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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 global value chains and firm dynamics, 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.

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An online Appendix is available at http://www.nber.org/data-appendix/w26995

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 trade policy shocks. U.S. tariffs on Chinese exports rose seven-fold from 2018 to 2020, with little sign of any policy reversal.[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 trade disputes could signify a weakening of global consensus regarding free trade, and may herald a changed environment, in which central banks may expect in the future to face yet more examples of 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 mostly relied on real models ignoring a monetary dimension; among the subset of the literature studying tariffs in a monetary context, no one has studied the optimal response of monetary policy to tariff shocks. (See the foundational work of Barattieri, et al. (2021), among others).[2] Existing analysis emphasizes that tariffs exhibit characteristics of supply shocks, implying a fall in aggregate output and rise in aggregate price inflation. A number of contributions on the topic have indeed modelled monetary policy, but assumed Taylor rules with a focus on countering the inflationary impact rather than the output contraction. The New Keynesian literature shows that a contractionary monetary stance is optimal in the context of supply shocks arising from productivity and markup disturbances. However, in this paper we argue that tariff shocks are fundamentally different from other types of supply shock, and show that the optimal monetary response to a tariff shock is expansionary (or in some model specifications only moderately contractionary), with the goal of mitigating its adverse output implications, at the expense of aggravating short-run headline inflation. Thus the optimal monetary response to tariff shocks is the opposite of that presumed in the existing literature based on standard Taylor rules, or that implied by the

[1] In 2022 they remained more than six times their 2018 levels. From Brown (2022).

[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).

New Keynesian literature with more standard supply shocks.

The fundamental logic is that tariff shocks differ from the supply shocks studied previously in the New Keynesian literature, namely, productivity shocks or markup shocks, in that tariffs raise the price that consumers pay on top of the sticky price charged by the firm. This is because tariffs are imposed on the foreign purchaser of an imported good, i.e., levied on the (border) price set by foreign firms. As such, the direct effect of a tariff is a fall in the demand for a firm's product (caused by a hike in its retail price), rather than an increase in marginal costs. To illustrate this point most sharply, we begin by studying a tariff shock in a highly simplified two-country monetary model, where we can derive optimal monetary policy analytically. The environment features two countries, one sector with differentiated products, one factor of production, and prices pre-determined one period ahead in the currency of the producer. We posit that tariff revenue paid by home households is rebated back to them, so that a tariff imposes no intrinsic resource cost. In this environment, we show most transparently that a fall in home production due to a tariff (since this lowers the demand for a country's exports) is inefficient. A monetary expansion is able to offset this inefficiency in part. The model also makes clear the optimal policy response to a tariff is the opposite of that to a standard adverse supply shock to productivity, where monetary policy lets output fall in line with higher marginal cost.

The paper goes on to study optimal monetary policy in a richer economic environment, which allows us to gauge the robustness of the analytical result of an optimal policy expansion, and to provide additional intuition for this result. The extended model includes features relevant for understanding optimal monetary policy, such as more realistic price adjustment dynamics, incomplete asset markets, and the addition of markup shocks. We also include features standard in trade models that may be important for understanding tariffs, such as international production chains, trade costs, and firm entry dynamics. We find that the optimality of a monetary expansion in response to a tariff shock is robust to realistic calibrations of these additional features. One feature particularly important to the sign of the optimal monetary response is the share of intermediates in production. In line with recent open economy macro, our model specifies a (highly stylized) value chain 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. Except for the case of economies where the share of intermediates in production is well above the norm in the empirical literature (in excess of 54%), the demand effects prevail---causing (ex-tariff) inflation to fall in a persistent way. Hence, the optimal monetary policy response is expansionary.

The extended model also provides additional intuition for why a monetary expansion is optimal for the case of tariff shocks, in contrast with standard supply shocks. When a tariff increases the price faced by foreign importers and lowers demand for home exports, the home firms would like to reduce their prices in line with wages and marginal costs, but they can only go part of the way because of price stickiness. Hence, PPI inflation moves in the opposite direction of CPI inflation (since a tariff is imposed on top of the price set by firms). This opposite movement in PPI and CPI inflation created by tariff shocks plays an important role in our model. A standard result in the open economy literature is that, when export prices are sticky in the currency of the producer, monetary policy should optimally focus on stabilizing PPI rather than CPI, since their relative adjustment corresponds to desirable adjustment in the relative price of domestic to foreign goods. According to the same logic, an expansionary home monetary response to a tariff helps redress the implied demand inefficiency by letting changes in CPI and PPI inflation (in opposite directions) realign relative prices (essentially, preventing an undesirable fall in the PPI). Contrast this result with the well-known policy prescription in response to an adverse home productivity shock. In such a case, firms would like to raise prices and reduce production: a monetary contraction helps facilitate this efficient output reduction.

Model simulations are especially useful for comparing implications of tariff shocks to another type of supply shock commonly studied in the macro literature, shocks to price markups. Tariff shocks differ from markup shocks in three key dimensions: (i) they apply selectively to export sales rather than all sales of a firm, (ii) the revenues accrue to the importing country rather than the exporting firm, and, most crucially, (iii) 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 markup shock raising prices.

The logic of our 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. The Ramsey (cooperative) optimal policy redresses the misalignment 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.

Further extensions to the model show that an optimal monetary expansion is robust to a variety of other concerns in the literature. For example, augmenting the model with wage stickiness can explain why measured PPI may not fall after a tariff increase, since market wages do not fall. Still, output does fall inefficiently, driving down the marginal disutility of labor at the ongoing wage. A monetary expansion remains optimal.

We also generalize our results to allowing for incomplete or asymmetric exchange rate pass-through and/or to a muted tariff pass-through from border to consumer prices. Remarkably, we establish that in a world of Dominant Currency Pricing (DCP), where one country issues a dominant currency in which world trade is invoiced, the different incidence of price stickiness on exporters induces a strong asymmetry in the optimal policy response even in a retaliatory, symmetric tariff war. The optimal monetary stance is expansionary in the dominant currency country, since price stickiness in the currency of producers makes it possible to redress the tariff distortion on domestic production via internal demand support 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 price stickiness among foreign exporters in home currency units insulates export prices from currency movements, while import prices remain highly sensitive to the exchange rate. As a result, only the issuer of the dominant currency is able to effectively redress the effects of the symmetric tariff through monetary policy.

In line with recent empirical evidence (Flaaen et al., 2020 and Cavallo et al., 2021), a high degree of tariff pass-through at border prices may correspond to a very low degree of pass-through at consumer prices. As a final exercise, we show that an extension of the model including a distribution sector (after Corsetti and Dedola, 2005) can match the evidence, and that our results regarding optimal policy are qualitatively robust to this environment.

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 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 are Auray et al. (2021) and Jeanne (2021), which share our focus on the interaction of tariff policy with monetary policy. Specifically, Auray et al. (2021) address the question of how alternative monetary policies affect an endogenous, strategic tariff policy; Jeanne (2021) considers a broad set of policy instruments set optimally by a government, including monetary policy and tariffs. This runs in the opposite direction of our question, the choice of optimal monetary policy in the face of an exogenous tariff policy shock. 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 firm dynamics.

The paper proceeds as follows. The next section studies a highly simplified model environment with pre-set prices, and derives an analytical solution for an optimal monetary policy response to a tariff shock. Section 3 describes a more general model environment and its calibration for numerical experiments. Section 4 uses this more general model to analyze the optimal policy response to a symmetric trade war, and section 5 repeats the analysis for the case of a unilateral hike in tariffs. In sections 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. Intuition from an analytically tractable specification of the model

To provide intuition for the main mechanism, we begin with the simplest model capable of demonstrating it. We utilize a standard framework from the sticky price literature (from Corsetti and Pesenti, 2009), augmented with ad-valorem tariffs.

2.1 Model setup

Consider two countries, home and foreign, each producing a country-specific good consumed by households in both countries. The home consumption index is Cobb-Douglas with no home bias: $C_t \equiv C_{H,t}^{1/2} C_{F,t}^{1/2}$, where $C_{H,t}$ is a CES index over home varieties on the unit interval: $C_{H,t} \equiv \left(\int_0^1 c_t(h)^{\frac{\phi-1}{\phi}} dh \right)^{\frac{\phi}{\phi-1}}$, and $C_{F,t}$ is a CES index of foreign varieties. All varieties are tradable internationally, subject to tariffs. Let T_t represent the quantity of 1 plus the ad-valorem tariff rate imposed by the home country on imports of foreign goods, and let T_t^* represent 1 plus the ad-valorem tariff rate imposed by the foreign country on foreign imports of home goods. This goods market structure implies a home price index:

$$P_t = 2P_{H,t}^{1/2} \left(T_t P_{F,t} \right)^{1/2}, \tag{1}$$

where $P_{H,t}$ and $P_{F,t}$ are 'ex-tariff' price indexes of home and foreign goods in home currency units, $P_{H,t} = \left(\int_0^1 p_t(h)^{1-\phi} dh \right)^{\frac{1}{1-\phi}}$ and $P_{F,t} = \left(\int_0^1 p_t(f)^{1-\phi} df \right)^{\frac{1}{1-\phi}}$. Demands are:

$$C_{H,t} = \frac{1}{2} \frac{P_t C_t}{P_{H,t}} \tag{2}$$

$$C_{F,t} = \frac{1}{2} \frac{P_t C_t}{T_t P_{F,t}}, \tag{3}$$

where the demand function for imports (Eq. (3)) depends on the 'tariff-inclusive' price, $T_t P_{F,t}$.

Household utility is defined as log in consumption and linear in labor

$$U_t = \ln C_t - \kappa l_t.$$

We follow Corsetti and Pesenti (2009) in defining a variable, $\mu_t = P_t C_t$, to denote nominal expenditure, and in using it to summarize the effect of monetary policy stance on aggregate nominal spending. Utility maximization implies the usual labor supply condition:

$$W_t = \kappa \mu_t. \tag{4}$$

Complete asset markets imply the usual risk-sharing condition:

$$e_t = \frac{\mu_t}{\mu_t^*}, \tag{5}$$

which shows that the relative monetary policy stance of the two countries determines the nominal exchange rate, e.[3]

Firms chose price, $p_t(h)$, in producer currency units to maximize expected discounted profit, $\pi_t(h)$:

$$E_{t-1}\left[\beta\frac{C_t^{-1}/P_t}{C_{t-1}^{-1}/P_{t-1}}\pi_t(h)\right]=E_{t-1}\beta\left[\frac{\mu_{t-1}}{\mu_t}\left[p_t(h)c_t(h)+p_t(h)c_t^*(h)-\frac{W_t}{\alpha_t}y_t(h)\right]\right]$$

subject to home and foreign demands for their variety, respectively,

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

$$c_t^*(h)=\left(p_t^*(h)/P_{H,t}^*\right)^{-\phi}C_{H,t}^*, \tag{7}$$

where $C_{H,t}$ was defined above, and the corresponding foreign demand may be written as

$C_{Ht}^*=\frac{P_t^*C_t^*}{2T_t^*\left(P_{Ht}/e_t\right)}=\frac{P_tC_t}{2T_t^*P_{Ht}}=\frac{C_{Ht}}{T_t^*}$. The production function is linear in labor

$$y_t(h)=\alpha_t l_t(h), \tag{8}$$

and the resource constraint is:

$$c_t(h)+c_t^*(h)=y_t(h). \tag{9}$$

Firms must set prices one period in advance. Importantly, note that firms pre-set the ex-tariff price, but that foreign demand for their good depends upon the tariff-inclusive price. As shown in Appendix A, the optimal pre-set price is:

$$P_{Ht}=\frac{\phi}{\phi-1}E_{t-1}\left[\left(1+\frac{1}{T_t^*}\right)\frac{\kappa\mu_t}{\alpha_t}\right]\Big/E_{t-1}\left[1+\frac{1}{T_t^*}\right]. \tag{10}$$

2.2. Optimal policy

We compute the optimal Ramsey policy by choosing the policy stance, μ_t^{OP}, to maximize expected utility subject to the equilibrium conditions listed in the preceding section. Appendix A derives this optimal policy in terms of the following rules:[4]

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[3] As shown in Corsetti and Pesenti (2009) and Cole and Obstfeld (1991), this condition does not require complete asset markets under the specification of preferences in this simplified model.

[4] The Nash and cooperative solutions coincide for this simple environment. As usual, the Nash solution chooses μ_t, to maximize $E_{t-1}[U_t]$ and foreign chooses μ_t^*, to maximize $E_{t-1}[U_t^*]$; the cooperative solution chooses μ_t and μ_t^* jointly to maximize $E_{t-1}\left[U_t+U_t^*\right]/2$. See appendix A for details.

$$\mu_t^{OP} = a\alpha_t\left(1+\frac{1}{T_t^*}\right)^{-1} \quad (11)$$

and
$$\mu_t^{OP*} = a^*\alpha_t^*\left(1+\frac{1}{T_t}\right)^{-1}, \quad (12)$$

where a is a constant of proportionality. As is standard in sticky price environments, the optimal monetary policy stance μ_t^{OP} is contractionary in response to an adverse domestic productivity shock (fall in α_t for home, α_t^* for foreign). This reflects the standard logic that firms would like to raise prices and reduce production in response to a rise in marginal cost, and a monetary contraction can replicate the same allocation when goods prices are fixed.

In contrast, the home optimal monetary policy response to a rise in foreign tariff on home exports is expansionary. Further, home policy responds only to foreign tariffs; it does not respond to tariffs levied by the home country on home imports. Consequently, the optimal response to a symmetric tariff war involving both home and foreign tariffs is also expansionary as summarized by (Eqs. (11)-(12)).

We can gain some intuition for this policy by comparing its implications for output, and comparing to alternative policies. As shown in Appendix A, output under the optimal policy (Eqs. (11)-(12)) will be:

$$Y_{H,t}^{OP} = \frac{\phi-1}{2\phi}E_{t-1}\left[1+\frac{1}{T_t^*}\right]\frac{\alpha_t}{\kappa}. \quad (13)$$

Note that under the optimal policy production does not fluctuate with realizations of tariff shocks, which appear only inside the expectation operator, and only fluctuates with realizations of the productivity shock.

In contrast, if we assume a monetary stance that does not vary with shocks, that is, a ‘no-policy” case in which $\mu_t^{NP} = 1$, the solution for output is:

$$Y_{H,t}^{NP} = \frac{\phi-1}{2\phi}\frac{E_{t-1}\left[1+\frac{1}{T_t^*}\right]}{E_{t-1}\left[\left(1+\frac{1}{T_t^*}\right)\frac{\kappa}{\alpha_t}\right]}\left(1+\frac{1}{T_t^*}\right). \quad (14)$$

Home production now falls when a rise in tariff dampens foreign demand for home goods.

It is instructive to compare the allocation under the optimal policy with the allocation implemented by a social planner which maximizes $\left(U_t + U_t^*\right)/2$ subject to the resource constraint implied by Eqs. (8-9) and the foreign counterparts. Note that tariffs do not enter the constraints for this problem since they are rebated to the households that pay them, and hence they have no real resource cost. The solution for efficient production is $Y_{H,t}^{SP} = \frac{\alpha_t}{\kappa}$ (see Appendix A). This confirms that it is efficient for production to remain constant in response to a change in tariff, a property shared with the Ramsey optimal monetary result above. However, comparing this result to (13), the Ramsey optimal monetary policy does not fully replicate the social planner allocation: the monetary policy does not eliminate the monopolistic markup $(\phi-1)/\phi$, and it does not eliminate the additional price markup implied by variability in tariff $\left(E_{t-1}\left[1+1/T_t^*\right]/2>1\right)$.

We conclude from this exercise that it is not efficient for output to fall in response to a tariff hike in this simple environment, and further, that optimal monetary policy can help achieve this outcome of insulating production from tariffs.

3. Full model

We now expand the model to a more general environment, to check robustness of the result above, and to provide deeper interpretation of the optimal monetary policy. We include features standard in international macro models relevant for understanding optimal monetary policy, such as price adjustment costs, incomplete asset markets, and markup shocks. We also include features standard in trade models that may be important for understanding tariffs, such as international production chains, trade costs, and firm entry dynamics.

3.1. Goods consumption demand and price indexes

Households now consume differentiated varieties produced by a time-varying number of monopolistically competitive firms in the home and foreign country. Each firm produces a single variety which is an imperfect substitute for any other variety, either of home or foreign origin, with elasticity ϕ.

The overall consumption index is specified as follows:

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

where n_t and n_t^* are the number of firms in home and foreign, respectively, which are time varying and endogenous. The corresponding welfare-based consumption price index is

$$P_t = \left(n_t p_t(h)^{1-\phi} + n_t^* \left(p_t(f) T_t \right)^{1-\phi} \right)^{\frac{1}{1-\phi}}. \tag{15}$$

As in the simplified analytical model of the preceding section, T_t represents the quantity of 1 plus the ad valorem tariff rate imposed by the home country on imports of foreign varieties. In reporting results, we will distinguish between the "ex-tariff" price determined by an exporter, $p_t(f)$, and the "tariff-inclusive" price, $p_t(f)T_t$, paid by an importer. 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 relative demand functions for domestic residents implied from our specification of preferences are listed below:

$$c_t(h) = \left(p_t(h) / P_t \right)^{-\phi} C_t \tag{16}$$

$$c_t(f) = \left(p_t(f) T_t / P_t \right)^{-\phi} C_t. \tag{17}$$

3.2 Home households' problem

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 generalized to

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

subject to the budget constraint:

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

In the utility function, the parameter σ denotes risk aversion and ψ is the inverse of the Frisch elasticity. 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 $\left(\Pi_t \right)$ 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 (Γ_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. 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.

Household optimization implies an intertemporal Euler equation:

$$\frac{1}{P_t C_t^{\sigma}} = \beta\left(1+i_t\right) E_t\left[\frac{1}{P_{t+1} C_{t+1}^{\sigma}}\right] \tag{18}$$

a labor supply condition:

$$W_t / P_t = l_t^{\psi} C_t^{\sigma} \tag{19}$$

a money demand condition:

$$M_t = P_t C_t^{\sigma}\left(\frac{1+i_t}{i_t}\right), \tag{20}$$

and a home interest rate parity condition:

$$\mathrm{E}_t\left[\frac{P_t C_t^{\sigma}}{P_{t+1} C_{t+1}^{\sigma}} \frac{e_{t+1}}{e_t}\left(1+\mathrm{i}_t^*\right)\left(1+\psi_{\mathrm{B}}\left(\frac{e_t B_{ft}}{p_{Ht} y_{Ht}}\right)\right)\right] = \mathrm{E}_t\left[\frac{P_t C_t^{\sigma}}{P_{t+1} C_{t+1}^{\sigma}}\left(1+\mathrm{i}_t\right)\right]. \tag{21}$$

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

3.3 Home firm problem and entry condition

The production of each variety follows

$$y_t(h) = \alpha_t\left[G_t(h)\right]^{\zeta}\left[l_t(h)\right]^{1-\zeta}, \tag{22}$$

where α_t is stochastic productivity common to all home firms, $l_t(h)$ 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 varieties that mirrors the consumption index. If we sum across firms, $G_t = n_t G_t(h)$ represents economy-wide demand for goods as intermediate inputs. Given that the index is the same as for consumption, this implies demands for goods varieties, $d_{G,t}(h)$ and $d_{G,t}(f)$, analogous to Eqs. (16) and (17).[5]

[5] See Appendix B for the demand equations not listed here.

Firms set prices $p_t(h)$ subject to an adjustment cost:

$$AC_{P,t}(h)=\frac{\psi_P}{2}\left(\frac{p_t(h)}{p_{t-1}(h)}-1\right)^2\frac{p_t(h)y_t(h)}{P_t}, \tag{23}$$

where ψ_P is a calibrated parameter governing the degree of price stickiness.[6]

Since all firms 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 evolves according to:

$$n_{t+1}=(1-\delta)(n_t+ne_t), \tag{24}$$

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 varies with the number of new firms, reflecting an entry congestion externality:

$$K_t=\left(\frac{ne_t}{ne_{t-1}}\right)^{\lambda}\overline{K}, \tag{25}$$

where $\overline{K}$ indicates the steady state level of entry cost.[7] The demands for varieties for use as entry investment, $d_{K,t}(h)$ and $d_{K,t}(f)$, are determined analogously to consumption demand.

We now can specify total demand facing a domestic firm:

$$d_t(h)=c_t(h)+d_{G,t}(h)+d_{K,t}(h)+d_{AC,P,t}(h)+d_{AC,B,t}(h) \tag{26}$$

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 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 for exports, so that market clearing for a firm's variety is:

$$y_t(h)=d_t(h)+(1+\tau)d_t^*(h). \tag{27}$$

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 firms (in our case, households). In order to

[6] 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.

[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.

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 $\left(1-T_{MU,t}\right)$ paid by the firm on each unit of revenue. So firm profits are computed as:

$$\pi_t\left(h\right)=\left[p_t\left(h\right)d_t\left(h\right)+e_t p_t^*\left(h\right)d_t^*\left(h\right)\right]T_{MU,t}-mc_t y_t\left(h\right)-P_t AC_{p,t}\left(h\right). \tag{28}$$

where $mc_t=\zeta^{-\zeta}\left(1-\zeta\right)^{\zeta-1}P_t^{\zeta}W_t^{1-\zeta}/\alpha_t$ 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:

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

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:

$$v_t\left(h\right)=P_tK_t\ . \tag{29}$$

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

$$\frac{P_tG_t(h)}{W_tl_t(h)}=\frac{\zeta}{1-\zeta}\ . \tag{30}$$

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

$$\begin{aligned}p_t\left(h\right)=&\frac{\phi}{(\phi-1)T_{MU,t}}mc_t+\frac{\psi_P}{2}\left(\frac{p_t\left(h\right)}{p_{t-1}\left(h\right)}-1\right)^2p_t\left(h\right)-\psi_P\frac{1}{\phi-1}\left(\frac{p_t\left(h\right)}{p_{t-1}\left(h\right)}-1\right)\frac{p_t\left(h\right)^2}{p_{t-1}\left(h\right)}\\&+\frac{\psi_P}{\phi-1}E_t\left[\beta\frac{\Omega_{t+1}}{\Omega_t}\left(\frac{p_{t+1}\left(h\right)}{p_t\left(h\right)}-1\right)\frac{p_{t+1}\left(h\right)^2}{p_t\left(h\right)}\right]\end{aligned} \tag{31}$$

expresses the optimal pricing as a function of the discounted demand for domestic varieties,

$$\begin{aligned}\Omega_t=&\left[\left(\frac{p_t\left(h\right)}{P_t}\right)^{-\phi}\left(C_t+G_t+ne_t\left(1-\theta_K\right)K_t+AC_{P,t}+AC_{B,t}\right)\right.\\&\left.+\left(\frac{(1+\tau)T_t^*p_t\left(h\right)}{e_tP_t^*}\right)^{-\phi}\left(1+\tau\right)\left(C_t^*+G_t^*+ne_t^*\left(1-\theta_K\right)K_t^*+AC_{P,t}^*+AC_{B,t}^*\right)\right]\Big/\left(P_tC_t^{\sigma}\right).\end{aligned}$$

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

$$p_t^*\left(h\right)=\left(1+\tau\right)p_t\left(h\right)/e_t\,, \tag{32}$$

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

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 is:

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

For reference, the home trade balance is computed $TB_t = n_{t-1} p_t^*(h) d^*_t(h) - n^*_{t-1} p_t(f) d_t(f)$, where $d_t(f)$ is overall home demand for foreign goods (for consumption, intermediates, etc.) as defined in Appendix B. Gross domestic product then is computed as $Y_t = C_t + ne_t K_t + TB_t$.

3.5 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 equilibrium conditions 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 adopt a timeless perspective.

For comparison, we also study three alternative nominal specifications. The first one assumes flexible prices and wages, so as to characterize the natural allocation. The second posits a monetary policy with a constant money growth rule:

$$\frac{M_t}{M_{t-1}} = \upsilon, \tag{33}$$

which we label the ‘no (stabilization) policy’ case. The last case specifies monetary policy with a Taylor rule of the form

$$1 + i_t = (1 + i_{t-1})^{\gamma_i} \left[(1 + \bar{i}) \left(\frac{P_t}{P_{t-1}} \right)^{\gamma_P} \left(\frac{Y_t}{\overline{Y}} \right)^{\gamma_Y} \right]^{1-\gamma_i}, \tag{34}$$

which responds to overall inflation and output deviations from steady state.

Across these different specifications of monetary policy, we will abstract from public

[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.

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:

$$\Gamma_t = \left(M_t - M_{t-1}\right) + \left(T_t - 1\right) n_{t-1}^* d_t(f) + \left(1 - T_{MU,t}\right)\left(n_{t-1} d_t(h) + n_{t-1}^* d_t(f)\right). \qquad (35)$$

3.6 Market clearing and equilibrium

To conserve space, market clearing conditions to close the model are reported in Appendix B. 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 firm optimality conditions; (ii) the market clearing conditions for each good and asset, including money; (iii) the resource constraints.

Shocks are normally distributed in logs. See Appendix B 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.[9]

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

3.7 Model calibration

See Table 1 for a list of parameter values. Where possible, parameter values are taken from standard values in the literature. 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 $\psi_p = 49$, a value which implies in simulations of a productivity shock that approximately three quarters of firms reset price after

[9] 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.

the first year.[10] The firm death rate is set at δ =0.025, the adjustment cost parameter for new firm entry, λ , is taken from Bergin and Corsetti (2020), and the mean sunk cost of entry is normalized to $\overline{K}$ =1.

The share of intermediates in production follows Jones (2007) by setting ζ =0.43.[11] The elasticity of substitution between varieties is ϕ =5.2, from estimates in Broda and Weinstein (2006).[12] The trade cost parameter is calibrated at τ = 0.44 so that exports represent 25% of GDP, as is the average in World Bank national accounts data for both the OECD average and for China from 2001-2019.[13] Calibration of policy parameters for the Taylor rule are taken from Coenen, et al. (2010).

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).[14] The standard deviation of 6 percentage points is taken from Caldara et al. (2020), to capture tariff increases 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.

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[10] 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.

[11] This is similar to the value 0.42 estimated by Miyamoto and Nguyen (2017) based on the 2011 U.S. Input-Output table. Robustness checks will consider a range of values.

[12] Based on their sample period for 1972-1988.

[13] See https://data.worldbank.org/indicator/NE.EXP.GNFS.ZS?locations=OE. The value for China is 25.7, and for OECD 25.6. Following standard accounting definitions, intermediates are included in the measure of exports, and excluded from the measure of GDP.

[14] 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.

4. Monetary stabilization with symmetric trade war

Simulations are conducted for two types of tariff shocks. This section studies a symmetric rise in tariffs in both countries---the case of a trade war with full retaliation. Section 5 below will study a unilateral foreign tariff on home exports, which will provide insight into the response of the exchange rate and trade balance.[15] 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 1. It includes the macroeconomic responses of selected variables under different assumptions about policy regimes. The figure contrasts the Ramsey optimal policy (solid line) with the cases of a "Taylor rule" (dotted line) and a "no-policy" case (dashed line), where the latter is obtained by imposing a constant money growth rule. Only home variables are reported, since the foreign counterparts are identical. These simulation results serve to confirm that the analytical results derived in the preceding section for the simplified model are robust to the richer environment of the full model, and to elaborate on the macroeconomic implications of the tariff.

4.1 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 line in Figure 1). 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)).[16] 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. As the shock abates, the economy in our baseline simulation actually

[15] The case of a symmetric global shock is modeled by drawing a single shock and feeding it directly into the autoregressive processes for both home and foreign tariffs.
[16] The decline in output induced by a tariff war reflects a common theme in the literature studying factors contributing to the Great Depression.

experiences a deflation, with the price level gently returning to trend over time.[17]

We take special note 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 1.)[18]

Higher tariffs depress consumption and output, working through multiple 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 number of firms, apparent from Figure 1. 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.

Monetary policy in the form of a standard Taylor rule responding to headline inflation (dotted lines in Figure 1), tends to amplify the initial contraction implied by the tariff in our model, relative to the responses seen above for the ‘no-policy’ regime. Policymakers would respond to the tariff-induced inflation by raising nominal rates, and thus exacerbate the fall in GDP and firm creation in the initial period. Note that, in light of our discussion above of a

[17] 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.

[18] 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.

falling PPI, 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 1, 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 in 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 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 $\varsigma = 0.53$ or greater, a tariff will raise PPI rather than lower it. This point will be discussed further below.

4.2 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 1, 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, consumption, and entry investment, 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 tariff shock as a supply shock 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)), our result obviously calls for a thorough theoretical reconsideration.[19] Our simulation results suggest we draw intuition from the observation that the CPI inflation of a tariff shock

[19] 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.

masks a PPI deflation. It is well understood in the open economy literature that, under price stickiness in the currency of the producer, optimal monetary policy tends to stabilize inflation in producer prices, where the price stickiness resides, rather than consumer price inflation. This helps explain our finding in simulations that the optimal policy response to a tariff war is a monetary expansion, even if it may exacerbate the effect of the tariff on CPI inflation.

The optimality of a monetary expansion is 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 optimal 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_T). 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 τ = 0. In the 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.[20]

The optimality of a monetary expansion is also robust to wage stickiness. See Appendix C for a description of how the simulation model is augmented by monopolistically competitive suppliers of labor that set wage subject to a Rotemberg adjustment cost analogous to price setters. Even for an essentially infinite calibration of the wage adjustment costs, implying no fall in nominal wage after a tariff increase, it remains optimal for monetary policy to respond by lowering interest rates. (See Appendix Figure 3 for full results.) In contrast with the benchmark model, PPI inflation now rises for a no-policy case, due to the frictions that prevent wages from falling in nominal terms. Nonetheless, it is still economically inefficient that producers reduce output in the face of a decline in disutility of labor.

[20] Conversely, a lower degree of openness reduces the magnitudes of responses of macroeconomic variables, as well as the magnitude of the interest rate cut implied by optimal policy; nonetheless, the signs of these responses are unchanged from the benchmark case. See the third column of Appendix Figure 2, where trade cost is set to τ =1.7 (value taken from Epifani and Gancia, 2017).

Our result does depend on 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 2 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.[21] This is higher than our benchmark calibration of 0.43 based on the estimate of Jones (2007), and somewhat higher than the norm in the literature.[22]

We close this section highlighting the role of firm entry dynamics. 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 (see Appendix Figure 4). Nonetheless, the optimal policy still prescribes comparable interest rate cuts in response to the tariff shock.

4.3 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 3 reports impulse responses for a symmetric adverse shock to productivity (α_t) in column (2), and a symmetric shock raising firm markups ($T_{MU,t}$) in column (3). For comparison, column (1) reiterates selected results for a symmetric tariff shock taken from Figure 1. Additionally, to aid intuition, this figure reports for each shock a set of impulse responses assuming flexible prices (shown as a dash-dot line; specified by $\psi_P = 0$, and assuming constant money growth).[23] As seen in Figure 3, the three shocks share in common a protracted fall in home GDP and a hike in inflation.[24] Despite these basic similarities, the tariff

[21] 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 in simulations of a case with a constant money growth rule. Figure 2 reports results for a calibration of $\varsigma = 0.6$, where both PPI and interest rate effects are inverted compared to the benchmark calibration.

[22] Miyamoto and Nguyen (2017) estimate a value of 0.42 based on the 2011 U.S. Input-Output table, and Epifani and Gancia (2017) adopt a value of 0.51 based on estimates specific to manufacturing.

[23] To avoid clutter, impulse responses for the Taylor rule case are not reported here.

[24] This is most clearly visible in the flexible price case; sticky prices dampen the rise in price and delay the fall in output somewhat, as will be explained further below.

shock differs from the other two shocks in key respects.

4.3.1 Productivity

The case of an adverse productivity shock is familiar from the literature and requires little discussion. But note in Figure 3 (column 2) that PPI and CPI inflation rise closely together in the no-policy case 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 (the impulse response of GDP under optimal policy is closer to the flex price impulse response than is the no-policy case response). 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 in the case of the tariff shock, the optimal policy actually implies an impulse response for GDP that is farther from the flexible price response than was true for the no-policy case. 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.

4.3.2 Markups

Like tariffs, also markup shocks impose a rise in prices 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 3 above, the markup shock (T_{MU}) appears explicitly inside the price setting rule for the firm (Eq. (31)), while the tariff shocks (T) does not. Instead it appears directly in the demand function for imports (Eq. (17)). An implication is that markup 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 firm managers at the border. As shown above, it is indeed plausible that, facing a lower demand in the destination country due to higher tariff-inclusive consumer prices, exporters actually reduce their preset price at the border.

Figure 3 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 in the no-policy case (dashed line); whereas for a tariff shock CPI rises with the tariff, but the producer price (ex-tariff) does not in the no-policy case. 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.

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 5) 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.[25] 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.[26]

The economics underlying this result lay in the different interactions of the two shocks

[25] See Appendix B section 5 for an explanation of model modifications required.
[26] Appendix Figure 5 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-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.

with price stickiness. In response to markup shocks, one the one hand, as shown in Figure 3, 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, favoring 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.

4.4 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.

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 0.098%---modest values are typical of business cycle analysis. As 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 0.098% 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 values 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.

5. 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 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. We choose to study the case of a foreign tariff imposed on home exports, since our focus is on how the home country can optimally respond in terms of monetary policy to an exogenous tariff shock imposed on it (by a foreign entity), rather than focusing on whether or how the home country can use domestic tariff policy to achieve macroeconomic objectives. Furthermore, the result of the analytical section (section 2) indicated that in the most simple and essential version of our model, optimal monetary policy only responds to foreign tariffs, and does not respond to domestically generated tariffs. Nonetheless, the macroeconomic implications and optimal policy response in the country imposing the tariff can be read in our results below by examining the response of the foreign country.

5.1 Transmission under suboptimal policy

Impulse responses in Figure 4 show that a foreign tariff shock is contractionary in the home country targeted by the tariff, generating a home trade deficit and fall in home GDP, both for the no-policy case (dashed line) and Taylor rule (dotted line). The effect on foreign GDP is mixed on impact depending on the monetary policy rule, but in all cases includes a prolonged contraction lasting several years. As discussed by Erceg et al. (2018), while a foreign trade surplus may raise foreign output, this may be dominated by a fall in consumption demand due to intertemporal substitution and expectations that the inflationary effects of tariffs will abate in the future. Additionally in our model, a fall in foreign investment expenditure on firm creation further works against the ability of a foreign trade surplus to raise demand.[27] The effects on inflation are also asymmetric across countries. Both CPI and PPI inflation rates fall at home in the initial period of the shock in the no-policy case, while they rise in foreign. In the absence of policy intervention, there is minimal movement in the nominal exchange rate in response to the unilateral tariff on home exports.

5.2 Efficient stabilization

An optimal cooperative response to a unilateral tariff shock highlights new channels and mechanisms. In response to the foreign tariff shock, the optimal cooperative policy (the solid line in Figure 4) still prescribes substantial monetary expansion at home (lower home interest rates). This coincides with the prescription for optimal policy in our analytical model of section 2. The optimal response abroad is now a contraction; this contrasts with the home policy, as well as with the result of the simplified analytical model, which included no monetary policy response to tariffs imposed by one's own country. 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 the positive PPI inflation in the foreign country. Another reason is that, under cooperation, an asymmetric monetary stance

[27] In our benchmark model assuming a Taylor rule, the version of the model most suitable for comparison to data, these opposing forces are balanced initially, implying nearly no effect on foreign GDP in the initial period of the tariff, but then imply a prolonged fall in foreign output over the subsequent several years. This dynamic of foreign GDP is similar to that in empirical impulse responses estimated in Barrattieri et al. (2021) and Furceri et al. (2022).

redresses the impact of the tariff on the terms of trade via currency depreciation. In Figure 4, the optimal policy counteracts the home terms of trade movements in the initial periods, compared to the no-policy case.

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 generates 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: 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 4.

5.3 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. In Figure 5, for purposes of comparison, the first column reiterates selected results for a foreign tariff shock on home exports from Figure 4. However, this figure replaces the Taylor rule case with a case assuming flexible prices ($\psi_p = 0$, and assuming constant money growth; reported as a dash-dot line). Columns 2 and 3 report corresponding impulse responses, respectively, for an adverse home productivity shock and markup shock.

The three shocks share in common a protracted fall in home GDP, though in the case of the adverse productivity shock, sticky prices delay the fall in output (as discussed previously in the case of a symmetric shock). However, the tariff shock differs from the other two supply shocks in key respects. Foremost, the optimal monetary policy responses to the recessions caused by the home productivity shock and markup shock call for a rise in home interest rate and a corresponding appreciation in home currency, whereas the opposite is optimal in response to the recession induced by the tariff shock.

It is also striking that optimal policy works in the direction of restoring a flexible price allocation in the other two supply shocks, but does the opposite in the case of the tariff shock. In the case of an adverse productivity shock, the impulse response of home GDP under optimal policy is quite similar to that under the flexible price case, in contrast to the no-policy case. The optimal policy thus works to counteract the effects of sticky prices. The reason, as discussed above for the symmetric shock, is that a fall in home GDP is efficient in the case of an adverse home productivity shock. The opposite is the case for a tariff shock, where the impulse response for home GDP is much farther from the flexible price case than is true for the no-policy case. As with the symmetric tariff case, the optimal policy does not aim to bring the allocation close to the flexible price (natural rate) one.[28] On the contrary, it brings most macro aggregates to overshoot their flex-price levels. By way of example, in the flex-price allocation, the home country experiences a large GDP contraction on impact: the optimal policy eliminates more than half of the negative effect of the tariff on activity.

5.4 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 the symmetric tariff war: 0.346% (column 4) as opposed to 0.098% (column 1). 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 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).[29]

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

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[28] 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.

[29] 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 from the cooperative optimal monetary policy response to counter foreign tariffs. In fact, the foreign country improvement in welfare (0.181%) is higher than that for the home country (0.165%)---while the cooperative monetary policy response to foreign tariffs lowers foreign GDP relative to the Taylor rule, it raises welfare due to higher consumption.

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 Appendix B section 3 for the modified price-setting equations, counterparts to Eqs. (31-32).

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 with constant money growth policy, depicted for the LCP case in Figure 6.[30] Comparing the corresponding PCP case in Figure 4 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 important result 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 transmission of the optimal policy. Comparing the LCP case in Figure 6 with the baseline PCP case of Figure 4, the optimal monetary policies in the two cases appear to be nearly the same – lowering home interest rate and raising foreign, implying a home currency depreciation. However, in contrast with the PCP case, this policy does not significantly dampen the home fall in output under LCP, and the fall in output in figure 6 with optimal policy is nearly the same as for the no-policy case. Under PCP, a monetary expansion can buffer the fall in home GDP by improving price competitiveness of home products via currency depreciation. Under LCP, a currency depreciation loses its effect on the price faced by foreign consumers, so 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.

[30] Appendix Table 2 reports welfare analysis for the LCP model, showing similar welfare losses as PCP.

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 7, with additional results reported in the appendix.[31] In column (1) of Figure 7, we assume that the foreign country imposes a tariff on home exports. If the home currency is dominant (i.e. home 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 7, 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 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 7 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 7), 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.

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. Empirical

[31] See Appendix Figures 6-8. Welfare implications are reported in Appendix Table 3.

estimates in Cavallo et al. (2021), Flaaen et al. (2020), and Fajgelbaum et al (2020) indicate that the tariff pass-through to import prices at the dock is high or even complete. It is however much lower to retail prices.

The impulse responses for the benchmark model reported in Figure 4 imply a pass-through of a unilateral foreign tariff to foreign import prices at the dock in the initial period that is nearly complete (97.6%), which matches the empirical evidence cited above.[32] Nonetheless, the pass-through of the tariff to the consumer price index in the foreign country (which includes both domestic and imported varieties) is a quite modest 17.5%, owing largely to home bias in this sector. This value compares favorably with the pass-through to consumer prices that Flaaen et al. (2020) estimate for 2016 China duties, though it is higher than the values (close to zero) estimated in Cavallo et al. (2021).

To account for a very low degree of tariff pass-through at consumer level, as suggested by estimates in Cavallo et al. (2021), we can modify the benchmark model to include 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 consumers do not purchase imported varieties directly from producers. Consumer goods combine imported goods with domestic labor and home domestic goods as inputs. We now specify the consumption index without the direct inclusion of imported varieties:

$C_t \equiv \left(\int_0^{n_t} c_t(h)^{\frac{\phi-1}{\phi}} dh \right)^{\frac{\phi}{\phi-1}}$, and correspondingly change consumer price indexes and demands.[33]

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 97.9% for a given imported variety; pass-through to the consumer price index is actually negative, and equal to -19.5%, in the initial period of the shock.[34]

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 9 for a unilateral shock and Appendix Figure 10 for a symmetric shock). The optimal policy still calls for a strong expansionary response to the macroeconomic effects of the tariff, with the home

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[32] See Appendix D section 1 for a more detailed discussion of the empirical evidence and comparison with a data-consistent measure of pass-through for our benchmark model.

[33] See Appendix D section 2 for the full list of modified equations.

[34] See Appendix D section 3 for a more detailed discussion of simulation results.

interest rate cut only slightly smaller in magnitude than in the corresponding cases using the benchmark model (comparing Appendix Figure 9 to Figure 4 in the main text for a unilateral shock, and comparing Appendix Figure 10 to Figure 1 in the main text for a symmetric shock). We conclude that our main claim, that a monetary expansion tends to be the appropriate response to a tariff, is robust to an environment with low pass-through to consumer prices.

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 firm dynamics. 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 alternative types of price stickiness and low pass-through of tariffs to consumer prices. The scope for monetary stabilization is 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.

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.

References

Auray, Stéphane, Michael B. Devereux, and Aurélien Eyquem, 2021. "Trade Wars and Currency Wars," NBER working paper # 27460.

Backus, David K., Patrick J. Kehoe and Finn E. Kydland, 1992. "International Real Business Cycles," *Journal of Political Economy* 100, 745-775.

Barattieri, Alessandro, Matteo Cacciatore, and Fabio Ghironi, 2021. "Protectionism and the Business Cycle," *Journal of International Economics* 129, 103417.

Bergin, Paul R. and Giancarlo Corsetti, 2020. "Beyond Competitive Devaluations: The Monetary Dimensions of Comparative Advantage," *American Economic Journal: Macroeconomics* 12(4), 246-86.

Bilbiie, Florin O., Fabio Ghironi, and Marc J. Melitz, 2008. "Monetary Policy and Business Cycles with Endogenous Entry and Product Variety," in Acemoglu, D., K. S. Rogoff, and M. Woodford, eds., *NBER Macroeconomics Annual 2007,* Univ. of Chicago Press, Chicago, 299-353.

Bloom, Nicholas, Philip Bunn, Scarlet Chen, Paul Mizen, Pawel Smietanka, and Gregory Thwaites, 2019. "The Impact of Brexit on UK Firms," NBER Working Papers 26218, National Bureau of Economic Research, Inc.

Born, B., G. J. Müller, M. Schularick, P. Sedláček, 2019. "The Costs of Economic Nationalism: Evidence from the Brexit Experiment," *The Economic Journal* 129: 2722-2744.

Breinlich, H., E. Leromain, D. Novy, and T. Sampson, 2017. "The Consequences of the Brexit Vote for UK Inflation and Living Standards: First Evidence", LSE mimeo.

Broda, Christian and David E. Weinstein, 2006. "Globalization and the Gains from Variety," *The Quarterly Journal of Economics* 121, 541-585.

Brown, Chad, 2022. "US-China Trade War Tariffs: An Up-to-Date Chart," Peterson Institute mimeo. https://www.piie.com/research/piie-charts/us-china-trade-war-tariffs-date-chart.

Caldara, Dario, Matteo Iacoviello, Patrick Molligo, Andrea Prestipino and Andrea Raffo, 2020. "The Economic Effects of Trade Policy Uncertainty," *Journal of Monetary Economics* 109, 38-59.

Caliendo, L., R. C. Feenstra, J. Romalis, and A. M. Taylor, 2017. "Tariff Reductions, Entry, and Welfare: Theory and Evidence for the Last Two Decades," working paper.

Cavallo, Alberto, Gita Gopinath, Brent Neiman, and Jenny Tang, 2021, "Tariff Pass-Through at the Border and at the Store: Evidence from US Trade Policy," *American Economic Review: Insights* 3(1), 19-34.

Clarida, Richard, Jordi Galí, and Mark Gertler, 1999. "The Science of Monetary Policy The Science of Monetary Policy: A New Keynesian Perspective," *Journal of Economic Literature* 37, 1661-1707.

Cole, H. L., Obstfeld M., 1991. "Commodity Trade and International Risk Sharing: How Much do Financial Markets Matter?" *Journal of Monetary Economics* 28, 3-24.

Coenen, G., G. Lombardo, F. Smets and R. Straub, 2010. "International Transmission and Monetary Policy Cooperation," in Jordi Galí and Mark J. Gertler, eds. *International Dimensions of Monetary Policy*, Chicago: University of Chicago Press, 157-192.

Corsetti, Giancarlo and Luca Dedola, 2005. "A Macroeconomic Model of International Price Discrimination," *Journal of International Economics* 67(1), 129-155.

Corsetti, Giancarlo, Luca Dedola, and Sylvain Leduc, 2010, "Optimal Monetary Policy in Open Economies," *Handbook of Monetary Economics*, vol III, ed by B. Friedman and M. Woodford, 861-933.

Corsetti, Giancarlo and Paolo Pesenti, 2009, "The Simple Geometry of Transmission and Stabilization in Closed and Open Economies," *NBER International Seminar on Macroeconomics 2007*, ed by Richard Clarida and Francesco Giavazzi, Francesco: University of Chicago press, Chicago, 65-116.

Crucini, Mario and James Kahn, 1996. "Tariffs and Aggregate Economic Activity: Lessons from the Great Depression," *Journal of Monetary Economics* 38(3), 427-467.

Davies, R. B. and Z. Studnicka, 2018. "The Heterogeneous Impact of Brexit: Early Indications from the FTSE." *European Economic Review*, Vol. 110, pp. 1-17.

Dhingra, S., H. Huang, G. Ottaviano, J. P. Pessoa, T. Sampson, and J. Van Reenen, 2017. "The Consequences of Brexit for UK Trade and Living Standards," *Economic Policy* 32(92), 651-705.

Epifani, Paolo and Gancia, Gino, 2017. "Global Imbalances Revisited: The Transfer Problem and Transport Costs in Monopolistic Competition," *Journal of International Economics* 108, 99-116.

Erceg, Christopher, Andrea Prestipino, and Andrea Raffo, 2018. "The Macroeconomic Effects of Trade Policy," Board of Governors of the Federal Reserve System International Finance Discussion Papers, Number 1242.

Fajgelbaum, Pablo D., Pinelopi K. Goldberg, Patrick J. Kennedy, and Amit K. Khandelwal, 2020. "The Return to Protectionism," *The Quarterly Journal of Economics* 135(1), 1–55.

Flaaen, Aaron., Ali Hortacsu, and Felix Tintelnot, 2020, "The Production, Relocation, and Price Effects of US Trade Policy: The Case of Washing Machines," *American Economic Review* 110(7), 2103-2127.

Furceri, Davide, A. Hannan Swarnali, Jonathan D. Ostry, and Andrew K. Rose, 2022. "The Macroeconomy After Tariffs," *World Bank Economic Review* 36(2), 361-381.

Hall, Robert E., 2009. "By How Much Does GDP Rise If the Government Buys More Output?" *Brookings Papers on Economic Activity* 2, 183–231.

Jeanne, Olivier, 2021. “Currency Wars, Trade Wars, and Global Demand,” Johns Hopkins University Working Paper.

Jones, Charles I., 2007. “Input-Output Multipliers, General Purpose Technologies, and Economic Development.” Unpublished manuscript, http://www-leland.stanford.edu/~chadj/io026.pdf.

Lindé, Jesper and Andrea Pescatori, 2019. "The Macroeconomic Effects of Trade Tariffs: Revisiting the Lerner Symmetry Result," *Journal of International Money and Finance* 95(C), 52-69.

Miyamoto, Wataru and Nguyen, Thuy Lan, 2017. “Understanding the cross country effects of U.S. technology shocks,” *Journal of International Economics* 106, 143-164.

Sampson, T., 2017. “Brexit: The Economics of International Disintegration,” *Journal of Economic Perspectives*, 31(4), 163-184.

Steinberg, J. B., 2019. “Brexit and the Macroeconomic Impact of Trade Policy Uncertainty.” *Journal of International Economics* 117, 175-195.

Van Reenen, J., 2016. “Brexit's Long-Run Effects on the UK Economy,” *Brookings Papers on Economic Activity* 47(2), 367-383.

World Bank, 2021. “World Bank National Accounts Data: Exports of Goods and Services (% of GDP).” https://data.worldbank.org/indicator/NE.EXP.GNFS.ZS?locations=OE.

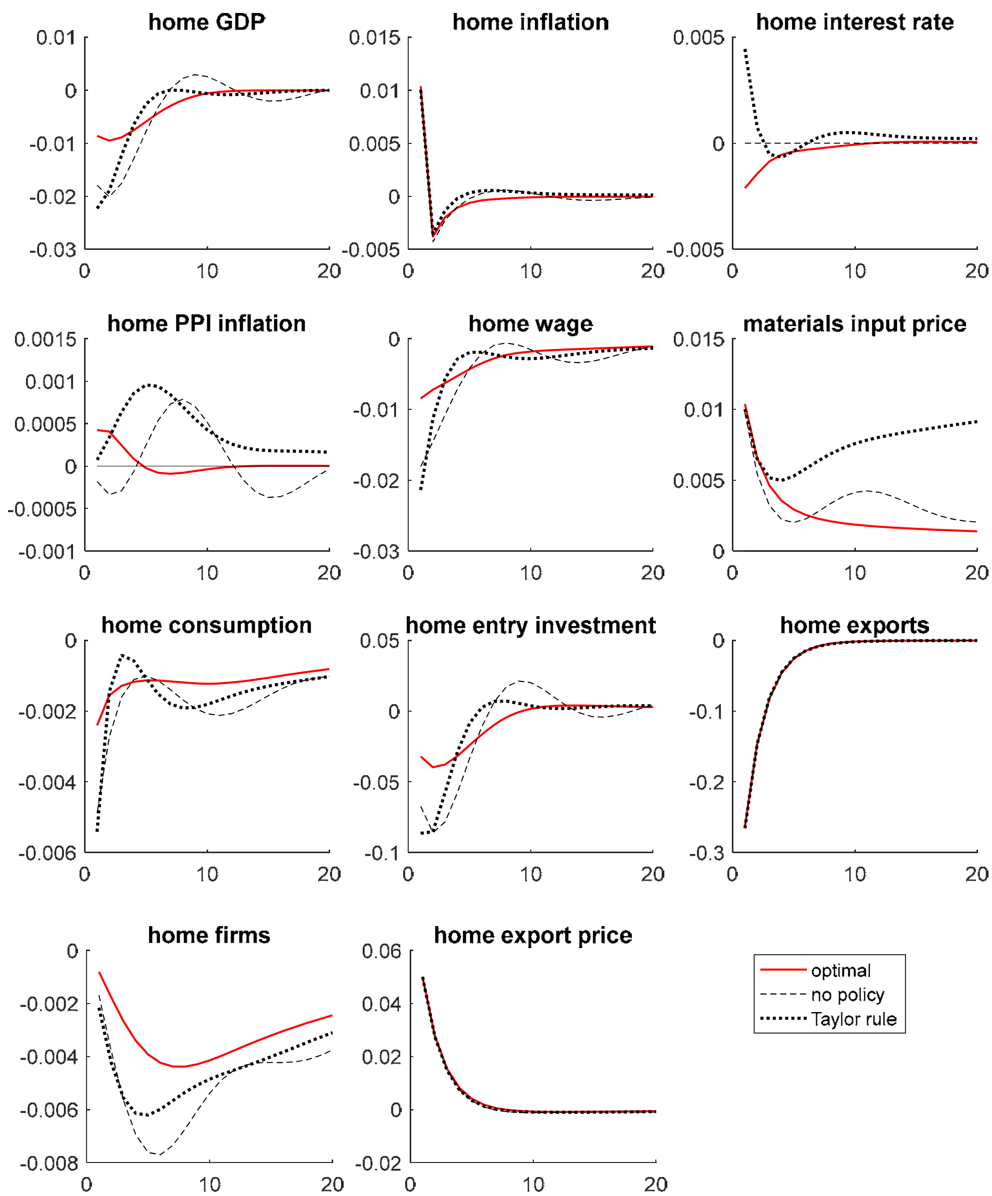
Table 1. Benchmark Parameter Values

Preferences	
Risk aversion	$\sigma = 2$
Time preference	$\beta = 0.99$
Labor supply elasticity	$1/\psi = 1.9$
Elasticity among varieties	$\phi = 5.2$
Technology	
Firm death rate	$\delta = 0.025$
Price stickiness	$\psi_P = 49$
Intermediate input share	$\varsigma = 1/3$
Trade cost	$\tau = 0.44$
Mean sunk entry cost	$\overline{K} = 1$
Firm entry adjustment cost	$\lambda = 0.10$
Bond holding cost	$\psi_B = 10^{-6}$
Tariff mean	$\overline{T} = 1.02$
Policy (for Taylor rule case)	
Interest rate smoothing	$\gamma_i = 0.7$
Inflation response	$\gamma_p = 1.7$
GDP response	$\gamma_Y = 0.1$

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

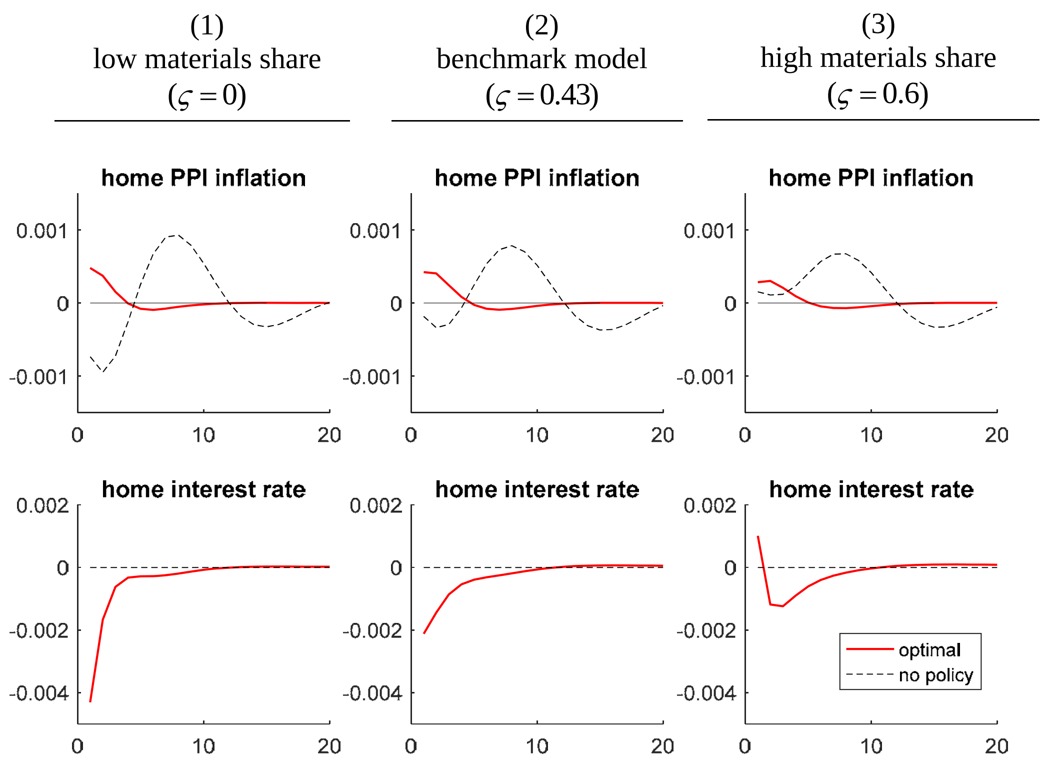
	common shock			independent shock		
	(1) benchmark	(2) no roundabout	(3) no firm entry or roundabout	(4) benchmark	(5) no roundabout	(6) no firm entry or roundabout
standard deviations in percent (difference from Ramsey)						
GDP	1.35	1.35	0.15	2.05	2.25	1.79
employment	0.96	1.27	0.17	2.27	2.64	2.16
consumption	0.19	0.33	0.19	-0.23	-0.14	-0.16
firm entry invest.	4.39	7.99	0.00	-7.31	-6.32	0.00
number of firms	0.35	0.85	0.00	-1.24	-0.84	0.00
inflation	-0.05	-0.10	-0.05	0.18	0.12	0.13
real exch. rate	0.00	0.00	0.00	-1.04	-0.83	-0.94
unconditional means of variables (percent change from Ramsey case)						
GDP	0.048	0.027	0.012	0.048	0.061	0.070
employment	0.025	0.012	0.010	0.114	0.051	0.064
consumption	-0.015	-0.010	0.000	-0.116	-0.043	0.029
firm entry invest.	-0.055	-0.077	0.000	-0.754	-0.718	0.000
number of firms	-0.055	-0.077	0.000	-0.754	-0.718	0.000
Welfare (percent change from Ramsey case, conditional, in consumption units):						
	-0.098	-0.057	-0.024	-0.346	-0.149	-0.105

Figure 1. Symmetric tariff war: Impulse responses to a rise in tariff in both countries



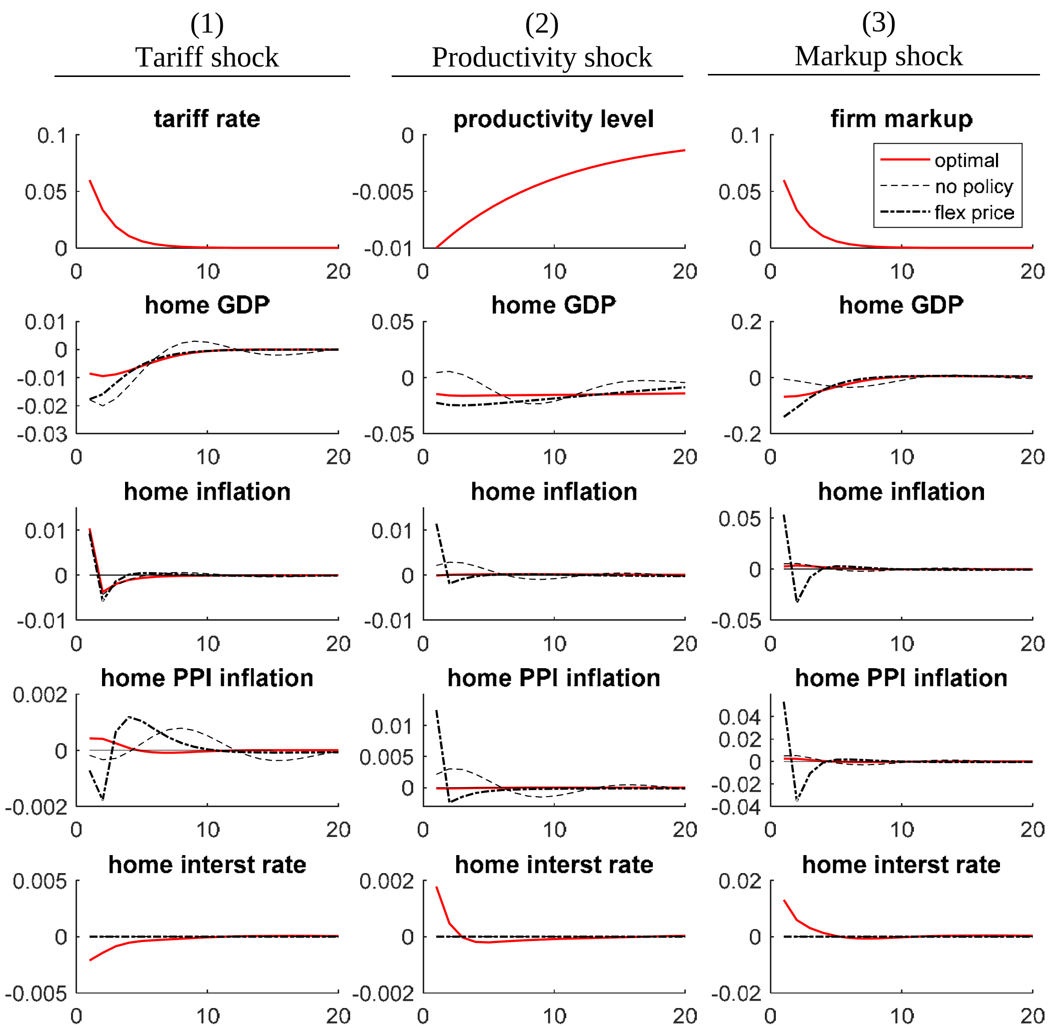
Vertical axis is percent deviation (0.01=1%) from steady state levels. Horizontal axis is time (in quarters).

Figure 2. Alternative calibrations of materials intput share,
symmetric tariff shock



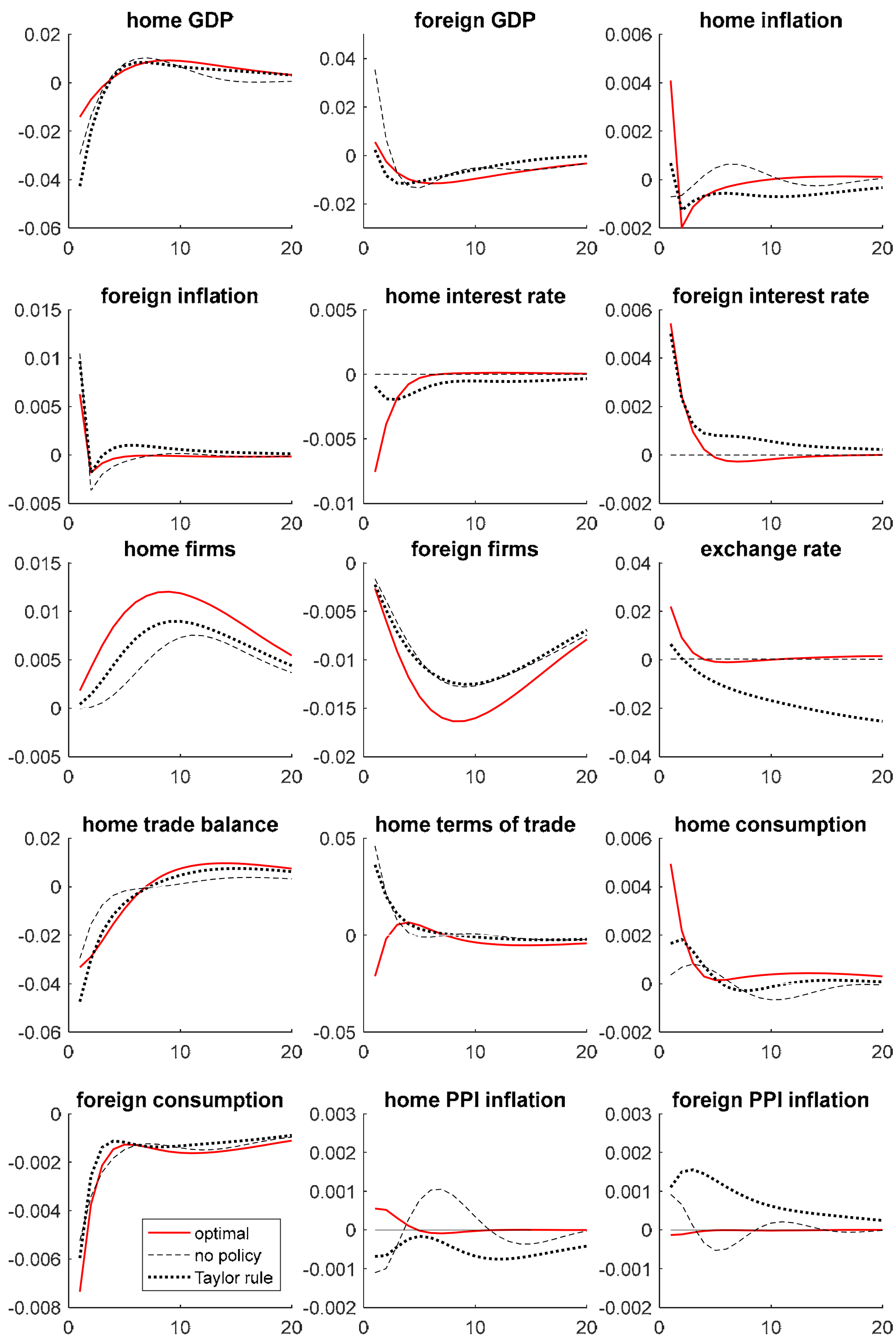
Vertical axis is percent deviation (0.01=1%) from steady state levels. Horizontal axis is time (in quarters).

Figure 3. Comparison of shocks: Impulse responses to three shocks to both countries



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

Figure 4. Unilateral tariff: Impulse responses to a rise in foreign tariff on home exports



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

Figure 5. Comparing unilateral shocks: Impulse responses to three shocks

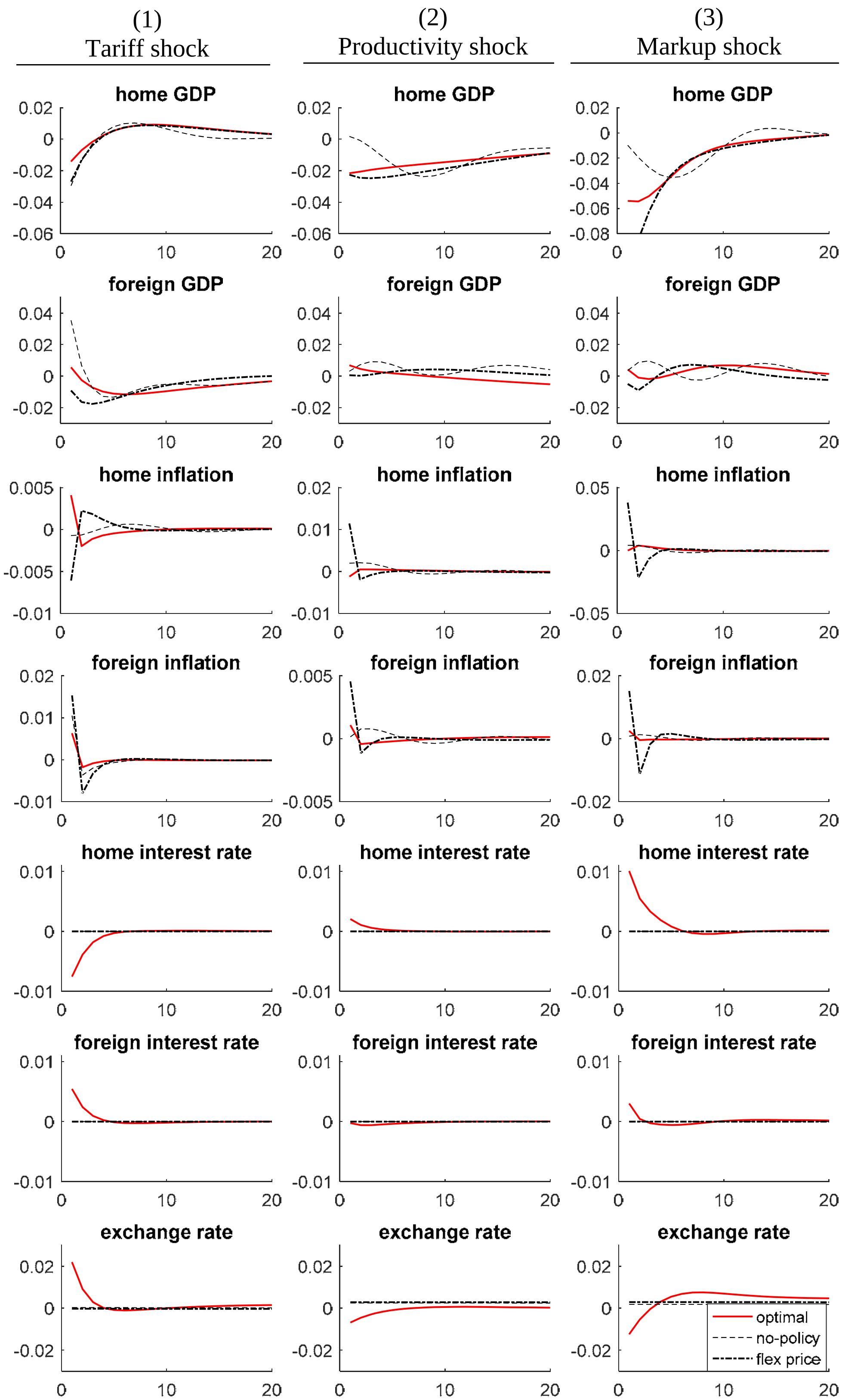
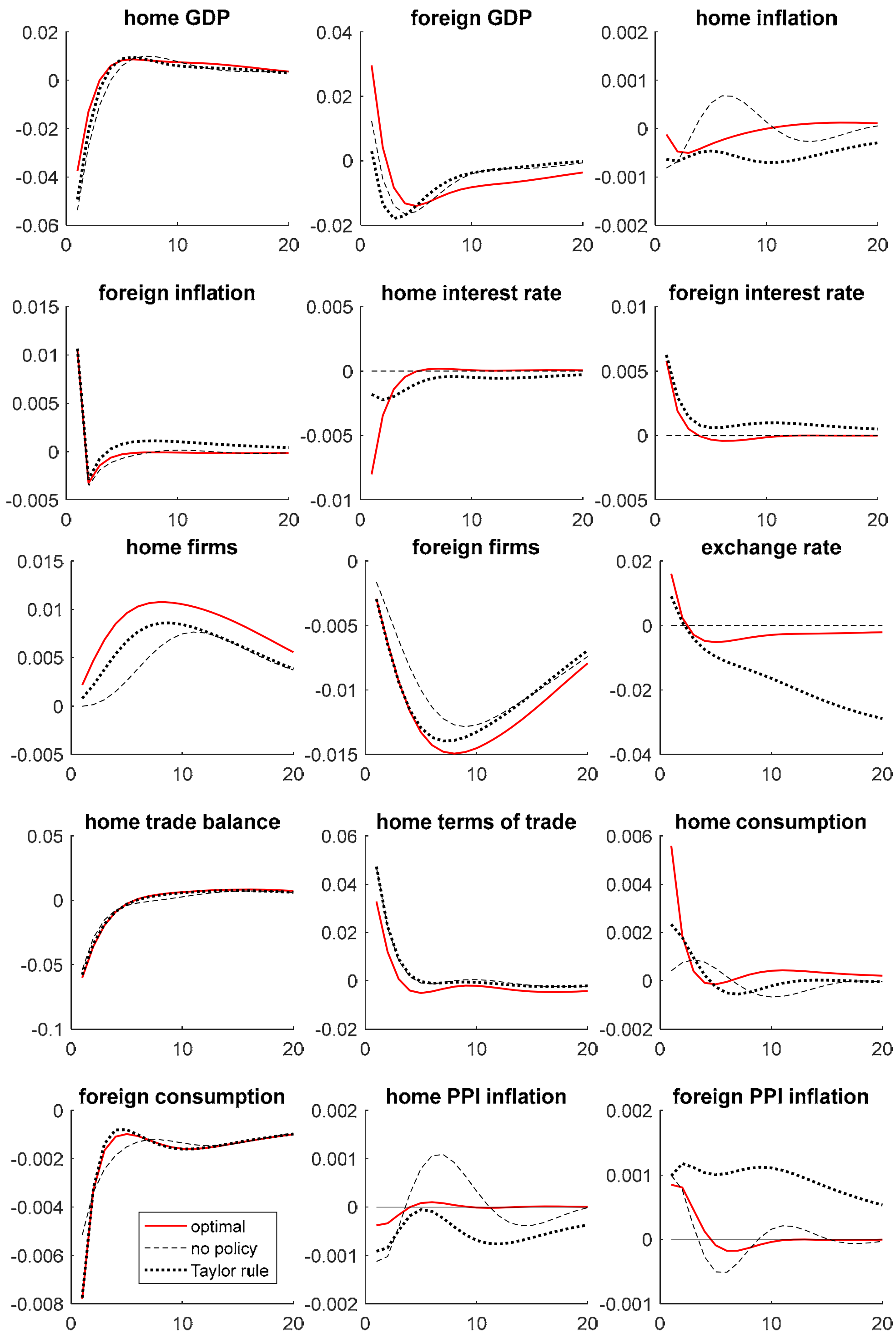


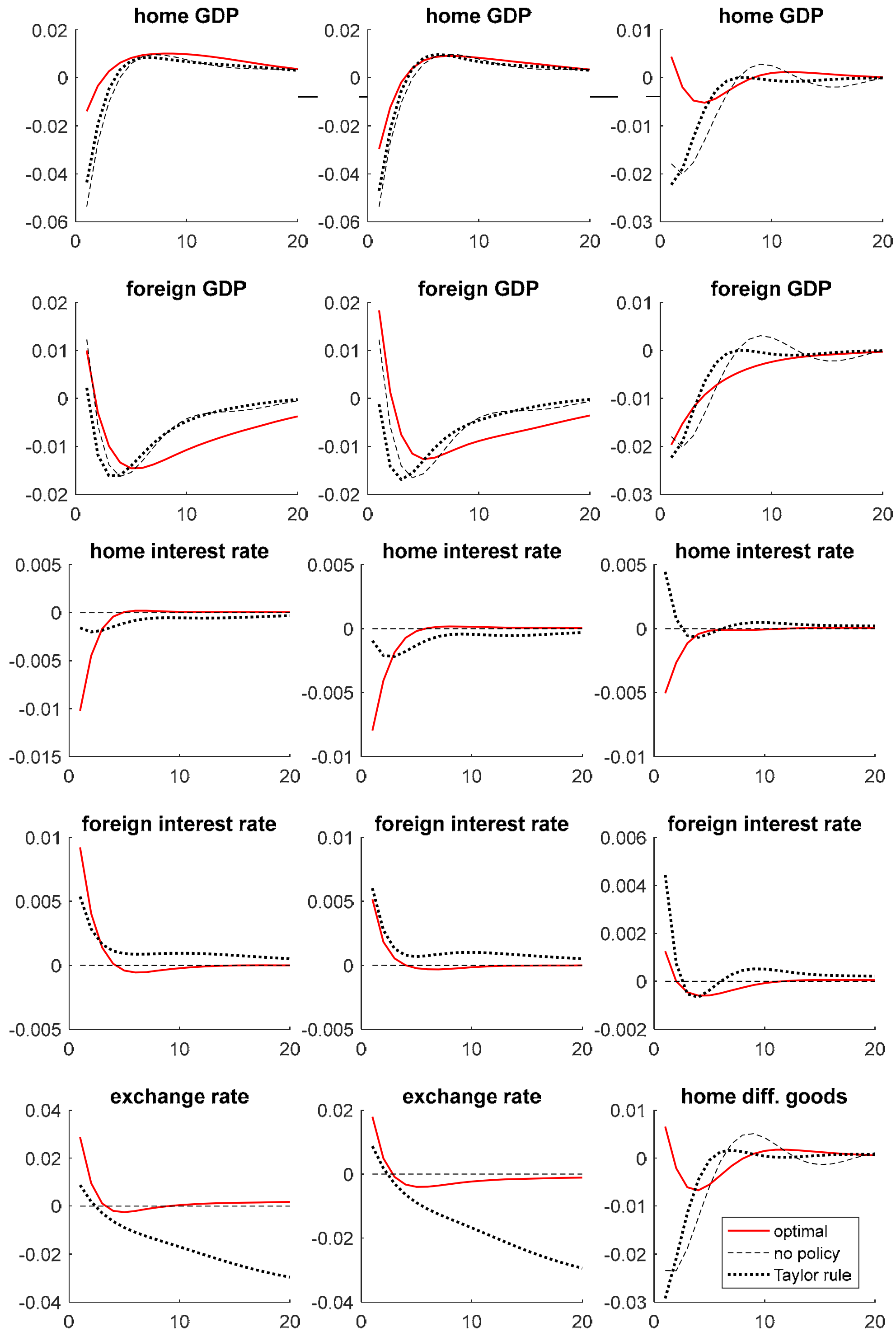
Figure 6. Local Currency Pricing: Impulse responses to a rise in foreign tariff on home exports,



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

Figure 7. Impulse responses under various specifications of dominant currency pricing

(1) shock to tariff on home exports, Home country DCP	(2) shock to tariff on home exports, Foreign country DCP	(3) shock to tariff on both countries, Home country DCP



Vertical axis is percent deviation (0.01=1%) from steady state levels. Horizontal axis is time (in quarters). Column (1) highlights selected results from Appendix Figure 6; column (2) from Appendix Figure 7, and column (3) from Appendix Figure 8.