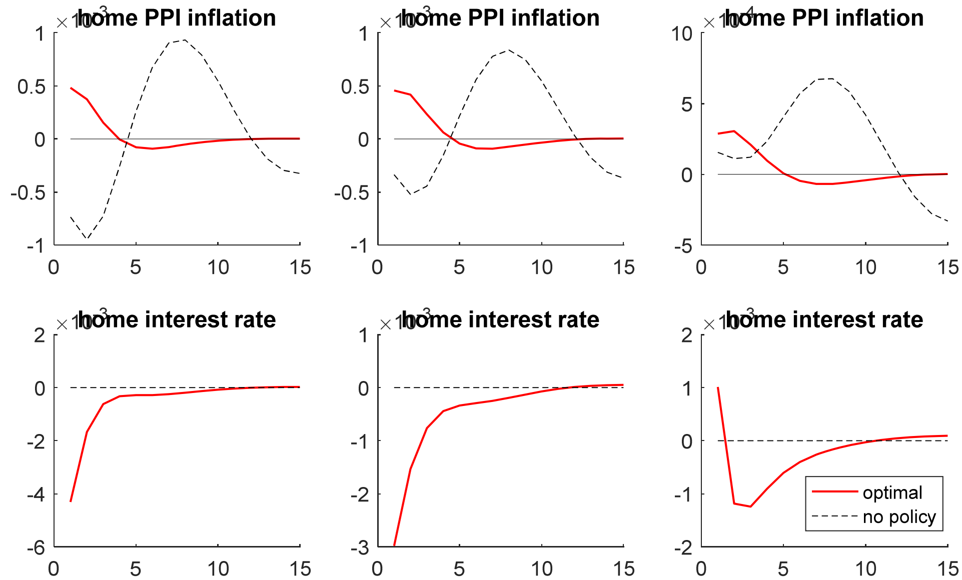
Figure 1a. Symmetric tariff war: Impulse responses to a rise in tariff in both countries, one-sector model



Vertical axis is percent deviation (0.01=1%) from steady state levels. Horizontal axis is time (in years).

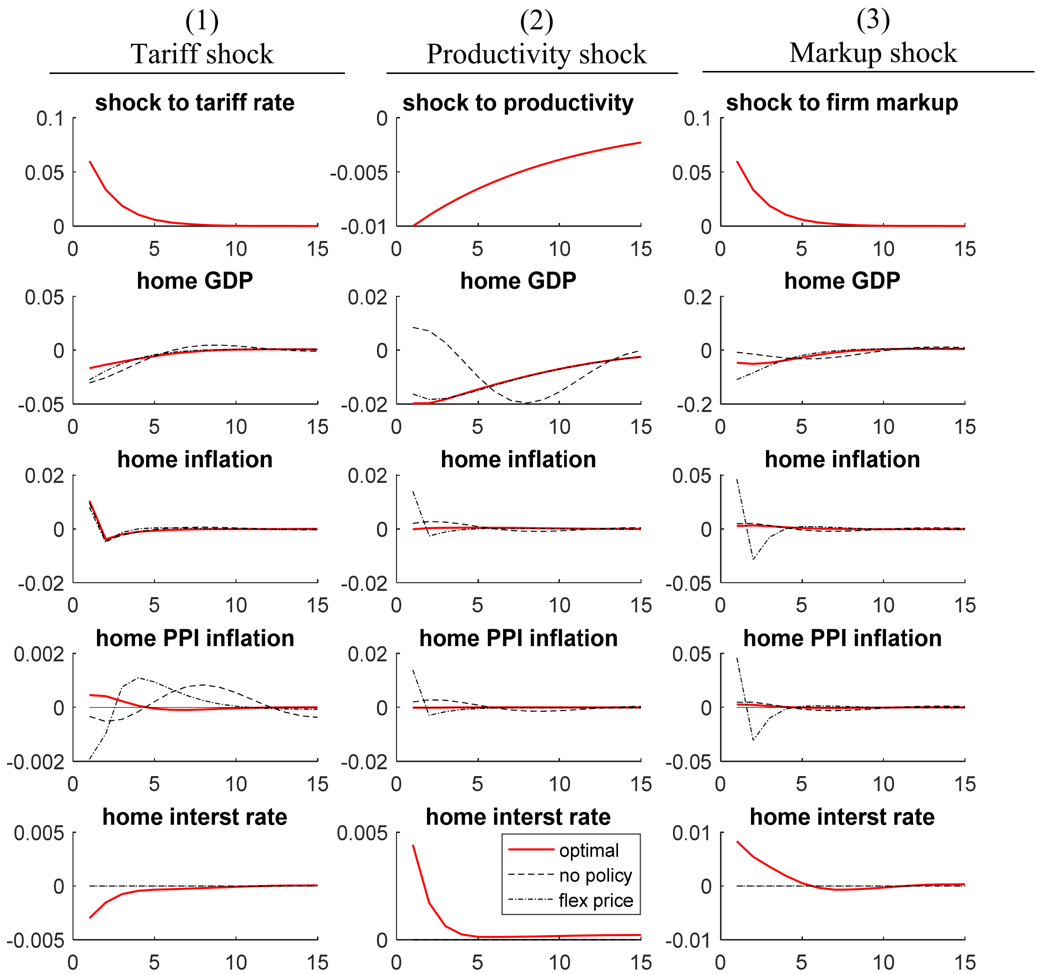
Figure 1b. Alternative calibrations of materials intput share,
symmetric tariff shock, one-sector model

(1) low materials share ($\varsigma = 0$)	(2) benchmark model ($\varsigma = 1/3$)	(3) high materials share ($\varsigma = 0.6$)



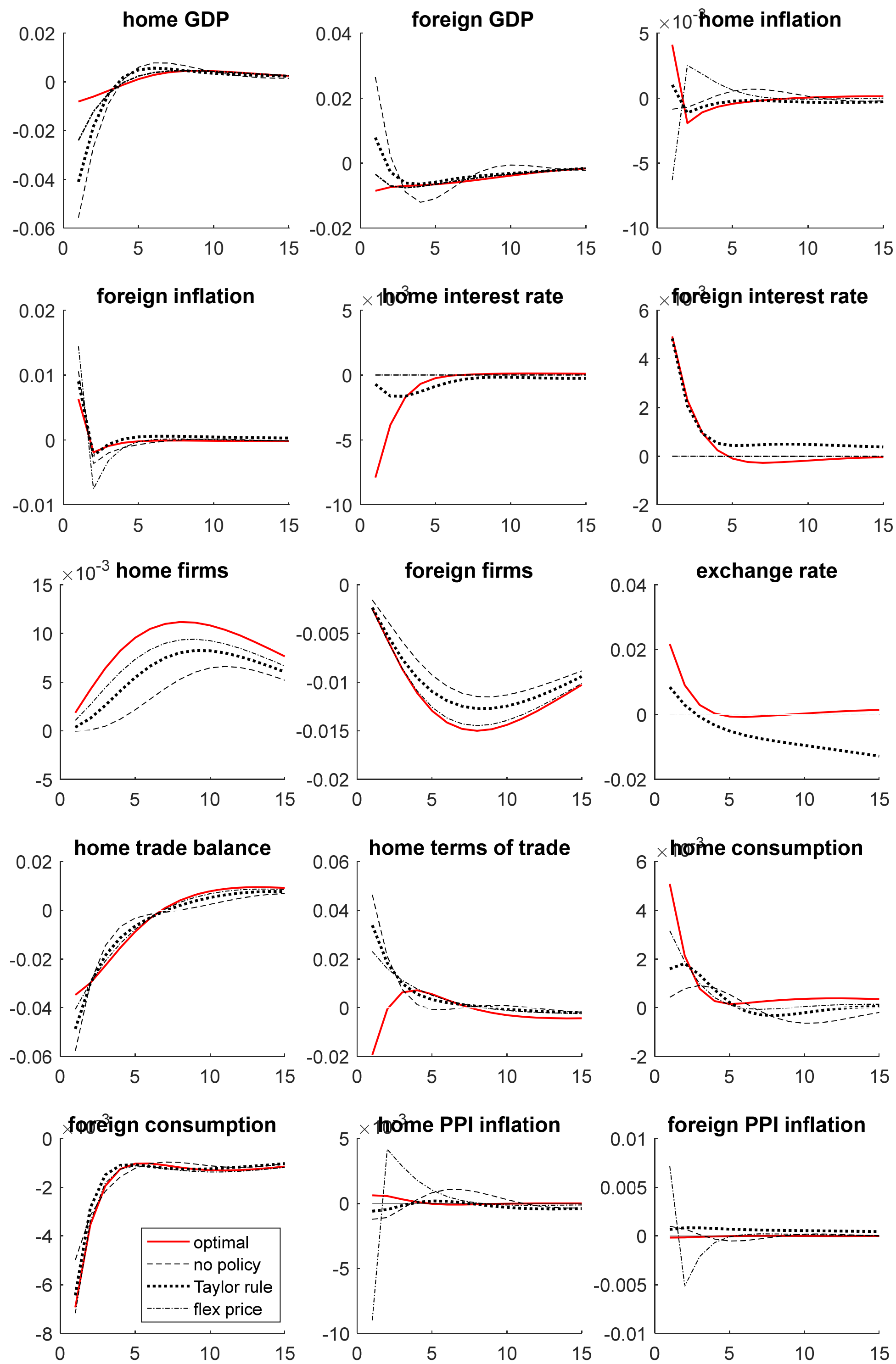
Vertical axis is percent deviation (0.01=1%) from steady state levels. Horizontal axis is time (in years).

Figure 1c. Comparison of shocks: Impulse responses to three shocks to both countries, one-sector model



Vertical axis is percent deviation (0.01=1%) from steady state levels. Horizontal axis is time (in years).

Figure 2a. Unilateral tariff: Impulse responses to a rise in foreign tariff on home exports, one-sector model



Vertical axis is percent deviation (0.01=1%) from steady state levels. Horizontal axis is time (in years).

Figure 2b. Comparison of unilateral shocks: Impulse responses to three shocks selectively impacting home country, one-sector model

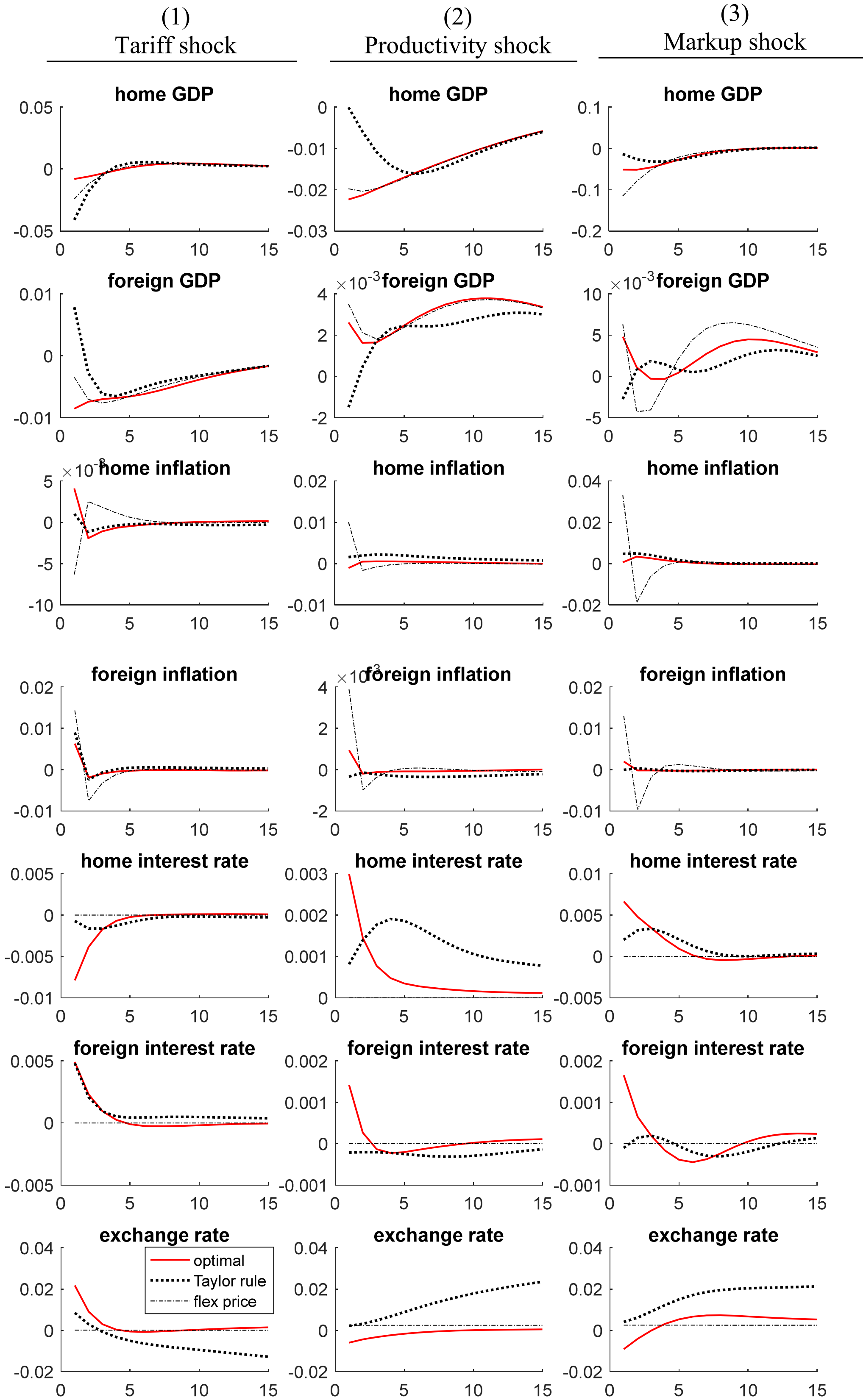
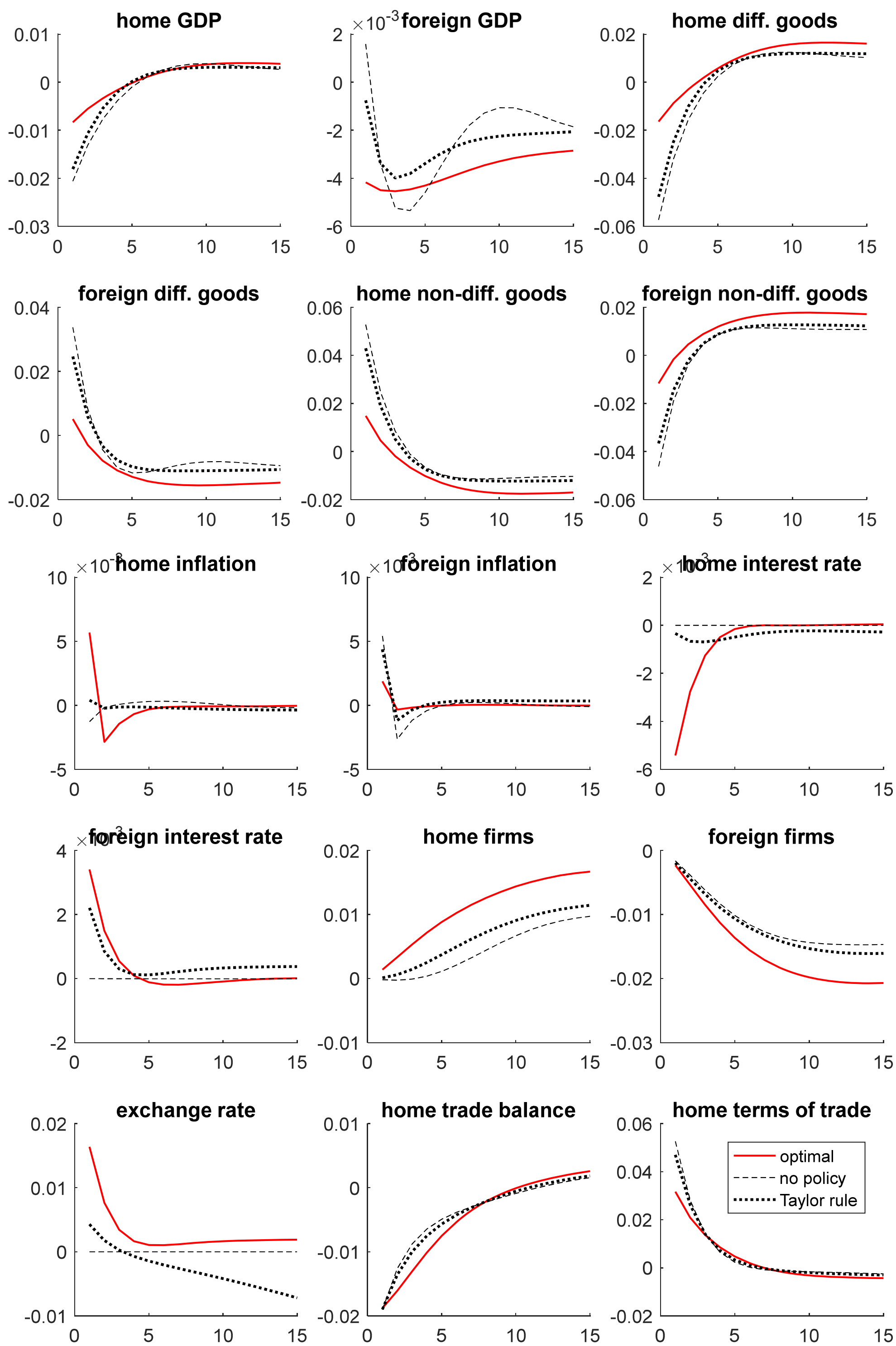
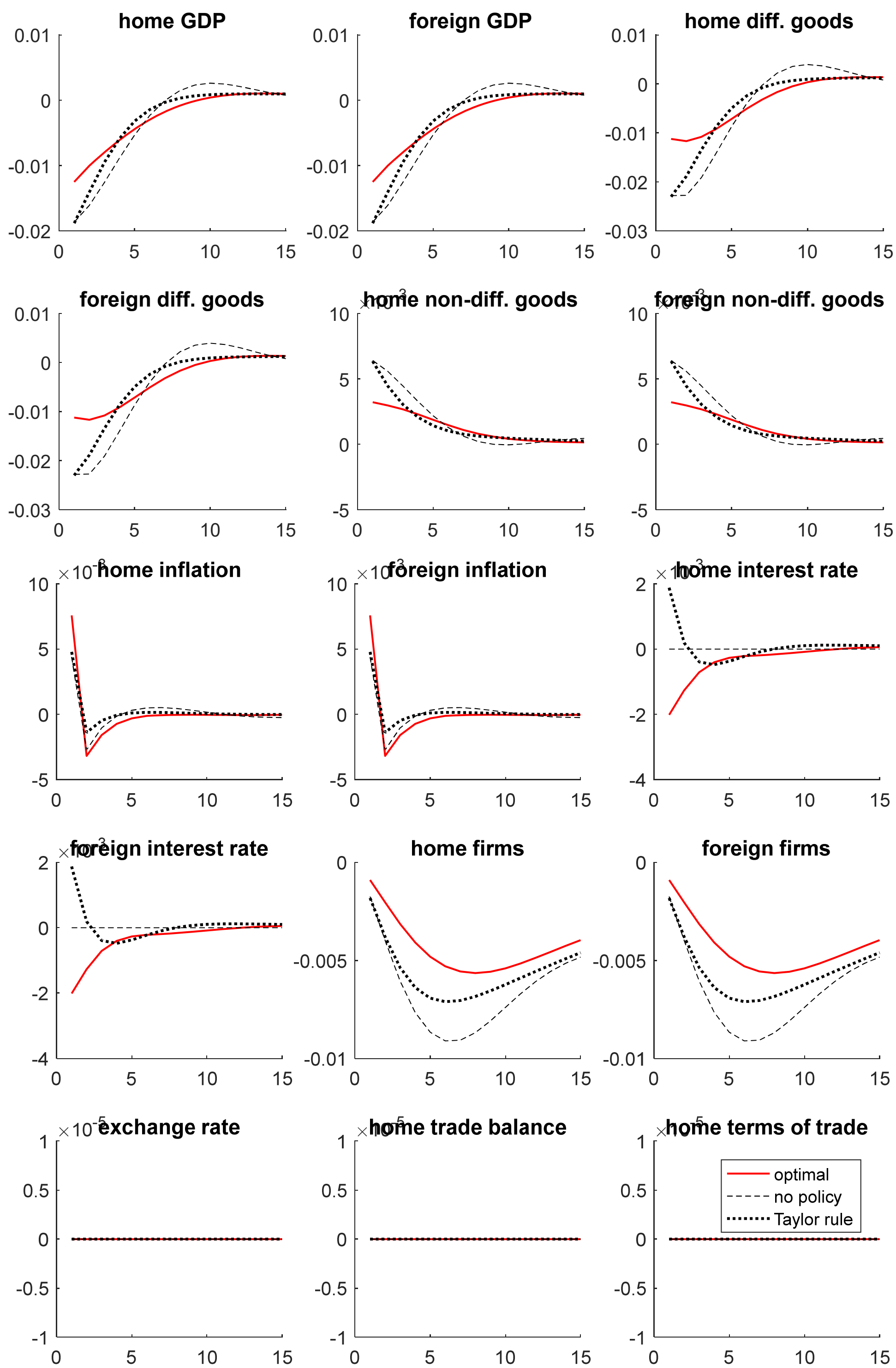


Figure 3. Impulse responses to a rise in foreign tariff on home differentiated exports, two-sector model



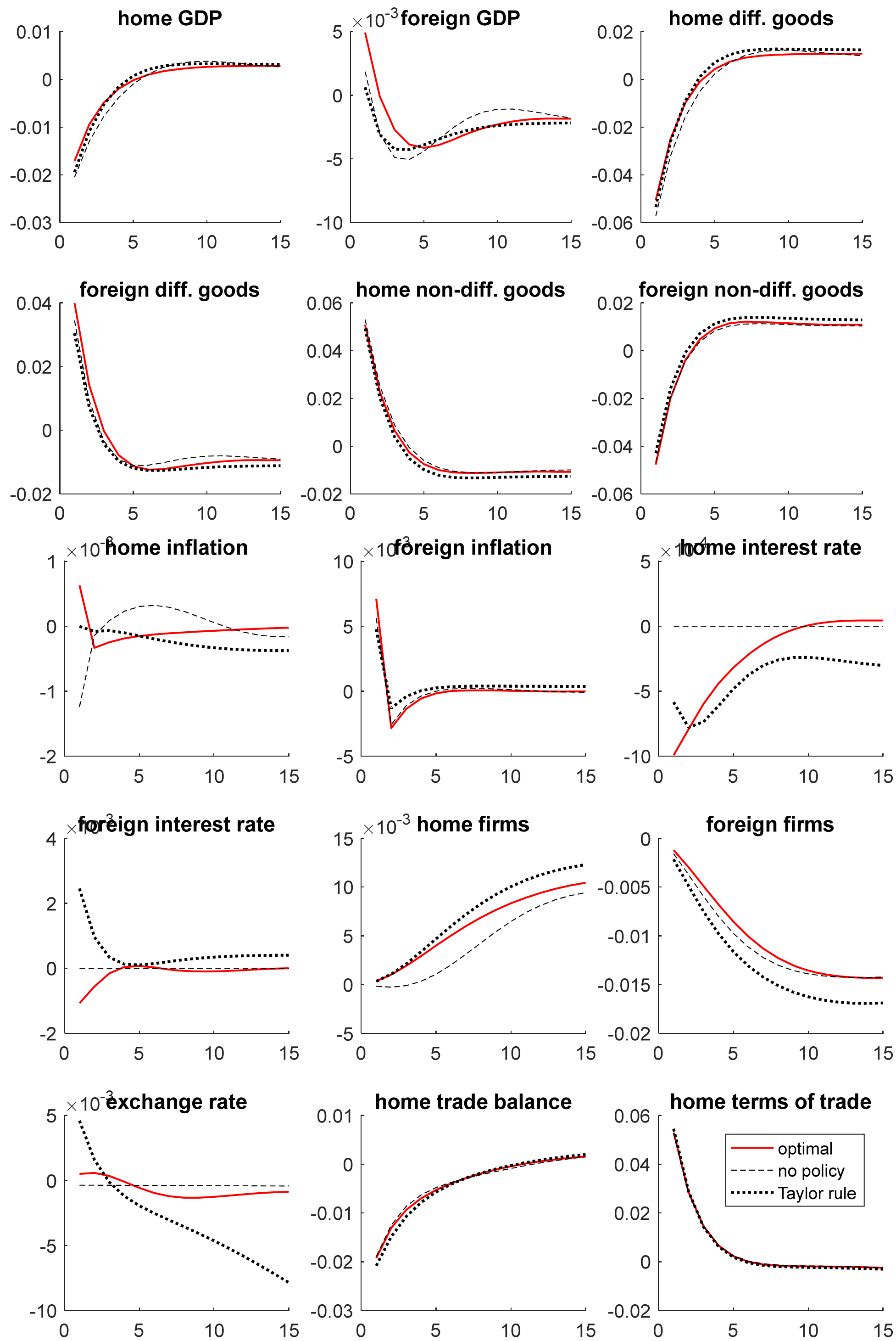
Vertical axis is percent deviation (0.01=1%) from steady state levels. Horizontal axis is time (in years).

Figure 4. Impulse responses to a rise in tariff on differentiated goods in both countries, two-sector model



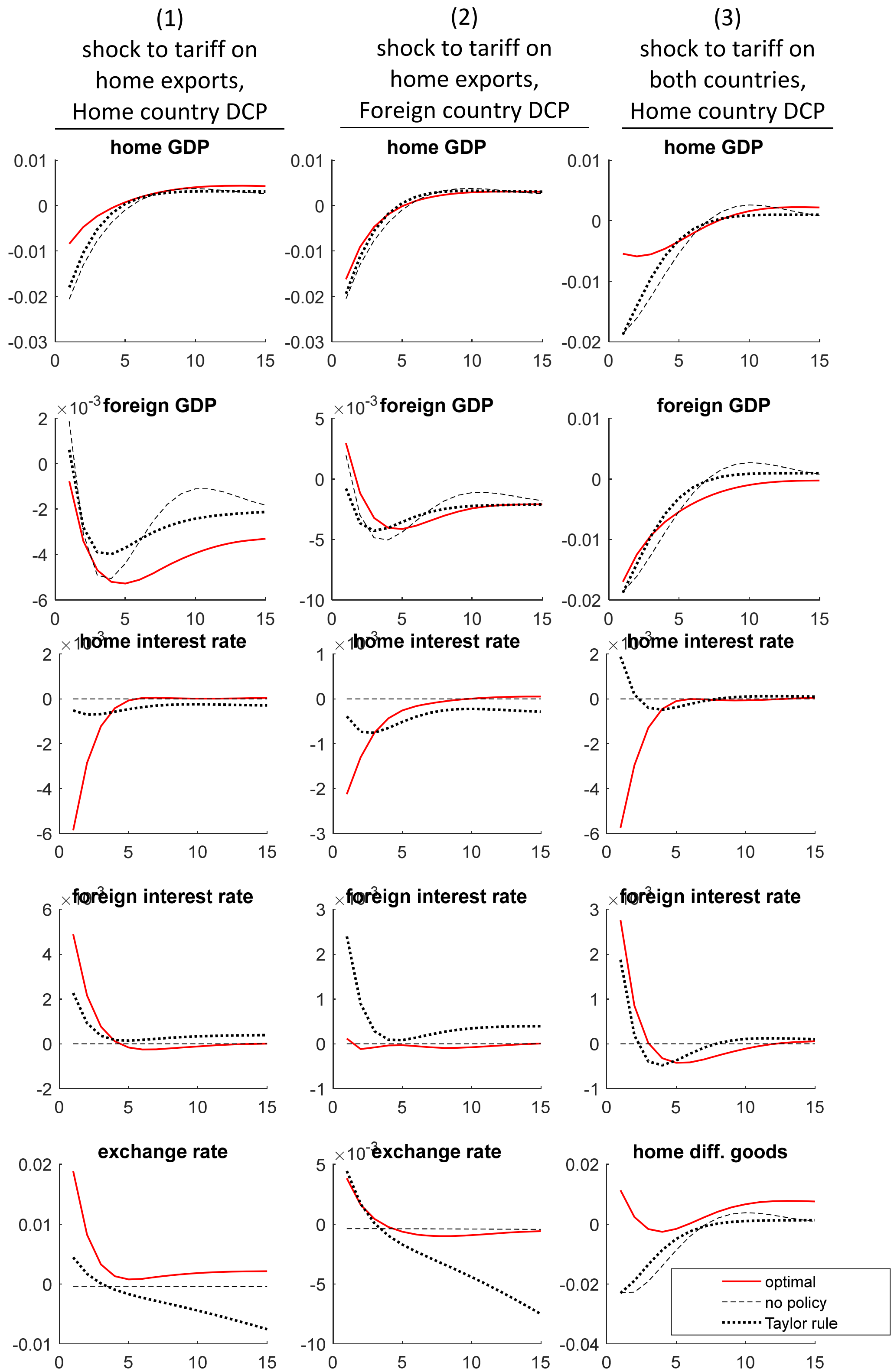
Vertical axis is percent deviation (0.01=1%) from steady state levels. Horizontal axis is time (in years).

Figure 5. Local Currency Pricing: Impulse responses to a rise in foreign tariff on home differentiated exports, two-sector model, LCP



Vertical axis is percent deviation (0.01=1%) from steady state levels. Horizontal axis is time (in years).

Figure 6. Impulse responses under various specifications of dominant currency pricing (tariff on differentiated goods in two-sector model)



Vertical axis is percent deviation (0.01=1%) from steady state levels. Horizontal axis is time (in years). Column (1) highlights selected results from Appendix Figure 13; column (2) from Appendix Figure 14, and column (3) from Appendix Figure 15.

Online Appendix

For
"The Macroeconomic Stabilization of Tariff Shocks:
What is the Optimal Monetary Response?"

by
Paul R. Bergin
and
Giancarlo Corsetti

1. Demand equations not listed in text

The composition of expenditure on adjustment costs, both for prices and bond holding, follows the same preferences as for consumption, and the associated demands mirror Eqs. (4)-(9). Adjustment costs for bond holding are as follows:

$$AC_{B,D,t} = \theta P_t AC_{B,t} / P_{D,t}$$

$$AC_{B,N,t} = (1-\theta) P_t AC_{B,t} / P_{N,t}$$

$$d_{AC,B,t}(h) = \left(p_t(h) / P_{D,t}\right)^{-\phi} AC_{B,D,t}$$

$$d_{AC,B,t}(f) = \left(p_t(f) T_{D,t} / P_{D,t}\right)^{-\phi} AC_{B,D,t}$$

$$AC_{B,H,t} = \nu \left(P_{H,t} / P_{N,t}\right)^{-\eta} AC_{B,N,t}$$

$$AC_{B,F,t} = (1-\nu)\left(P_{F,t} T_{N,t} / P_{N,t}\right)^{-\eta} AC_{B,N,t} .$$

The economy-wide demand for goods arising from price adjustment costs sums across the demand arising among *n* home firms: $AC_{P,t} = n_t AC_{P,t}(h)$. This is allocated as follows:

$$AC_{P,D,t} = \theta P_t AC_{P,t} / P_{D,t}$$

$$AC_{P,N,t} = (1-\theta) P_t AC_{P,t} / P_{N,t}$$

$$d_{AC,P,t}(h) = \left(p_t(h) / P_{D,t}\right)^{-\phi} AC_{P,D,t}$$

$$d_{AC,P,t}(f) = \left(p_t(f) T_{D,t} / P_{D,t}\right)^{-\phi} AC_{P,D,t}$$

$$AC_{P,H,t} = \nu \left(P_{H,t} / P_{N,t}\right)^{-\eta} AC_{P,N,t}$$

$$AC_{P,F,t} = (1-\nu)\left(P_{F,t} T_{N,t} / P_{N,t}\right)^{-\eta} AC_{P,N,t} .$$

The demand for differentiated goods for use as intermediates in production mirrors Eqs. (6)-(7), as follows:

$$d_{G,t}(h) = \left(p_t(h) / P_{D,t}\right)^{-\phi} G_t$$

$$d_{G,t}(f) = \left(p_t(f) T_{D,t} / P_{D,t}\right)^{-\phi} G_t .$$

The demand for differentiated goods for use in the sunk entry investment of new firms mirrors Eqs. (6)-(7), as follows:

$$d_{K,t}(h) = \left(p_t(h) / P_{D,t}\right)^{-\phi} ne_t K_t$$

$$d_{K,t}(f) = \left(p_t(f) T_{D,t} / P_{D,t}\right)^{-\phi} ne_t K_t .$$

2. Market clearing conditions and shock processes not listed in the text

Market clearing for the non-differentiated goods market requires:

$$y_{H,t} = C_{H,t} + AC_{P,H,t} + AC_{B,H,t} + \left(1+\tau_N\right)\left(C^*_{H,t} + AC^*_{P,H,t} + AC^*_{B,H,t}\right)$$

$$y_{F,t} = \left(1+\tau^*_N\right)\left(C_{F,t} + AC_{P,F,t} + AC_{B,F,t}\right) + C^*_{F,t} + AC^*_{P,F,t} + AC^*_{B,F,t} .$$

The market clearing condition for the manufacturing goods market is given in Eq. (19) in the main text.

Labor market clearing requires:

$$\int_0^{n_t} l_t(h) dh + l_{H,t} = l_t .$$

Bond market clearing requires:

$$B_{Ht} + B^*_{Ht} = 0$$

$$B_{Ft} + B^*_{Ft} = 0 .$$

Balance of payments requires:

$$\int_0^{n_t} p^*_t(h)\left(d^*_t(h)\right) dh - \int_0^{n^*_t} p_t(f)\left(d_t(f)\right) df + P^*_{Ht}\left(C^*_{H,t} + AC^*_{P,H,t} + AC^*_{B,H,t}\right)$$
$$-P_{F,t}\left(C_{F,t} + AC_{P,F,t} + AC_{B,F,t}\right) - i_{t-1} B^*_{H,t-1} + e_t i^*_{t-1} B_{F,t-1} = \left(B^*_{H,t} - B^*_{H,t-1}\right) + e_t\left(B_{F,t} - B_{F,t-1}\right).$$

Shocks are assumed to follow joint log normal distributions. In the case of tariffs, we can write

$$\begin{bmatrix} \log T_{D,t} - \log \overline{T_D} \\ \log T^*_{D,t} - \log \overline{T^*_D} \\ \log T_{N,t} - \log \overline{T_N} \\ \log T^*_{N,t} - \log \overline{T^*_N} \end{bmatrix} = \rho_T \begin{bmatrix} \log T_{D,t-1} - \log \overline{T_D} \\ \log T^*_{D,t-1} - \log \overline{T^*_D} \\ \log T_{N,t-1} - \log \overline{T_N} \\ \log T^*_{N,t-1} - \log \overline{T^*_N} \end{bmatrix} + \varepsilon_{Tt}$$

with autoregressive coefficient matrix ρ_T, and the covariance matrix $E\left[\varepsilon_{Tt}\varepsilon_{Tt}^{'}\right]$. In the case of productivity shocks:

$$\begin{bmatrix} \log \alpha_{D,t} - \log \overline{\alpha_D} \\ \log \alpha_{N,t} - \log \overline{\alpha_N} \end{bmatrix} = \rho_A \begin{bmatrix} \log \alpha_{D,t-1} - \log \overline{\alpha_D} \\ \log \alpha_{N,t-1} - \log \overline{\alpha_N} \end{bmatrix} + \varepsilon_{At}$$

with autoregressive coefficient matrix ρ_A, and the covariance matrix $E\left[\varepsilon_{At}\varepsilon_{At}^{'}\right]$. Foreign productivity follows an analogous process.

In the case of markup shocks:

$$\begin{bmatrix} \log T_{MU,t} - \log \overline{T_{MU}} \\ \log T^*_{MU,t} - \log \overline{T^*_{MU}} \end{bmatrix} = \rho_{MU} \begin{bmatrix} \log T_{MU,t} - \log \overline{T_{MU}} \\ \log T^*_{MU,t} - \log \overline{T^*_{MU}} \end{bmatrix} - \varepsilon_{MUt}$$

3. Price-setting equations assuming stickiness in the local currency (LCP model)

Under the assumption that firms set separate prices in the two markets, in units of domestic currency for sale in the domestic market, and in units of foreign currency for sale in the foreign market, the price setting equations (Eqns. 23-24) are replaced by the following:

$$p_t(h) = \frac{\phi}{\phi-1} mc_t + \frac{\psi_P}{2}\left(\frac{p_t(h)}{p_{t-1}(h)} - 1\right)^2 p_t(h) - \psi_P \frac{1}{\phi-1}\left(\frac{p_t(h)}{p_{t-1}(h)} - 1\right)\frac{p_t(h)^2}{p_{t-1}(h)}$$
$$+\frac{\beta\psi_P}{\phi-1} E_t\left[\frac{\mu_t}{\mu_{t+1}}\frac{\Omega_{H,t+1}}{\Omega_{H,t}}\left(\frac{p_{t+1}(h)}{p_t(h)} - 1\right)\frac{p_{t+1}(h)^{2-\phi}}{p_t(h)^{1-\phi}}\right]$$

and

$$p^*_t(h) = \frac{\phi}{\phi-1}\frac{mc_t(1+\tau_{Dt})}{e_t} + \frac{\psi_P}{2}\left(\frac{p^*_t(h)}{p^*_{t-1}(h)} - 1\right)^2 p^*_t(h) - \frac{1}{\phi-1}\psi_P\left(\frac{p^*_t(h)}{p^*_{t-1}(h)} - 1\right)\frac{p^*_t(h)^2}{p^*_{t-1}(h)}$$
$$+\beta\frac{\psi_P}{\phi-1}E_t\left[\frac{\mu_t}{\mu_{t+1}}\frac{\Omega^*_{H,t+1}}{\Omega^*_{H,t}}\left(\left(\frac{p^*_{t+1}(h)}{p^*_t(h)} - 1\right)\frac{e_{t+1}}{e_t}\frac{p^*_{t+1}(h)^{2-\phi}}{p^*_t(h)^{1-\phi}}\right)\right]$$

where $\Omega_{H,s} = \left(\frac{p_s(h)}{P_{D,s}}\right)^{-\phi}\left(C_{D,s} + G_s + ne_s(1-\theta_K)K_s + AC_{P,D,s} + AC_{B,D,s}\right)\frac{1}{\mu_s}$, and

$$\Omega^*_{H,s} = \left(\frac{(1+\tau_D) p_s(h)}{e_s P^*_{D,s}} \right)^{-\phi} \left(C^*_{D,s} + G^*_s + ne^*_s (1-\theta_K) K^*_s + AC^*_{P,D,s} + AC^*_{B,D,s} \right) \frac{1}{\mu_s}.$$

4. Selection of parameter values for numerical experiments

Where possible, parameter values are taken from standard values in the literature. See table Risk aversion is set at $\sigma = 2$; labor supply elasticity is set at $1/\psi = 1.9$ following Hall (2009). Consistent with a quarterly frequency, $\beta = 0.99$.

The price stickiness parameter is set at ψ_p=49, a value which implies in simulations of a productivity shock that approximately three quarters the firms resetting price after the first year. [39] The firm death rate is set at δ =0.025. The mean sunk cost of entry is normalized to the value $\overline{K}$=1, and the adjustment cost parameter for new firm entry, λ, is taken from Bergin and Corsetti (2020). The share of intermediates in differentiated goods production follows Bergin and Corsetti (2020) to a modest value of ζ =1/3.

To choose parameters for the differentiated and non-differentiated sectors we draw on Rauch (1999). In the two-sector version of the model, we choose θ so that differentiated goods represent 55 percent of U.S. trade in value; in the one-sector version θ =1. We assume the two countries are of equal size with no exogenous home bias, $\nu = 0.5$, but allow trade costs to determine home bias ratios. To set the elasticities of substitution within the differentiated and non-differentiated sectors we draw on the estimates by Broda and Weinstein (2006), classified by sectors based on Rauch (1999). The Broda and Weinstein (2006) estimate of the elasticity of substitution between differentiated goods varieties is ϕ=5.2 (the sample period is 1972-1988). The corresponding elasticity of substitution for non-differentiated commodities is η = 15.3. We initially adopt a Cobb-Douglas specification for the aggregator function combining the two sectors ($\xi \to 1$), but sensitivity analysis will report results for alternative calibrations of this parameter.

[39] As is well understood, a log-linearized Calvo price-setting model implies a stochastic difference equation for inflation of the form $\pi_t = \beta E_t \pi_{t+1} + \lambda mc_t$, where *mc* is the firm's real marginal cost of production, and where $\lambda = (1-q)(1-\beta q)/q$, where *q* is the constant probability that a firm must keep its price unchanged in any given period. The Rotemberg adjustment cost model used here gives a similar log-linearized difference equation for inflation, but with $\lambda = \phi/\psi_P$. Under our parameterization, an adjustment cost parameter of ψ_P = 49 implies a Calvo probability of not changing price *q* = 0.725. This implies that 27.5% of firms have reset price after one quarter, and that 72% ($1-0.725^4$) of firms have reset after one year.

To set trade costs, we calibrate τ_D so that exports represent 26% of GDP, as is the average in World Bank national accounts data for OECD countries from 2000-2017.[40] This requires a value of τ_D =0.44.[41] This is somewhat larger than the value of 0.25 used for trade costs in Obstfeld and Rogoff, (2001), but it is small compared to some trade estimates, such as 1.7 suggested by Anderson and van Wincoop 2004, and adopted by Epifani and Gancia (2017). We follow the standard assumption of trade models that the homogeneous good is traded frictionlessly (τ_N =0).

Calibration of policy parameters for the historical monetary policy Taylor rule are taken from Coenen, et al. (2010): γ_i=0.7, γ_p =1.7, γ_Y=0.1.

The process for tariff shocks is calibrated with a mean value of 1.02 (2 percentage point mean tariff rate) to match U.S. tariff data in Barattieri et al. (2021). The autoregressive parameter is set to 0.56, estimated from Barattieri et al. (2021).[42] The standard deviation of 6 percentage points is taken from Caldara et al. (2020), chosen to capture tariff increases that have been threatened on imports from China and on imports of autos and motor-vehicle parts in 2018-2019.

When productivity shocks are simulated, we calibrate based on standard values from Backus et al. (1992). Innovations follow a standard deviation of 1% with an international correlation of 0.25. Autoregressive coefficients are chosen as 0.90 on own lags and 0.09 on lags of foreign productivity. Parameterization of markups shocks will be identical to that for tariff shocks, to facilitate comparison.

5. Modifications of model for alternative versions of markup shock

To specify that markup shocks only affect export prices, the firm budget constraint (20) is modified as follows:

$$\pi_t(h) = p_t(h)d_t(h) + e_t p_t^*(h)d_t^*(h)T_{MU,t} - mc_t y_t(h) - P_t AC_{p,t}(h).$$

which implies that the price setting equation for domestic sales (23) does not include a markup shock, but the equation for exports (24) does, as follows:

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[40] See https://data.worldbank.org/indicator/NE.EXP.GNFS.ZS?locations=OE.

[41] To coincide with standard accounting definitions, differentiated goods used as intermediates are included in the measure of exports, and excluded in the measure of GDP, as is appropriate.

[42] We do not adopt the standard deviation of shocks estimated in Barattieri et al (2021), as these estimates are based on a sample from normal times with low volatility in tariffs compared to the more recent period of Brexit and Trump tariffs.

$$p_t^*(h)=\frac{\phi}{(\phi-1)T_{MU,t}}\frac{(1+\tau_D)mc_t}{e_t}+\frac{\psi_P}{2}\left(\frac{p_t^*(h)}{p_{t-1}^*(h)}-1\right)^2 p_t^*(h)-\psi_P\frac{1}{\phi-1}\left(\frac{p_t^*(h)}{p_{t-1}^*(h)}-1\right)\frac{p_t^*(h)^2}{p_{t-1}^*(h)}$$
$$+\frac{\psi_P}{\phi-1}E_t\left[\beta\frac{\Omega_{t+1}^*}{\Omega_t^*}\left(\frac{p_{t+1}^*(h)}{p_t^*(h)}-1\right)\frac{p_{t+1}^*(h)^2}{p_t^*(h)}\right]$$

In addition, the government budget constraint (31) becomes:

$$T_t=(M_t-M_{t-1})+(T_{D,t}-1)n_{t-1}^*d_t(f)+(1-T_{MU,t})n_{t-1}^*d_t(f)$$
$$+(T_{N,t}-1)(C_{F,t}+AC_{P,F,t}+AC_{B,F,t})$$

Next, specifying an international swap of revenue from the markup shocks in each country requires the home government budget constraint be modified further:

$$T_t=(M_t-M_{t-1})+(T_{D,t}-1)n_{t-1}^*d_t(f)+(1-T_{MU,t}^*)n_{t-1}d_t^*(h)$$
$$+(T_{N,t}-1)(C_{F,t}+AC_{P,F,t}+AC_{B,F,t})$$

Finally, specifying that markup shock for exports are placed outside of price stickiness implies the price setting rule (24) becomes the following (conditional on maintaining the specification above that markup shocks do not affect domestic prices):

$$p_t^*(h)=\frac{(1+\tau_D)}{e_tT_{MU,t}}p_t(h).$$

6. Model with low pass-through of tariffs to consumer prices

In this section, we investigate the sensitivity of our results to the degree of pass-through of tariffs to consumer prices. The motivation from this exercise comes from empirical studies that, utilizing data from the recent trade war, have documented a high degree of pass-through of tariffs to import prices measured at the dock, but have produced mixed evidence on the pass-through to prices at the consumer level. We will show that extending our model to account for distribution can bring our analysis closely in line with a realistic account of differences in tariff pass-through at the dock and at consumer level. Remarkably, our main conclusions and results remain broadly unaffected in this exercise.

6.1 Empirical motivation for low tariff pass-through

The empirical literature on tariff pass-through has flourished after 2016, due to the combined effects of Brexit and the aggressive trade initiatives by the Trump administration. Based on regressions of U.S. import price indexes controlling for inflation, Cavallo et al.

(2019) find that, for a typical good imported from China, only 7.5% of a tariff increase is offset by a drop in price set by the exporter: the pass-through to prices at the dock is 92.5%. When additional controls are included in the regression, the change in exporter price is insignificantly different from zero, implying a pass-through indistinguishable from 100%. Looking at retail prices, however, the same authors find mixed results, differentiated by product. By way of example, pass-through appears high for washing machines, initially slow but eventually high pass-through for tires, and low pass-through for bicycles. Flaaen et al. (2020) find a pass-through as low as 21% for washing machines after the 2016 anti-dumping duties on China; and in a range between 58% and 125% after the 2018 tariffs on Chinese exports (depending on estimation method). Both Flaaen et al. (2020) and Cavallo et al. (2019) highlight that tariffs led to a similar degree of price rise across washing machine brands directly affected by the tariffs, and other brands, including domestic brands, not affected directly by the tariff.[43]

Our benchmark model with PCP fits the empirical evidence of nearly complete pass-through of tariffs to import prices at the dock. Price stickiness at the dock increases the degree of tariff pass-through, since it precludes producers from adjusting their export price to offset tariffs imposed on importers. To underscore this point, using as our reference the case of a unilateral foreign tariff in the two-sector sticky-price model with constant money growth, we find that pass-through of the tariff to the import price at the dock is 100%.[44] In the flexible price version of the model, exporters would lower the ex-tariff price by 5.7%, implying a pass-through of 94.3%.

The fit of our benchmark model in terms of pass-through to retail prices is more difficult to evaluate, given the range of estimates in the recent empirical literature. In the reference case of the model singled out above, we find that the pass-through of the tariff to the sectoral consumer price index of differentiated goods in the foreign country (which includes

[43] Cavallo et al. (2019) interpret this as evidence that the direct effect of the tariff on import prices was close to zero – estimating regressions based on a comparison of brands directly affected by the tariff and those not affected, they find that a 20 percent tariff is associated with only a 0.9 percent increase in the retail prices of affected household goods, and a 1.4 percent increase in the retail prices of affected electronics products after one year. In contrast, Flaaen et al. (2020) attribute the similarity among affected and unaffected brands to factors such as rising materials costs or to domestic producers using their market power to raise prices.
[44] To measure pass-through to an import price index, we can define a data-consistent import price index that holds constant the number of varieties: $\widehat{P}^*_{Mt} = \left(\bar{n}\left(p^*_t(h)T^*_{D,t}\right)^{1-\phi}\right)^{\frac{1}{1-\phi}} = \bar{n}^{\frac{1}{1-\phi}} p^*_t(h)T^*_{D,t}$. The percentage change from steady state for this index will be identical to that simply of the foreign import price of a representative home variety: $p^*_t(h)T^*_{D,t}$.

both domestic and imported varieties) is a modest 24.3%, owing largely to home bias in this sector.[45] This compares favorably with the pass-through to consumer prices Flaaen et al. (2020) estimate for 2016 China duties, but is smaller than the pass–through the same authors estimate for the 2018 tariffs. It is higher than the values (close to zero) estimated in Cavallo et al. (2019).

Price stickiness in local currency (LCP) does not reduce tariff pass-through in the model. In the scenario of a unilateral foreign tariff in the two-sector model with constant money growth policy, depicted in Figure 5, home exporters actually *raise* their ex-tariff export price. The pass-through of the tariff to the import price is 108.7%, larger than the 100% found for the PCP model; the pass-through to the consumer price index of differentiated goods is 26.7%, similar but slightly higher than for the PCP model. As noted above, tariffs are imposed directly on the importer: if the exporter leaves its supply price at its pre-tariff level, the importer will have to have to adjust its supply price to the full extent of tariff, or suffer a drop in its margin.

6.2 Modified model with distribution

Hereafter, to account for a moderate degree of tariff pass-through at consumer level, we model the incidence of local production inputs and/or distribution on the price of imports faced by consumers. We extend the model in the spirit of Corsetti and Dedola (2005), positing that, realistically, consumers do not purchase imported differentiated varieties directly from producers. Consumer goods combine imported goods with domestic labor and home differentiated domestic goods as inputs. Analytically, we now specify the consumption index without the direct inclusion of imported varieties: $C_{D,t} \equiv \left(\int_0^{n_t} c_t(h)^{\frac{\phi-1}{\phi}} dh \right)^{\frac{\phi}{\phi-1}}$, and correspondingly change in the consumer price indexes and demand equations in the main text (Eqs. 4-7) as follows:

$$C_{D,t} = \theta \left(P_{D,t}^C / P_t^C \right)^{-\xi} C_t$$

$$C_{N,t} = (1-\theta)\left(P_{N,t} / P_t^C \right)^{-\xi} C_t$$

[45] We can define a data-consistent price index for foreign differentiated goods holding the number of varieties fixed: $\widehat{P}_{D,t}^* \equiv \left(\overline{n^*} p_t^*(f)^{1-\phi} + \overline{n}\left(p_t^*(h) T_{D,t}^* \right)^{1-\phi} \right)^{\frac{1}{1-\phi}}$.

$$c_t(h) = \left(p_t(h) / P_{D,t}^C\right)^{-\phi} C_{D,t}$$

$$c_t(f) = 0,$$

where we define additional price indexes specific to consumption:

$$P_{D,t}^C = \left(n_t p_t(h)^{1-\phi}\right)^{\frac{1}{1-\phi}}$$

$$P_t^C = \left(\theta P_{D,t}^{C\ 1-\xi} + (1-\theta)\left(P_{N,t}\right)^{1-\xi}\right)^{\frac{1}{1-\xi}}.$$

To be clear: given the roundabout production structure, domestic firms use imported differentiated goods as inputs, hence households do consume foreign differentiated goods indirectly. They purchase them from domestic firms that combine them with home differentiated goods and additional labor inputs, according to the extended production function shown in the appendix. One can interpret this labor and material inputs as part of a domestic distribution cost. Consistently, we recalibrate the trade cost for differentiated goods (τ_D = 0.23) to maintain the same ratio of imports as a share of GDP as in the benchmark version of the model.

6.3 Simulation results for modified model with low tariff pass-through

This version of the model is able to reconcile the empirical evidence of a near zero pass-through to consumers, with a near perfect pass-through at the dock, both for PCP and LCP versions of price stickiness. Simulating a foreign tariff shock on home exports in the two-sector model with a constant money growth rule, we find that, for the PCP case, pass-through at the dock is 99.0% for a given imported variety; pass-through to the consumer price index of differentiated goods is actually negative, and equal to -14.25%, in the initial period of the shock. Under a suboptimal constant money growth rule, the tariff has the counterintuitive effects of lowering the prices of differentiated goods faced by consumers, since, for lack of stabilization, the economic slows down causes wages and hence marginal costs of domestic producers to fall markedly. One year after the shock, the pass-through to consumer prices rises to 23.8%. Results are similar under LCP price stickiness: the tariff pass-through to consumer prices is -16.6% in the initial period of the shock, 26.7% one year later.

In light of the similarity of PCP and LCP specifications in terms of matching the empirical pass-through of the tariff, we focus our discussion on the PCP economy, allowing for either unilateral or symmetric shocks. Simulation results are reported in Appendix Figure 16 (unilateral shock) and Appendix Figure 17 (symmetric shock). In our distribution-augmented two-sector model, the optimal policy and macroeconomic dynamics in response are close to our baseline---i.e., it is only moderately affected by the degree of tariff pass-through to consumer prices. Relative to our baseline, a low pass-through to consumer prices only slightly dampens the transmission of the shock to GDP and the interest rate change mandated by optimal policy.

Key to this remarkable result is the use of imports as intermediates. Even if the tariff does not impact consumer prices on a one-to-one basis, it still has large effects on GDP and other macroeconomic aggregates through the demand for imported intermediate goods by domestic producers. On impact, Home GDP falls 1.45% in the low pass-through specification, compared to 2.06% in the benchmark model (shown in Figure 3). Consequently, the optimal policy calls for a similarly strong expansionary response to moderate the macroeconomic effects of the tariff, with a home interest rate cut (by 0.53 percentage points, compared to a cut of 0.54 percentage points in the benchmark model shown in Figure 3). In a symmetric tariff war shock, a low tariff pass through to consumer prices even amplifies the home contraction: in our no-policy specification, GDP falls by 2.71%, versus 1.86% for the benchmark case. We conclude that a low pass-through to consumer prices does not necessarily moderate the macroeconomic effects of tariff shocks, nor reduces the need for a thorough assessment of the correct monetary policy response.

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Appendix Table 1. Moments of variables, and welfare:
just foreign tariff shock (one sector model)
Comparing Taylor Rule policy to Ramsey

	One-sector model	
	home	foreign
standard deviations in percent (difference from Ramsey case)		
GDP	3.09	-0.60
employment	2.60	0.72
consumption	-0.27	-0.08
firm entry investment	-6.18	-4.17
number of firms	-1.05	-0.56
inflation	-0.27	0.28
real exch. rate	-0.67	-0.67
unconditional means of variables (percent change from Ramsey case)		
GDP	0.041	0.386
employment	0.027	0.054
consumption	-0.052	-0.025
firm entry investment	-0.453	-0.240
number of firms	-0.453	-0.240
Welfare (percent change from Ramsey case, conditional, in consumption units):		
	-0.124	-0.125

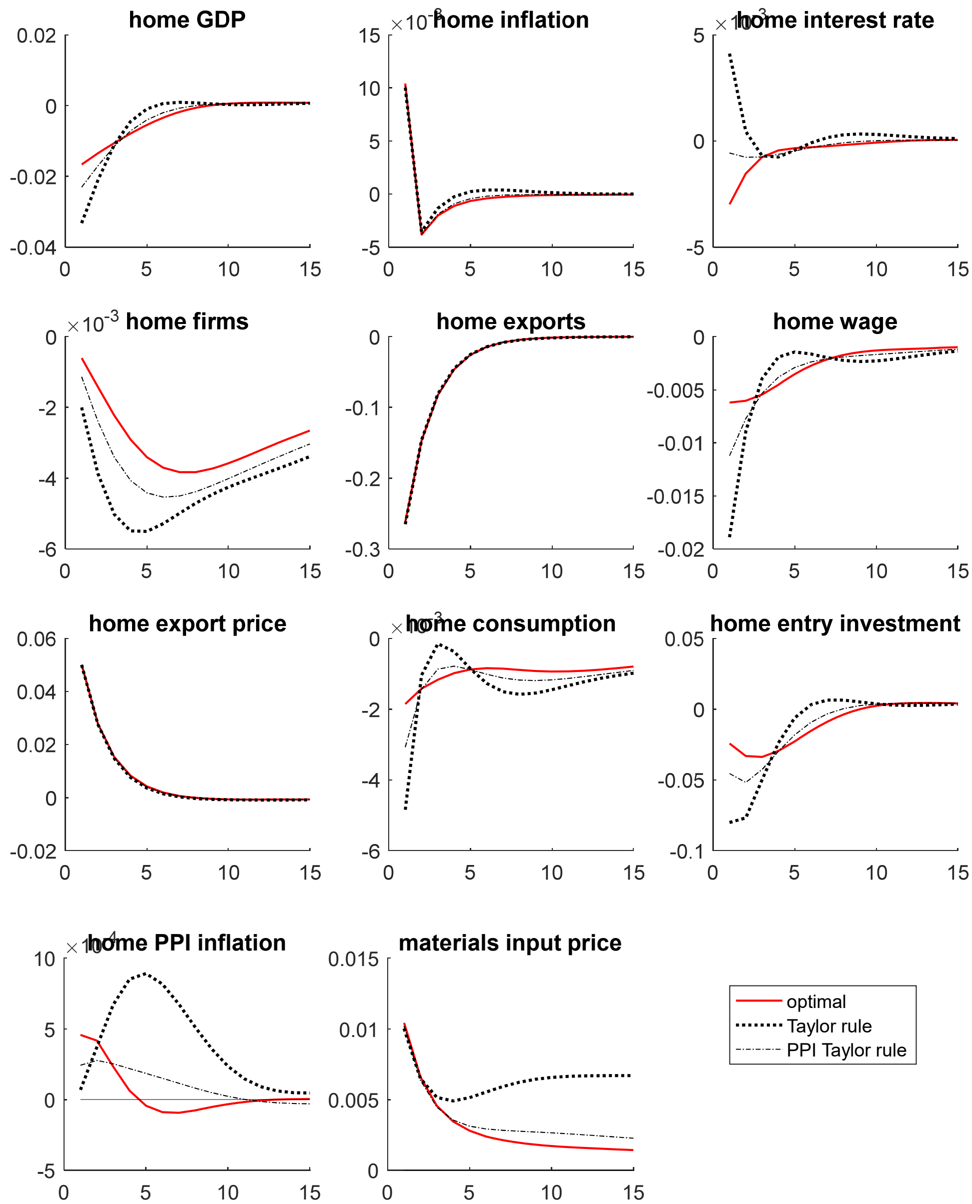
Appendix Table 2. Moments of variables, and welfare: LCP version
Comparing Taylor Rule policy to Ramsey

	One-sector model		Two-sector model	
	Common shock	Independent shock	Common shock	Independent shock
standard deviations in percent (difference from Ramsey case)				
GDP	1.64	0.98	0.76	0.15
employment	1.23	0.61	0.51	0.07
consumption	0.28	-0.11	0.05	0.04
firm entry investment	6.17	-3.10	5.39	2.15
number of firms	0.61	-0.56	0.59	0.36
inflation	-0.06	0.00	-0.29	-0.15
real exch. rate	0.00	-0.75	0.00	0.08
unconditional means of variables (percent change from Ramsey case)				
GDP	0.045	0.020	0.019	0.039
employment	0.021	0.019	0.015	0.048
consumption	-0.011	-0.040	-0.010	-0.047
firm entry investment	-0.054	-0.209	-0.084	-0.354
number of firms	-0.054	-0.209	-0.084	-0.354
Welfare (percent change from Ramsey case, conditional, in consumption units):				
	-0.084	-0.105	-0.056	-0.122

Appendix Table 3. Moments of variables, and welfare: DCP version
Comparing Taylor Rule policy to Ramsey

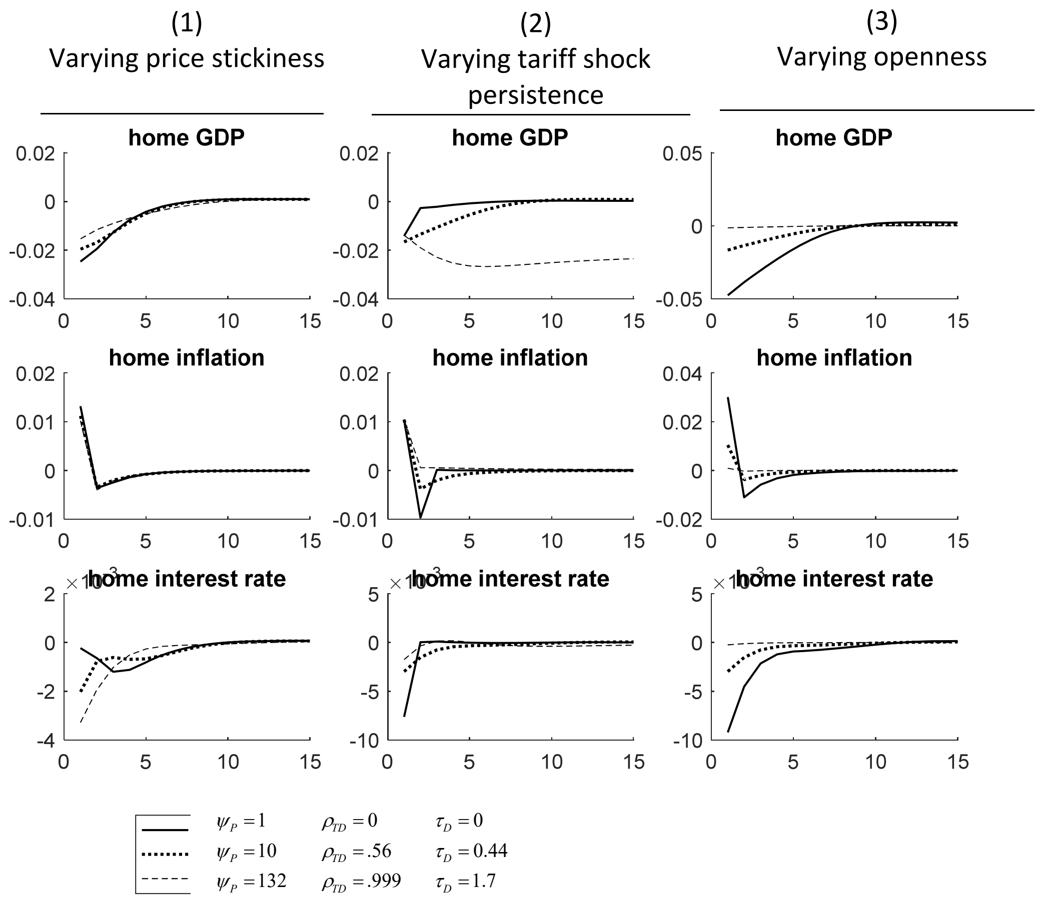
	common shock		independent shock	
	home	foreign	home	foreign
standard deviations in percent (difference from Ramsey case)				
GDP	1.13	0.15	0.05	-0.05
employment	0.49	0.25	-0.04	0.00
consumption	0.09	-0.19	-0.20	-0.26
firm entry investment	8.34	-6.56	-6.05	-7.83
number of firms	-0.56	-3.47	-2.71	-2.88
inflation	-0.53	0.01	-0.21	0.11
real excn. rate	-1.13	-1.13	-0.64	-0.64
unconditional means of variables (percent change from Ramsey case)				
GDP	0.013	-0.005	0.062	3.887
employment	-0.106	0.178	-0.018	0.140
consumption	0.162	-0.181	0.018	-0.131
firm entry investment	1.560	-1.853	0.120	-1.262
number of firms	1.560	-1.853	0.120	-1.262
Welfare (percent change from Ramsey case, conditional, in consumption units):				
	0.362	-0.528	0.051	-0.331

Appendix Figure 1. Impulse responses under a PPI-based Taylor rule to a symmetric tariff shock



Vertical axis is percent deviation (0.01=1%) from steady state levels. Horizontal axis is time (in years).

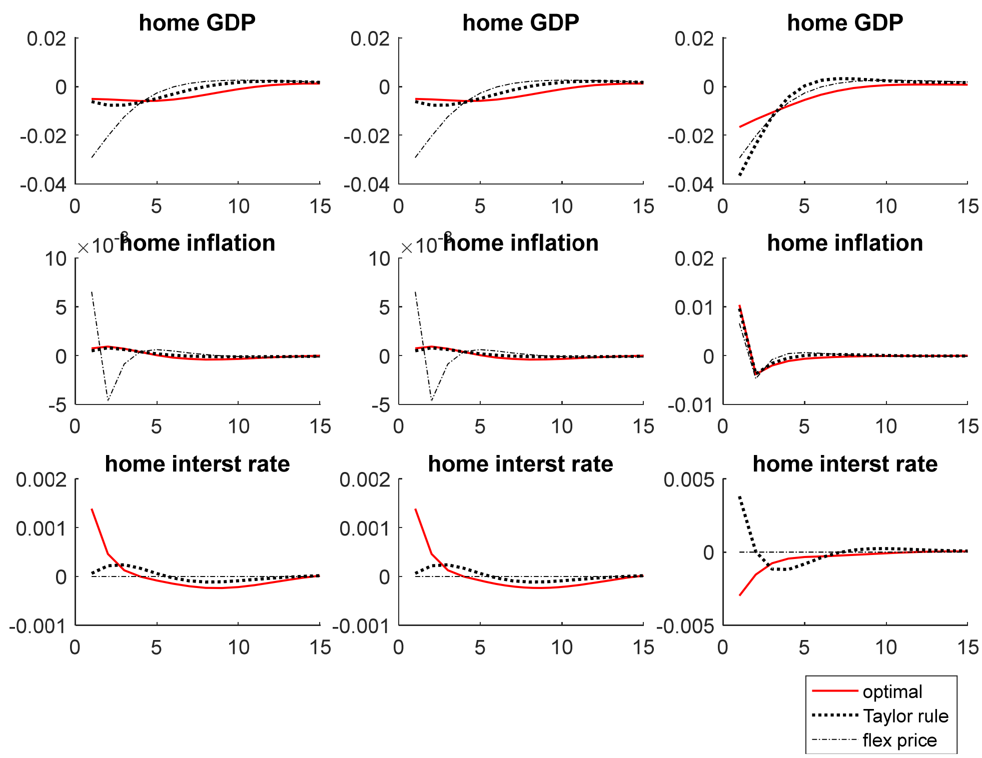
Appendix Figure 2. Sensitivity: impulse responses to a rise in tariff in both countries, under optimal policy



Vertical axis is percent deviation (0.01=1%) from steady state levels. Horizontal axis is time (in years).

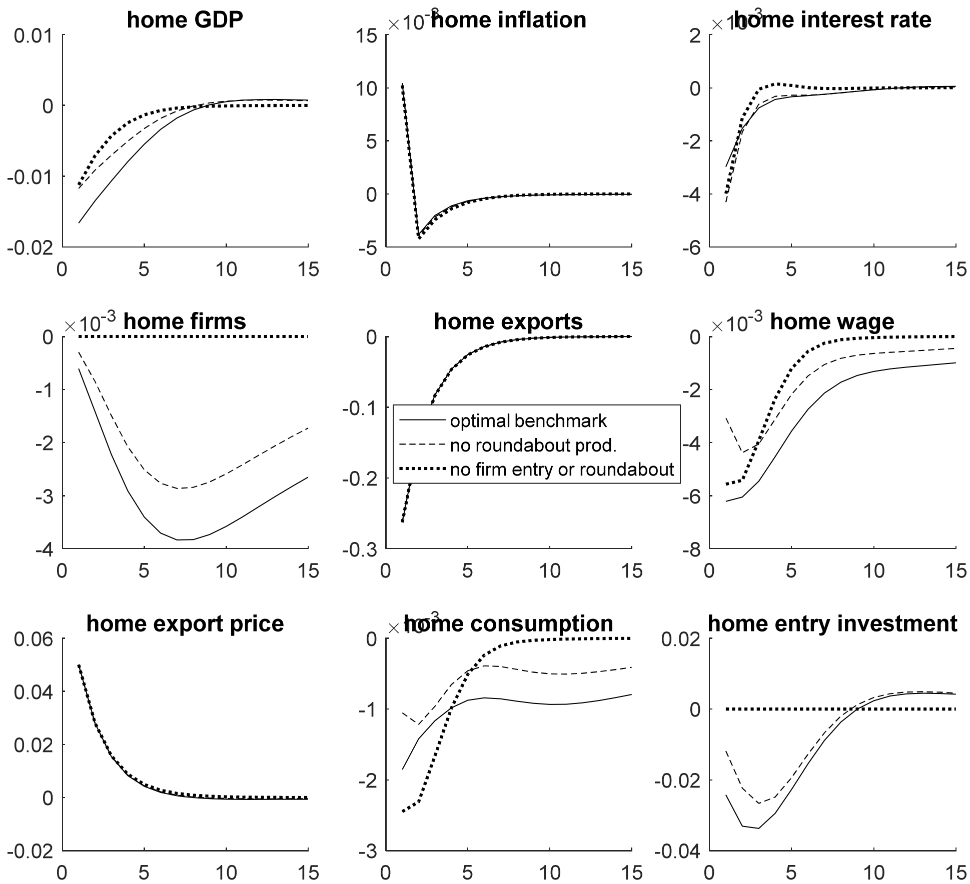
Appendix Figure 3. Impulse responses to a markup shock with varying specifications

(1) Shock only on exports	(2) Shock only on exports, International transfers	(3) Shock only on exports, International transfers, Not subject to stickiness



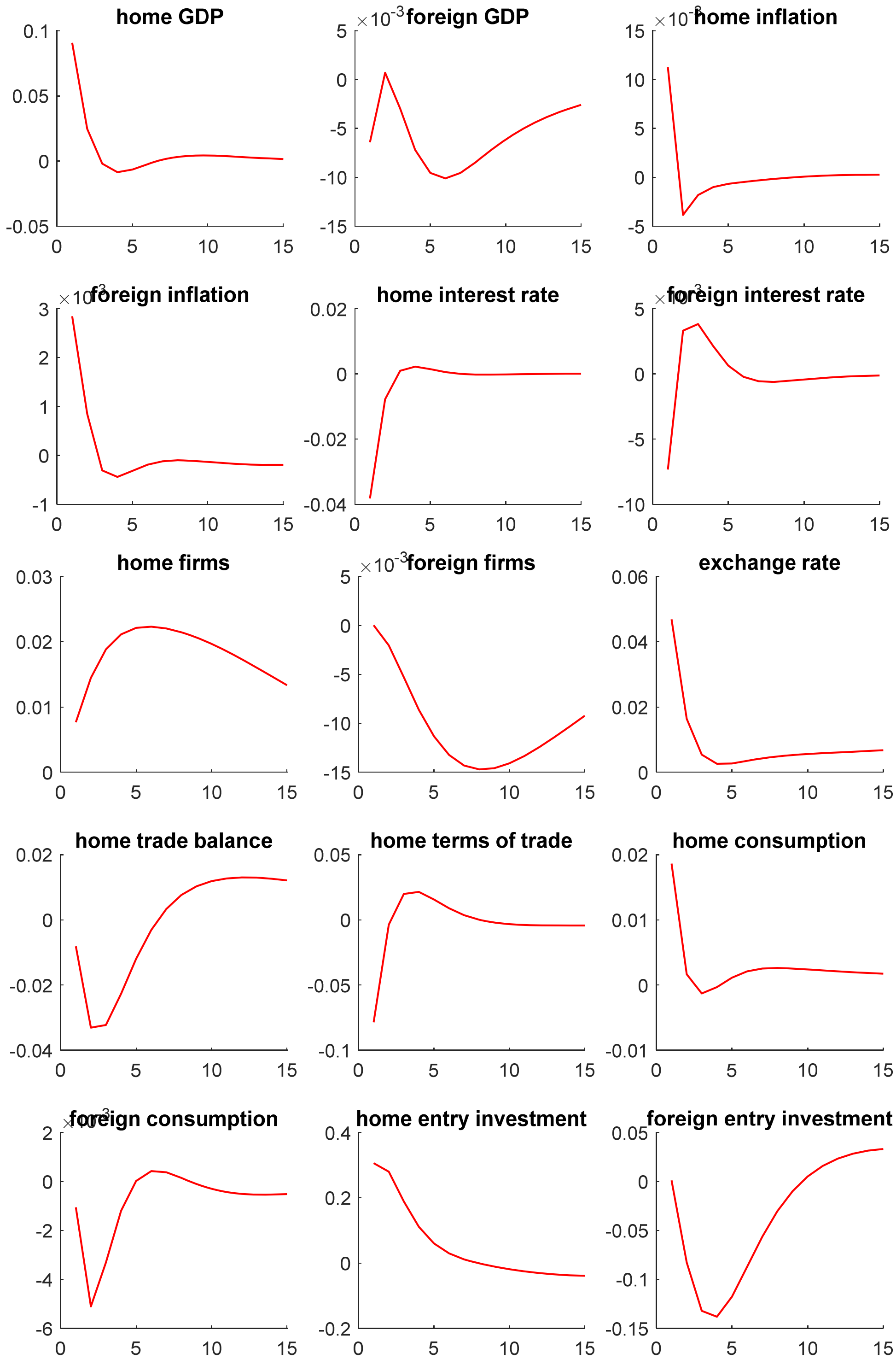
Vertical axis is percent deviation (0.01=1%) from steady state levels. Horizontal axis is time (in years).

Appendix Figure 4. Impulse responses to a rise in tariff in both countries, one-sector model, optimal policy for various model specifications



Vertical axis is percent deviation (0.01=1%) from steady state levels. Horizontal axis is time (in years).

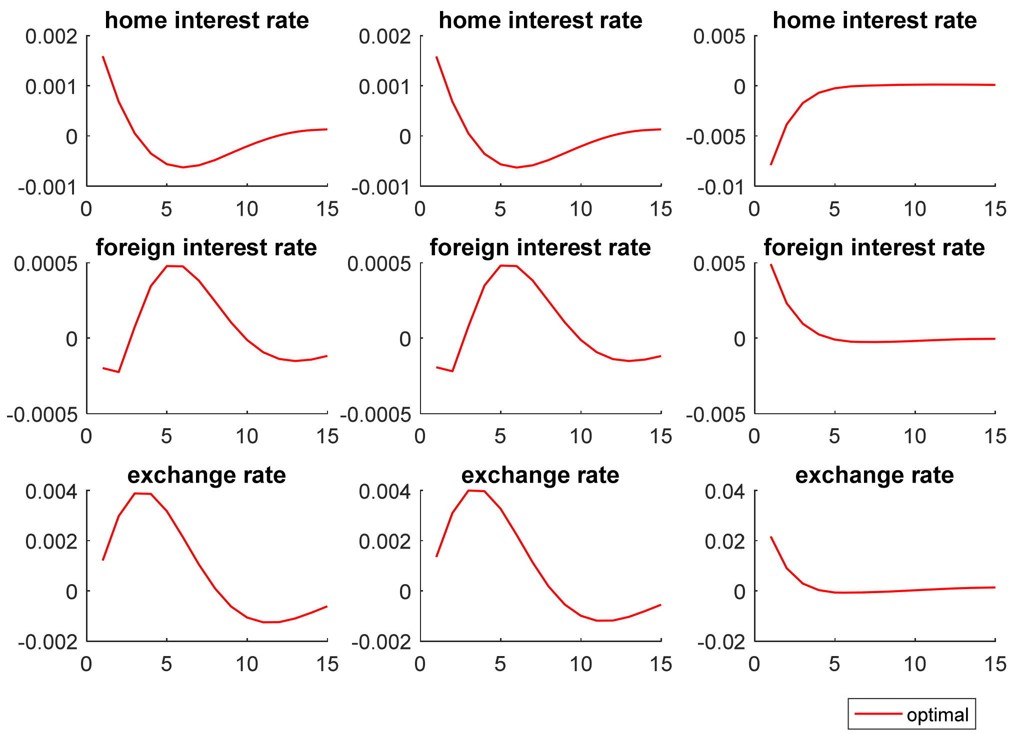
Appendix Figure 5. Ramsey optimal policy with zero weight on home welfare, foreign tariff shock (one sector model)



Vertical axis is percent deviation (0.01=1%) from steady state levels. Horizontal axis is time (in years).

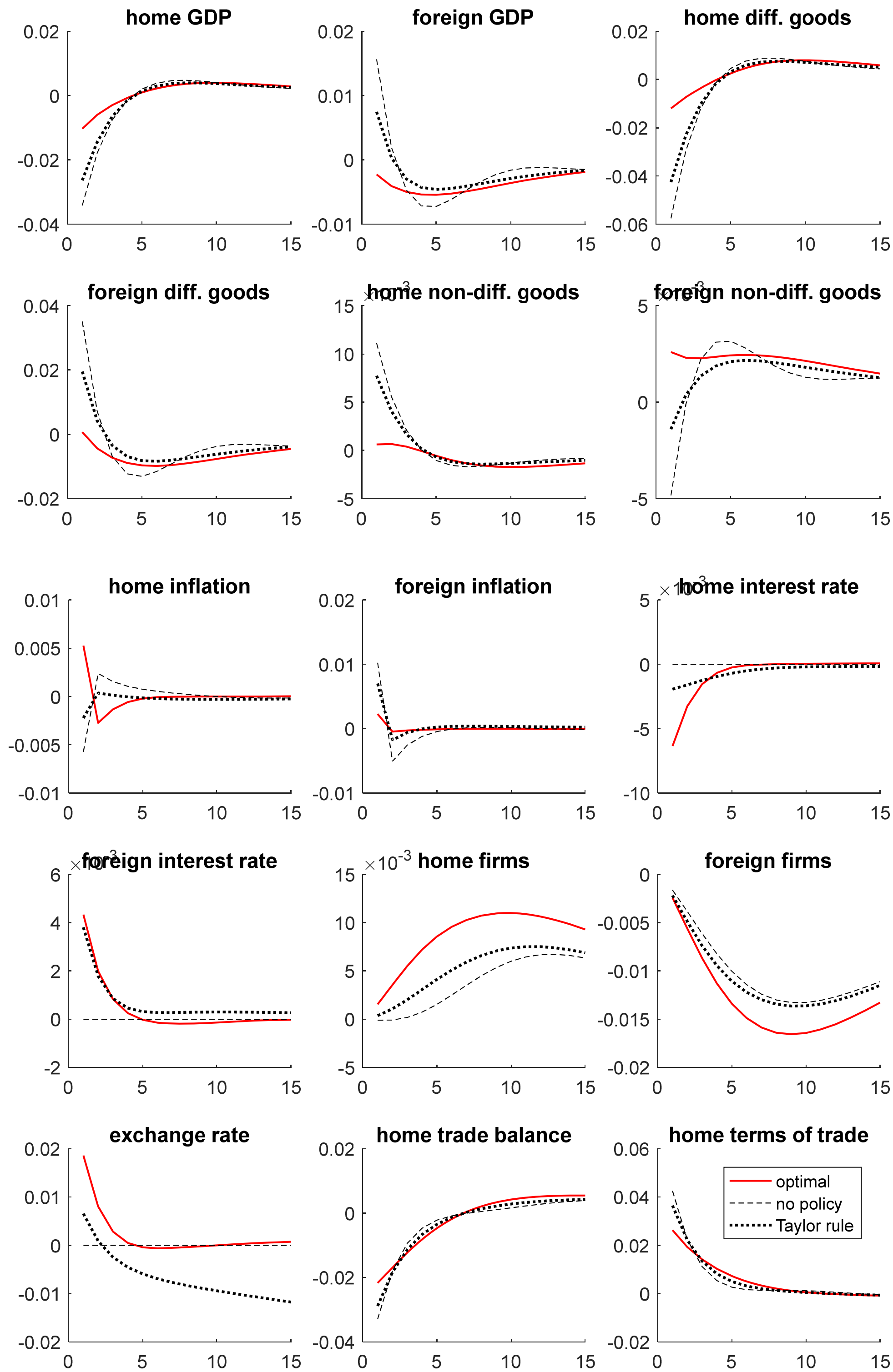
Appendix Figure 6. Impulse responses to a markup shock to home country, with varying specifications

(1) Shock only on exports	(2) Shock only on exports, International transfers	(3) Shock only on exports, International transfers, Not subject to stickiness

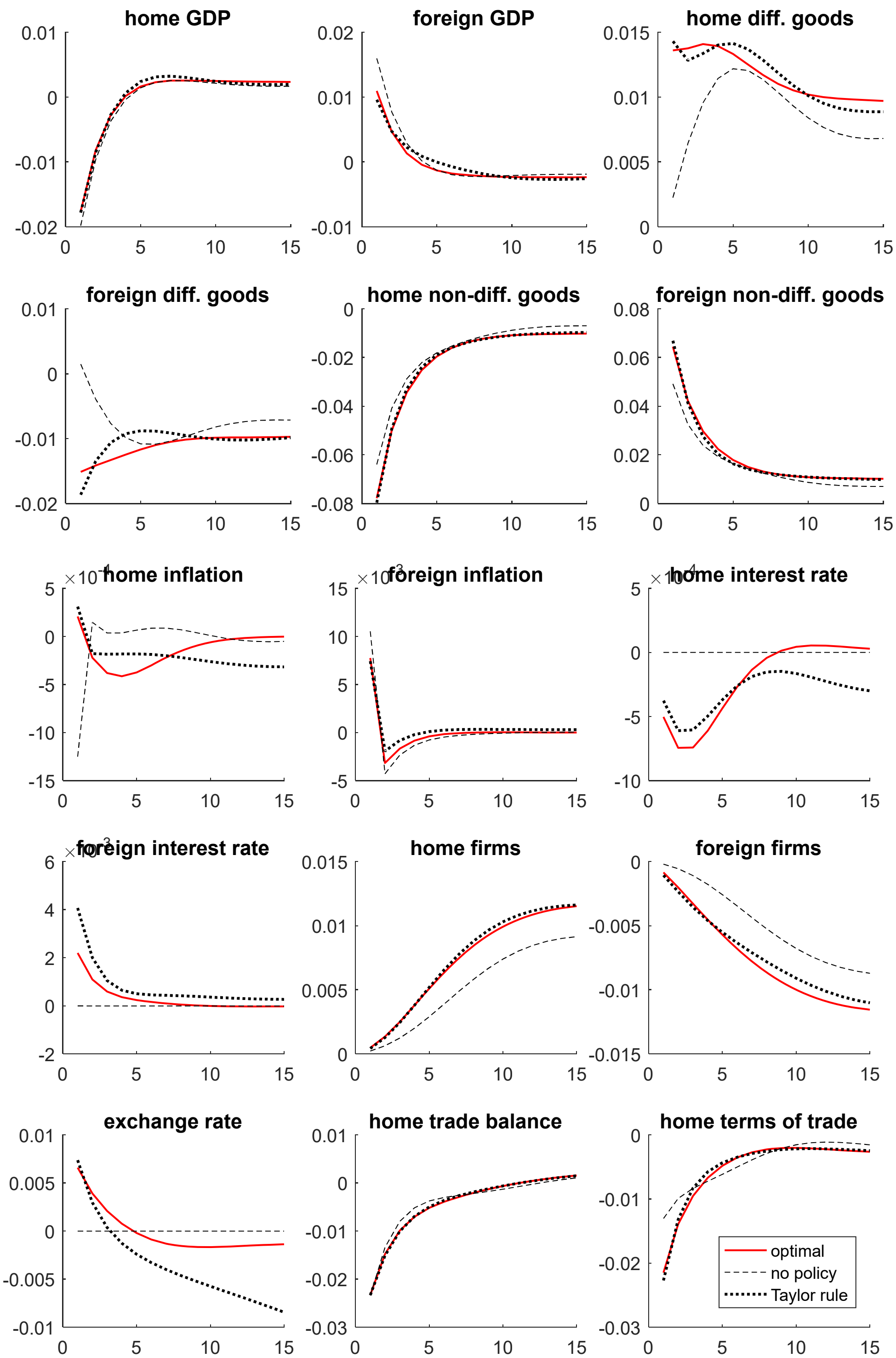


Vertical axis is percent deviation (0.01=1%) from steady state levels. Horizontal axis is time (in years).

Appendix Figure 7. Impulse responses to a rise in foreign tariff on home differentiated exports, with a nontraded non-differentiated sector

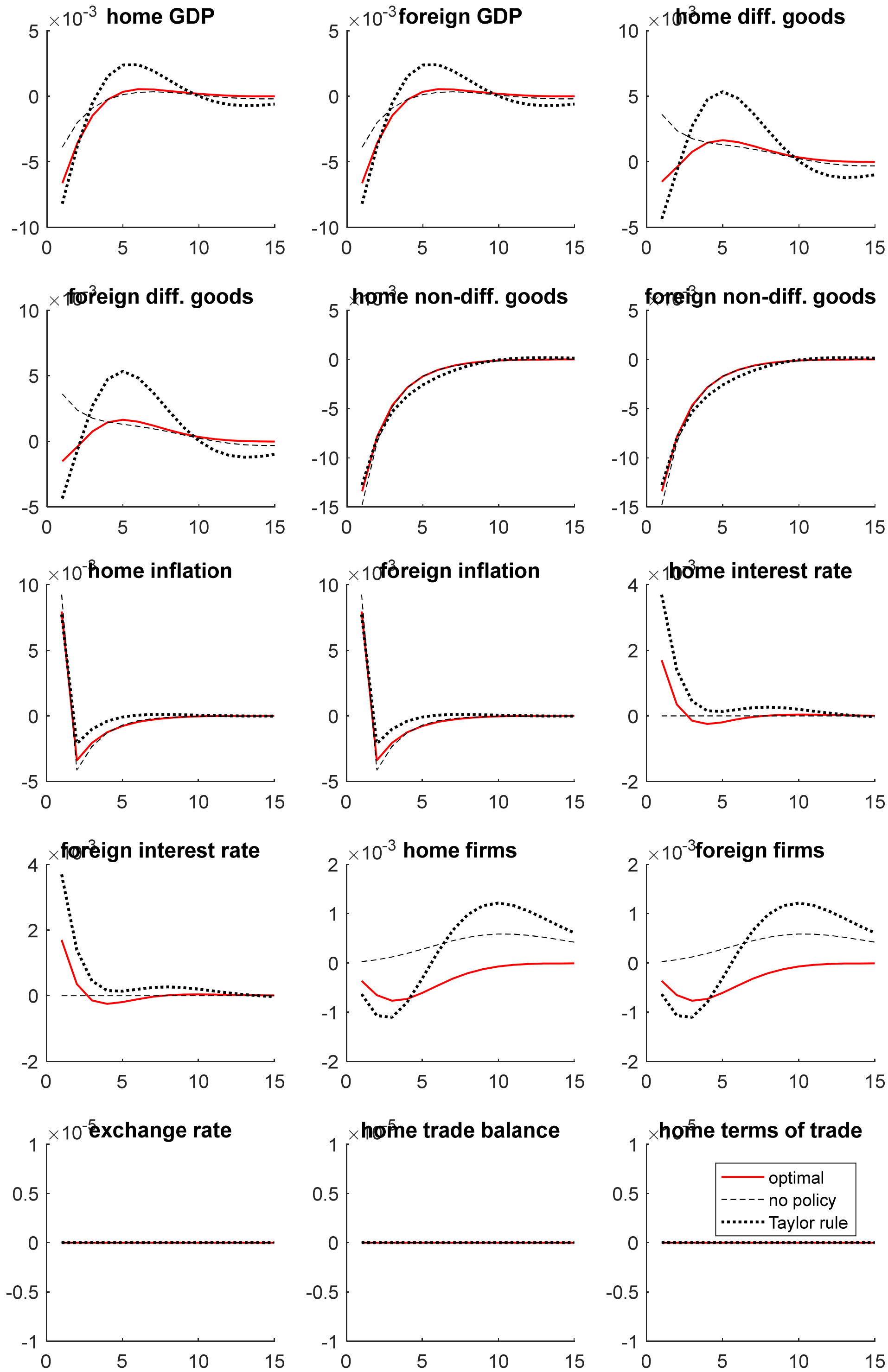


Appendix Figure 8. Impulse responses to a rise in foreign tariff on home non-differentiated exports, two-sector model



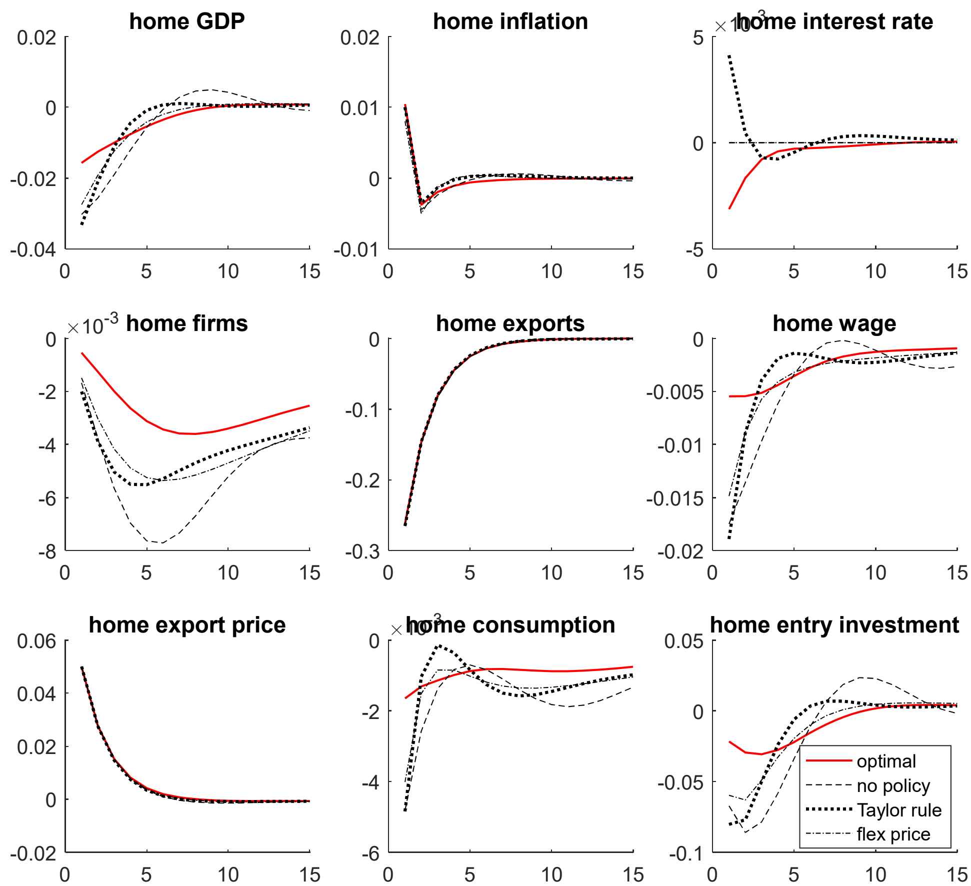
Vertical axis is percent deviation (0.01=1%) from steady state levels. Horizontal axis is time (in years).

Appendix Figure 9. Impulse responses to a rise in tariff on non-differentiated exports in both countries, two-sector model

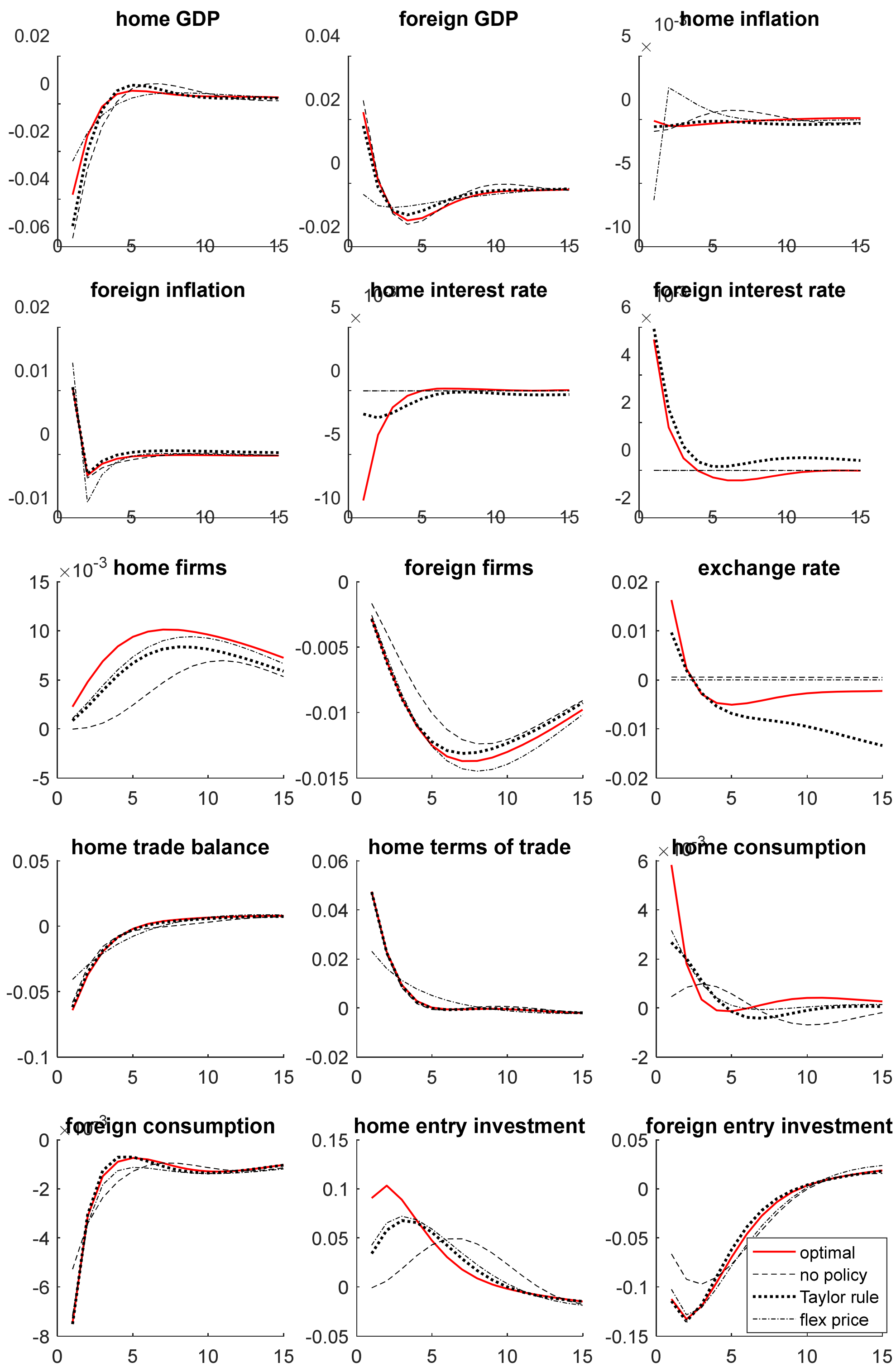


Vertical axis is percent deviation (0.01=1%) from steady state levels. Horizontal axis is time (in years).

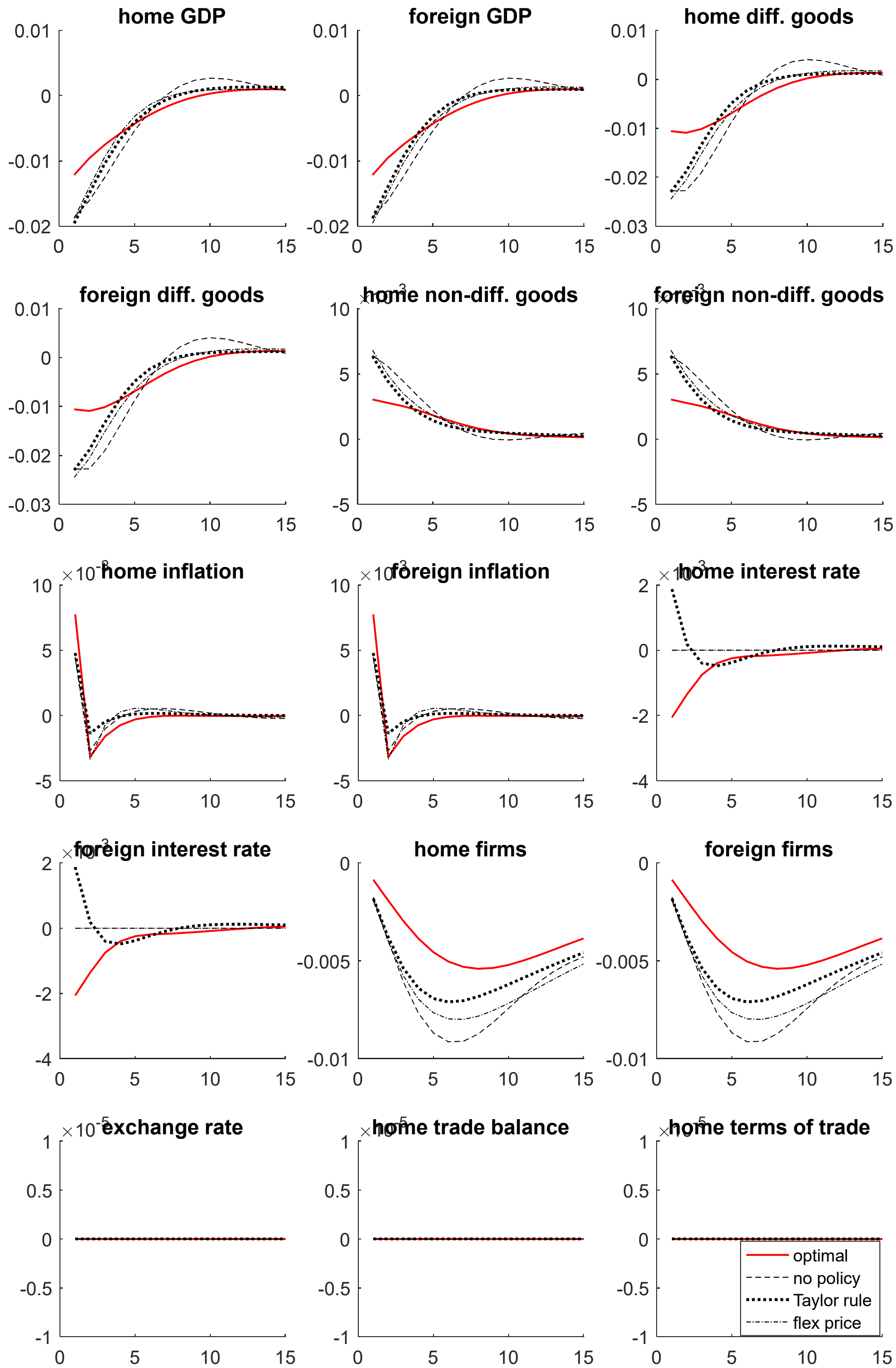
Appendix Figure 10. Impulse responses to a rise in tariff in both countries, one sector Model, LCP



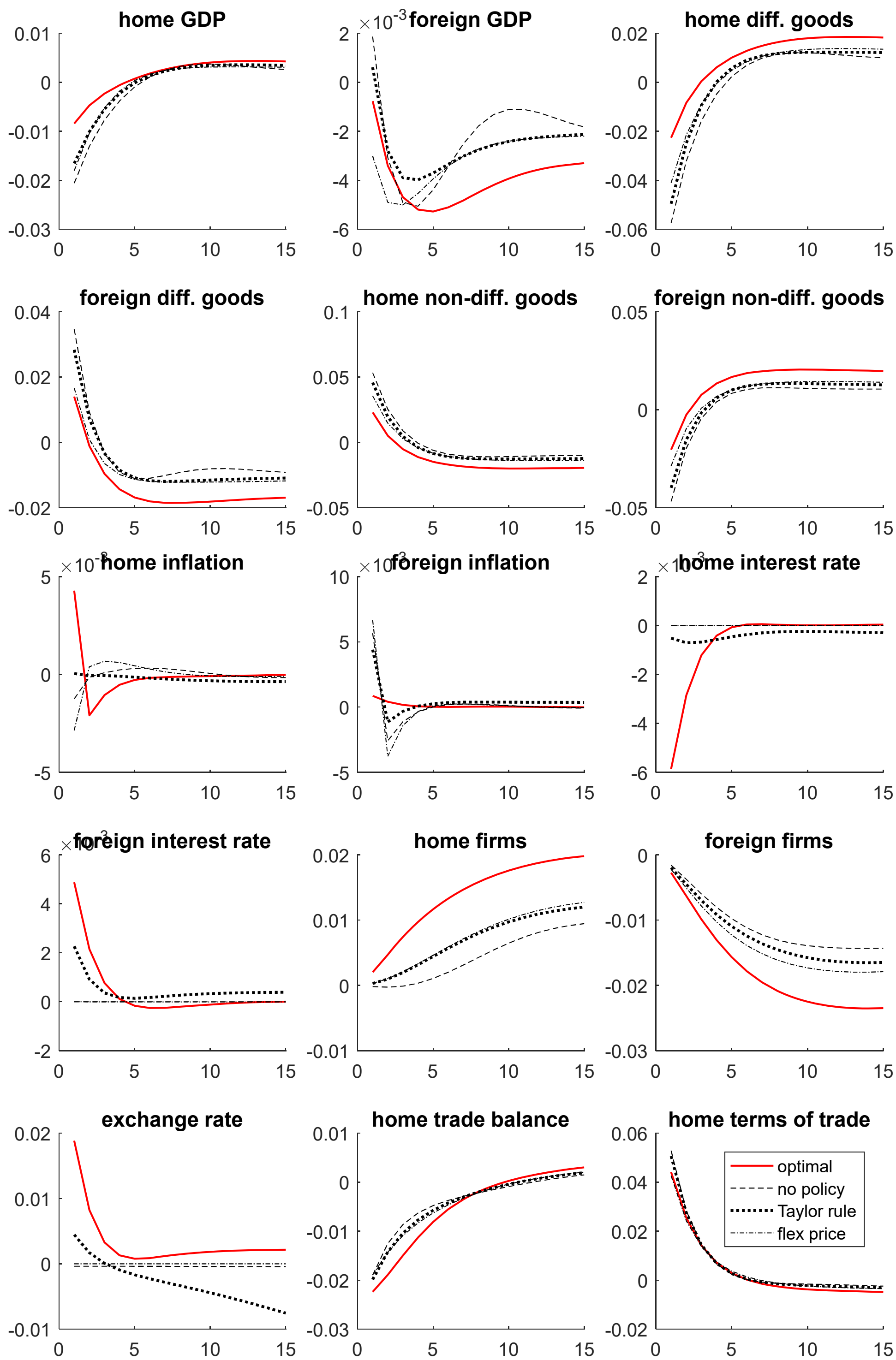
Appendix Figure 11. Impulse responses to a rise in foreign tariff on home exports, one-sector model, LCP



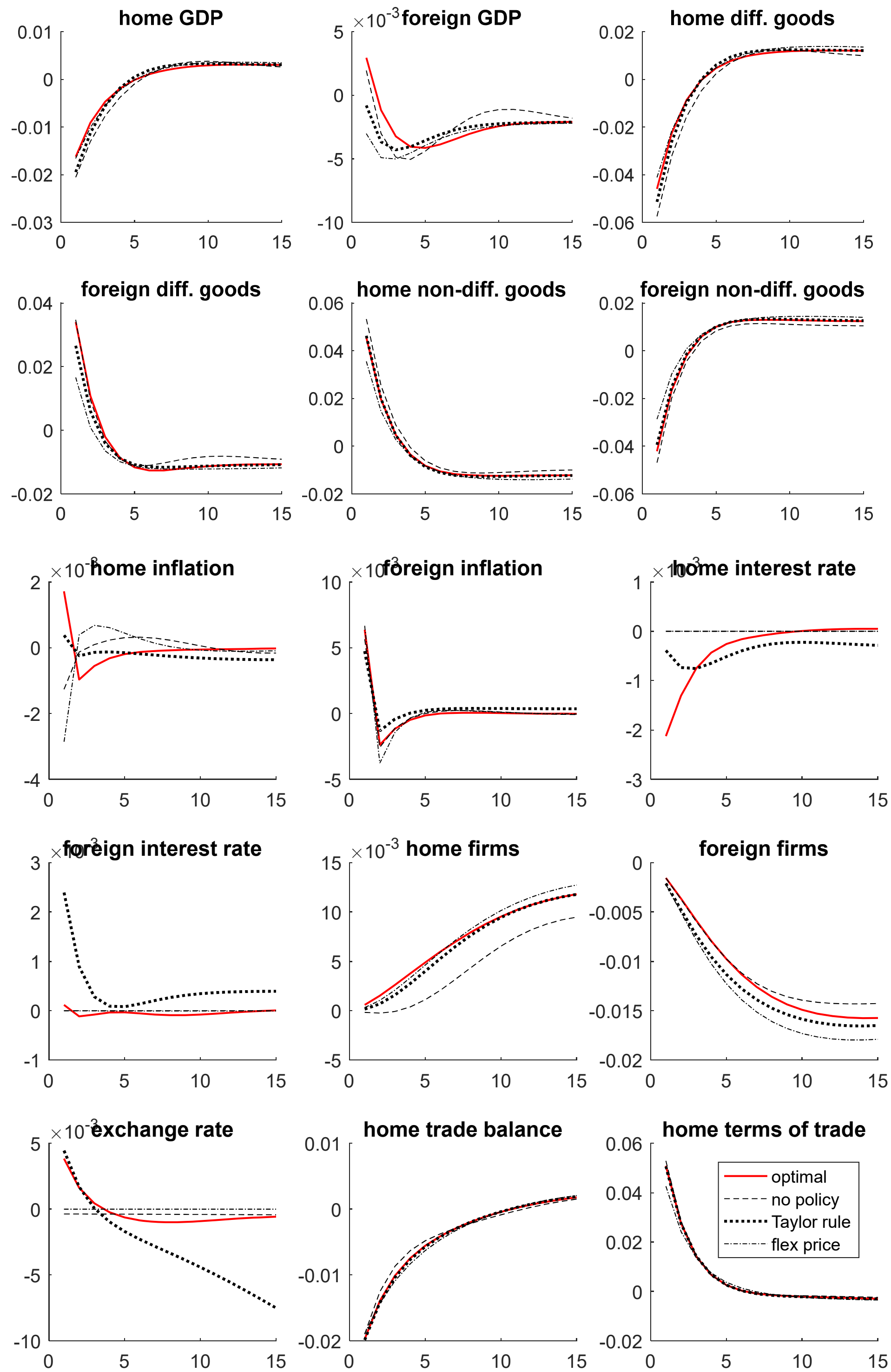
Appendix Figure 12. Impulse responses to a rise in tariff on differentiated exports in both countries, two-sector model, LCP



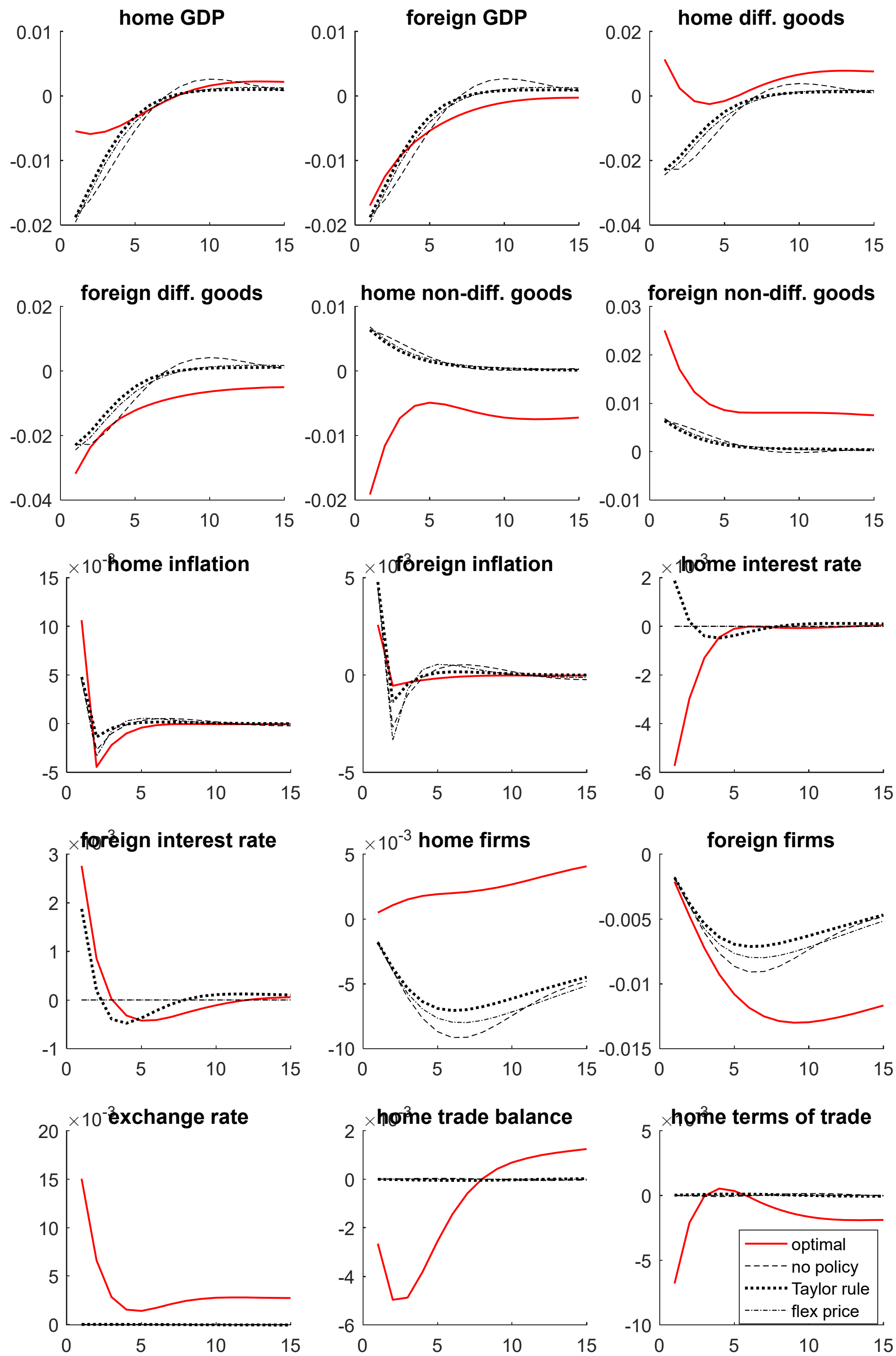
Appendix Figure 13. Impulse responses to a rise in foreign tariff on home differentiated exports, two-sector model, home country dominant currency (home PCP and foreign LCP)



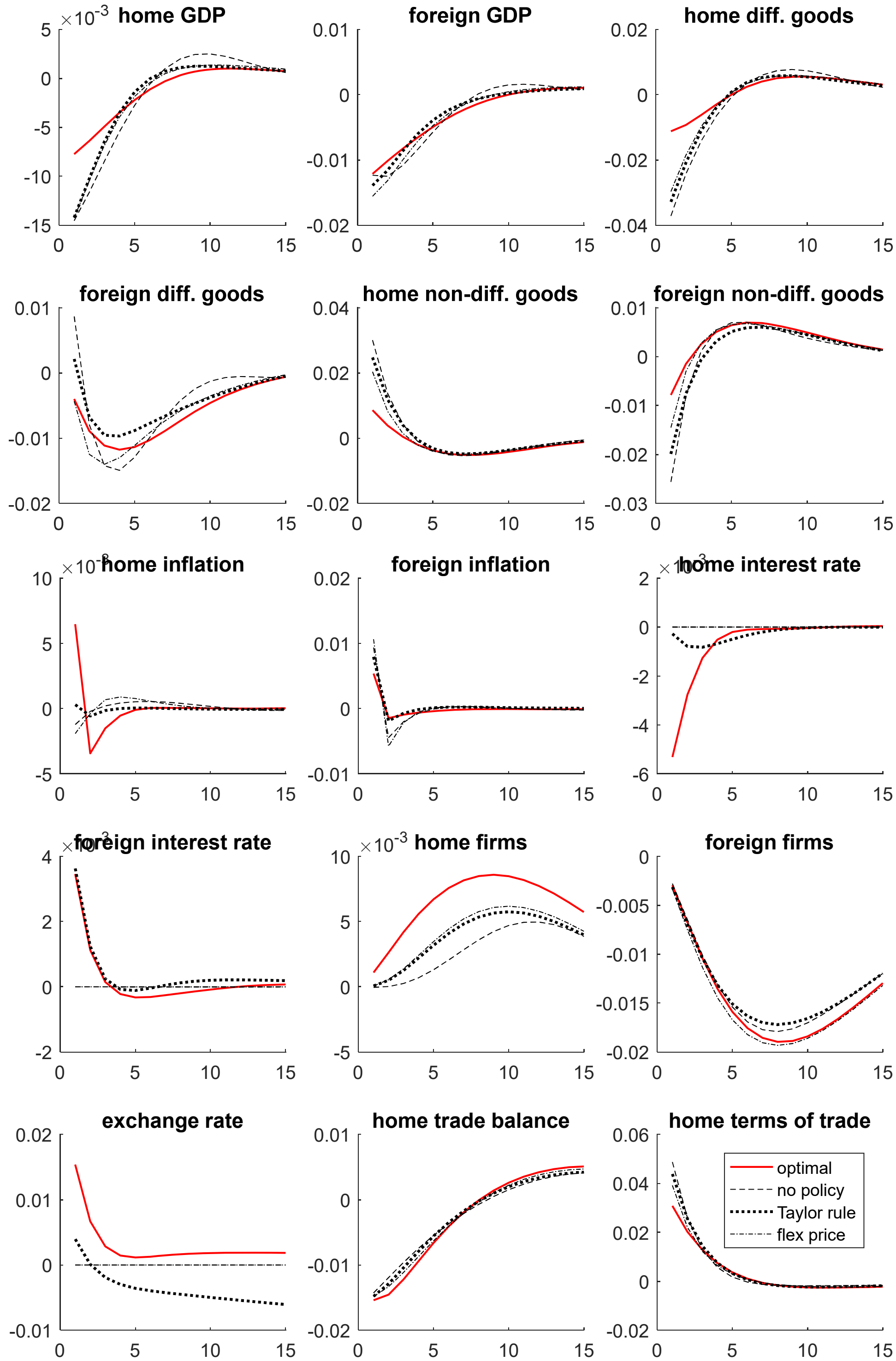
Appendix Figure 14. Impulse responses to a rise in foreign tariff on home differentiated exports, two-sector model, foreign currency dominant (home LCP and foreign PCP)



Appendix Figure 15. Impulse responses to a symmetric rise in tariff on differentiated goods in both countries, two-sector model, home currency dominant (home PCP and foreign LCP)



Appendix Figure 16. Impulse responses to a rise in foreign tariff on home differentiated exports, two-sector low pass-through model



Appendix Figure 17. Impulse responses to a symmetric rise in tariff on differentiated goods in both countries, two-sector low pass-through model