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ABSTRACT

In the wake of Brexit and the Trump tariff war, and a general weakening of the political support for free trade, central banks have been faced with the need to reconsider the role of monetary policy in managing the economic effects of unexpected hikes in tariffs and trade costs. Although tariffs induce a slowdown with rising inflation like supply shocks, their distortionary effects on production and relative prices distinguish them from standard supply disturbances, and thus motivate a different monetary response. This paper studies the optimal monetary stabilization of tariff shocks using a New Keynesian model enriched with elements from the trade literature, including global value chains in production, firm dynamics, and comparative advantage between traded sectors. We find that, in response to tariff shocks, the optimal monetary stance is generally expansionary: central banks support activity at the expense of further aggravating short-run inflation—contrary to the prescription of the standard Taylor rule. If the tariff is imposed unilaterally by a trading partner, currency depreciation partly offsets the effects of tariffs on relative prices, without completely redressing the effects of the tariff on the broader set of macroeconomic aggregates. Remarkably, the country issuing a dominant currency can shelter its economy from the adverse effects of a selective tariff war on comparative advantage.

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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 these shocks. U.S. tariffs on Chinese exports rose seven-fold from 2018 to 2020, and they show little sign of abating under a new U.S. administration, remaining in 2021 more than six times their 2018 levels.[1] During the four years after the Brexit referendum in the absence of a trade agreement, uncertainty over trade relations with Europe is thought to have dampened investment and production in the U.K.; even in the wake of an agreement implemented in 2021 trade remains hampered by increased regulatory requirements. More to the point, these notable recent trade disputes could signify a weakening of global consensus regarding free trade, and may herald a changed environment, in which central banks will again face this new type of shock.

While these events have motivated a recent swell in research on the macroeconomic effects of trade policy, this nascent literature has not focused on the monetary dimension. Research has been conducted mostly in the context of real trade models, or monetary models with at best a stylized monetary side.[2] But the question central banks have been facing is how to respond efficiently to surprise shifts in trade policy. This calls for a welfare-based analysis of the optimal policy, capable of providing economic insight on how this can redress the macroeconomic impact of a tariff shock. This paper is the first we know of to conduct such an analysis.

Tariff shocks combine elements of both demand and supply disturbances, creating a policy trade-off between stabilizing inflation (rising per effect of the tariff) or the output gap (reflecting the tariff-induced fall in activity). In recent theoretical research on the macroeconomics of tariff shocks, monetary policy is modelled in terms of Taylor rules, without however deriving them from an optimal policy exercise. This approach is tantamount to assuming that tariff shocks are akin to supply disturbances, so that the best

[1] Figures from Brown (2021).

[2] See 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), as well as Barattieri et al. (2021), which 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).

monetary response consists of countering their inflationary effects with a contraction. (See Barattieri et al. (2021), Caldara et al. (2020), and Linde and Pescatori (2019) for examples.) In this paper, we show that this is a highly suboptimal policy strategy.

We study the Ramsey optimal monetary policy response to tariff shocks in a New Keynesian model that exhibits nominal rigidities along with two key features we deem particularly relevant for understanding the effects of tariffs. First, in line with recent open economy macro, the model features (if only in a stylized way) value chains in production, in which imported goods are used in the production of exports. This implies that tariff protection of domestic exporters also raises the cost of production for domestic firms. Second, drawing on the trade literature, the model features two traded sectors, one consisting of monopolistically competitive differentiated goods, characterized by sticky prices and sunk entry cost, and the other perfectly competitive non-differentiated goods. Hence, a country's comparative advantage is endogenous, with shocks causing reallocation of production across countries and sectors as well as changes in the composition of international trade. Without loss of generality, we will focus our analysis on tariffs imposed on the differentiated good sector, which the incidence of nominal rigidities makes more sensitive to monetary policy stabilization.

Our main conclusion is as follows. Although the macroeconomic impact of tariffs resembles that of an adverse supply shock—whereby a hike in inflation is accompanied by a fall in output – tariff shocks differ in terms of welfare implications and call for a very different policy response. The contraction and reallocation of production between countries and sectors caused by trade policy is not driven by a shift in fundamental economic costs of production. Rather, it is a cost artificially created by policy, which is distortionary even if the revenue is rebated back to consumers. We show that monetary policy can play a key role in mitigating this first-order distortion. We find that the Ramsey optimal response to a policy shock raising tariffs is broadly expansionary across a wide range of economic environments—the opposite of the optimal response to supply shocks, which is generally anti-inflationary.

The benefits of a monetary expansion should be intuitive when tariffs are imposed asymmetrically. In line with the conventional view, currency depreciation associated with an expansion can be expected to redress, at least in part, the distortionary effects of a tariff on international relative prices. Our main contribution however is to show that the rationale for the optimal policy prescription is more general. Specifically, an expansion is optimal also in response to symmetric tariff wars where exchange rate adjustment has no useful role to play, and works through a different channel, distinct from correcting international prices. A monetary expansion is desirable insofar as it helps offset the distortionary effects of a tariff on the level of production, as well as on the composition of output and exports.

We show that the benefits from an efficient monetary stabilization of tariff shocks are amplified in economic environments featuring international production chains. They remain significant in the presence of multiple sectors producing tradables. Inter-sectoral adjustment may moderate the aggregate impact of the tariff on output and activity, which per se reduces the need for monetary stimulus. Yet, the tariff-induced distortion on comparative advantage brings forward an additional policy trade-off for monetary authorities that can be quite consequential in terms of both societal welfare and policy design (but is missed in standard monetary analysis). The welfare benefits from sustaining entry and production in the sector producing differentiated (manufacturing) goods motivates a monetary stimulus well beyond the one required to support the (distorted) natural rate.

These results are robust to a symmetric reduction in the degree of exchange rate pass-through, corresponding to the assumptions of Local Currency Pricing (LCP). As is well known, nominal rigidities of import prices in the local currency reduce the effect of currency depreciation on relative prices. Under Local Currency Pricing (LCP), the optimal monetary policy is less reliant on currency depreciation as a remedy. However, the optimal policy prescriptions are somewhat more involved in a world where one country issues a dominant currency and exchange rate pass-through differs across borders, the case of Dominant Currency Pricing (DCP). With DCP, the different incidence of price stickiness on exporters induces a strong asymmetry in the transmission of the tariff shocks and the optimal policy response. In a retaliatory, symmetric tariff war, the optimal stance is expansionary in the dominant currency country, since PCP price stickiness among domestic producers of differentiated tradables makes it possible to redress the tariff distortion on domestic production via internal demand and currency depreciation, while a weaker currency has a muted effect on imported inflation. The optimal stance is instead contractionary in the other country, as LCP price stickiness among foreign exporters insulates export prices from currency movements, while import prices remain highly sensitive to the exchange rate. As a result, although activity contracts in both countries, it falls by less in the country issuing the dominant currency. Most strikingly, from a positive perspective, implementing a monetary expansion allows the issuer of the dominant currency to redress the effects of the symmetric tariff on the differentiated goods sector. Although the tariff war is symmetric, this country actually gains comparative advantage in the production and export of these goods. From a normative perspective, however, the main benefits from such policy are nonetheless global, i.e., they accrue to the other country. While the home production of the differentiated good rises, home welfare deteriorates relative to adopting a Taylor rule.

We conclude our analysis showing that our results are qualitatively robust to accounting for incomplete pass-through of tariffs to consumer prices, in line with recent empirical evidence (Flaaen et al. (2020) and Cavallo et al. (2019)). We model incomplete pass-through allowing for domestic production chains and distribution costs that drive a wedge between border and consumer prices. We also show that the monetary trade-off between activity, inflation and comparative advantage across multiple tradable goods is distinct from the one associated with the coexistence of tradables and non-tradables. The classical model relying on this distinction misses the need for stabilization to address distortions affecting the composition of exports.

Our work is related to a number of recent papers studying the macroeconomic effects of trade policies in dynamic stochastic general equilibrium models. 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 is the recent paper by Auray et al. (2020), which shares our focus on the interaction of tariff policy with alternative monetary policies, including cooperative optimal policy. Specifically, they address the question of how alternative monetary policies affect an endogenous, strategic tariff policy. This runs in the opposite direction of our question, the choice of optimal monetary policy in the face of an exogenous tariff policy. As already mentioned, the question we ask is directly motivated by the need to design an effective monetary response to trade policy initiatives best viewed as exogenous shocks, either imposed by a foreign country over which central banks have no control, or reflecting an unexpected shift in the political agenda of the domestic government. Further, the economic environments of our models differ. Auray et al. (2020) specify a standard New Keynesian DSGE model, whereas we consider a model with economic features found important in the trade literature, such as international production chains and multiple traded sectors with the resulting shifts in comparative advantage.

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

2. Model

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

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

2.1. Goods consumption demand and price indexes

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

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

The overall consumption index is specified as follows:

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

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

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

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

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

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

where

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

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

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

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

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

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

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

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

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

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

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

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

2.2 Home households' problem

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

Household optimization for the home country may be written:

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

where utility is defined by

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

subject to the budget constraint:

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

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

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

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

Defining $\mu_t = P_t C_t^{\sigma}$, household optimization implies an intertemporal Euler equation:

(10) $$\frac{1}{\mu_t} = \beta\left(1+i_t\right) E_t\left[\frac{1}{\mu_{t+1}}\right]$$

a labor supply condition:

(11) $$W_t = l_t^{\psi} \mu_t$$

a money demand condition:

(12) $$M_t = \mu_t \left(\frac{1+i_t}{i_t}\right),$$

and a home interest rate parity condition:

(13) $$\mathrm{E}_{\mathrm{t}}\left[\frac{\mu_{\mathrm{t}}}{\mu_{\mathrm{t+1}}} \frac{e_{\mathrm{t+1}}}{e_{\mathrm{t}}}\left(1+\mathrm{i}_{\mathrm{t}}^{*}\right)\left(1+\psi_{\mathrm{B}}\left(\frac{e_t B_{ft}}{p_{Ht} y_{Ht}}\right)\right)\right] = \mathrm{E}_{\mathrm{t}}\left[\frac{\mu_{\mathrm{t}}}{\mu_{\mathrm{t+1}}}\left(1+\mathrm{i}_{\mathrm{t}}\right)\right].$$

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

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

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

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

where $\alpha_{D,t}$ is a productivity shock specific to the production of differentiated goods but common to all firms within that sector, $l_t(h)$ is the labor employed by firm *h*, and $G_t(h)$ is a composite of differentiated goods used by firm *h* as an intermediate input. $G_t(h)$ is specified as an index of home and foreign differentiated varieties that mirrors the consumption index specific to differentiated goods ($C_{D,t}$). If we sum across firms, $G_t = n_t G_t(h)$ represents economy-wide demand for differentiated goods as intermediate inputs. Given that the index is the same as for consumption, this implies demands for differentiated goods varieties, $d_{G,t}(h)$ and $d_{G,t}(f)$, analogous to Eqs. (6)–(7).[3]

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

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

where ψ_P is a calibrated parameter governing the degree of price stickiness. For the sake of tractability, we follow Bilbiie et al. (2008) in assuming that new entrants inherit from the price history of incumbents the same price adjustment cost, and so make the same price setting decision.[4]

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

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

where ne_t denotes new entrants.

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

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

where $\overline{K}$ indicates the steady state level of entry cost, and the parameter λ indicates how much the entry cost rises with an increase in entry activity. The congestion externality plays a similar role as the adjustment cost for capital standard in business cycle models, which moderates the response of investment to match dynamics in data. In a similar vein, we calibrate the adjustment cost parameter, λ, to match data on the dynamics of new firm

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

entry.[5] The demands for varieties for use as entry investment, $d_{K,t}(h)$ and $d_{K,t}(f)$, are determined analogously to demands for consumption of differentiated goods.

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

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

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

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

Firm profits are computed as:

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

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

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

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

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

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

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

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

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

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[5] 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.

(23)

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

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

$$\Omega_t=\left[\left(\frac{p_t(h)}{P_{D,t}}\right)^{-\phi}\left(C_{D,t}+G_t+ne_t\left(1-\theta_K\right)K_t+AC_{P,D,t}+AC_{B,D,t}\right)\right.$$
$$\left.+\left(\frac{\left(1+\tau_D\right)T^*_{D,t}p_t(h)}{e_tP^*_{D,t}}\right)^{-\phi}\left(1+\tau_D\right)\left(C^*_{D,t}+G^*_t+ne^*_t\left(1-\theta_K\right)K^*_t+AC^*_{P,D,t}+AC^*_{B,D,t}\right)\right]\Big/\mu_t \; .$$

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

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

(24)
$$p^*_t(h)=\left(1+\tau_D\right)p_t(h)/e_t\,,$$

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

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

$$\Pi_t=n_t\pi_t(h)-ne_tv_t(h).$$

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

2.4 Home firm problem in the undifferentiated goods sector

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

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

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

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

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

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

Analogous conditions apply to the foreign non-differentiated sector.

2.5 Monetary policy

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

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

under the constraints of the economy defined above. As common in the literature, we write the Ramsey problem by introducing additional co-state variables, which track the value of the planner committing to a policy plan.

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

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

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

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

where terms with overbars are steady-state values. In this rule, inflation is defined in terms of differentiated goods producer prices, while Y_t is a measure of GDP defined net of intermediates as:[6]

[6] For computational simplicity, the Taylor rule is specified in terms of deviations of GDP from its steady state value, which is distinct from the output gap.

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

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

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

2.6 Shocks process and equilibrium definition

Shocks are assumed to follow joint log normal distributions. In the case of productivity, for instance, we can write:

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

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

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

with autoregressive coefficient matrix ρ_T, and the covariance matrix $E\left[\varepsilon_{Tt}\varepsilon_{Tt}^{'}\right]$.

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

2.8 Welfare computation

We report the effects on welfare of a given policy regime configuration relative to the Ramsey allocation. The change in welfare customarily is computed in terms of consumption units that households would be willing to forgo to continue under the Ramsey policy regime; that is, we compute Δ solving the following:

$$\sum_{t=0}^{\infty}\beta^{t}\left(u\left(C_t^{alt.policy}, l_t^{alt.policy}\right)\right)=\frac{u\left[\left(1+\frac{\Delta}{100}\right)\left(C_t^{Ramsey}, l_t^{Ramsey}\right)\right]}{1-\beta}.$$

We posit identical initial conditions across different monetary policy regimes using the Ramsey allocation, and we include transition dynamics in the computation to avoid spurious welfare reversals.[7]

2.9 Model calibration

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 ψ_p =49, a value which implies in simulations of a productivity shock that approximately half the firms resetting price during the first year. [8] The firm death rate is set at δ =0.025. The mean sunk cost of entry is normalized to the value $\overline{K}$ =1, and the adjustment cost parameter for new firm entry, λ, is taken from Bergin and Corsetti (2020). The share of intermediates in differentiated goods production follows Bergin and Corsetti (2020) to a modest value of ζ =1/3.

To choose parameters for the differentiated and non-differentiated sectors we draw on Rauch (1999). In the two-sector version of the model, we choose θ so that

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[7] 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.

[8] 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 $\lambda = (1-q)(1-\beta q)/q$, with 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 $\lambda = (\phi - 1)/\kappa$. Under our parameterization, a Calvo probability of q = 0.5 implies an adjustment cost parameter of ψ_P = 49.

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

To set trade costs, we calibrate τ_D so that exports represent 26% of GDP, as is the average in World Bank national accounts data for OECD countries from 2000-2017.[9] This requires a value of τ_D =0.44.[10] This is somewhat larger than the value of 0.25 used for trade costs in Obstfeld and Rogoff, (2001), but it is small compared to some trade estimates, such as 1.7 suggested by Anderson and van Wincoop 2004, and adopted by Epifani and Gancia (2017). We follow the standard assumption of trade models that the homogeneous good is traded frictionlessly (τ_N =0).

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

The process for tariff shocks is calibrated with a mean value of 1.02 (2 percentage point mean tariff rate) to match U.S. tariff data in Barattieri et al. (2021). The autoregressive parameter is set to 0.56, estimated from Barattieri et al. (2021).[11] The standard deviation of 6 percentage points is taken from Caldara et al. (2020), chosen to capture tariff increases that have been threatened on imports from China and on imports of autos and motor-vehicle parts in 2018-2019.

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

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

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

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.

3. Optimal policy in the workhorse (one sector) open macro model

We begin our analysis focusing on the one-sector version of our model, as this is close to the standard specification in the macroeconomic literature on tariff shocks. Both countries produce differentiated goods (the non-differentiated goods sector is shut down by setting $\theta = 1$). Simulations are conducted for two types of shocks: first, we study a symmetric rise in tariff in both countries---the case of a trade war with full retaliation; second, we study a unilateral foreign tariff on home exports, which will allow us to gain insight on the response of the exchange rate and trade balance.[12] In all cases tariffs rise by one standard deviation, based on the calibration presented above. Exchange rate pass-through is assumed to be symmetrically complete across borders.

3.1 Stabilization policy in a tariff war with full retaliation

We first consider an unexpected, symmetric rise in tariffs in both countries. Figure 1 shows the macroeconomic effects on a selection of variables under different policy regimes, contrasting the Ramsey optimal policy (solid line) with the cases of "flexible prices" (dot-dash line), "Taylor rule" (dotted line), and "no-policy" (dashed line), where the latter is obtained by imposing a constant money growth rule. Note that the figure reports impulse responses only for home variables, since the foreign counterparts are identical.

3.1.1 The transmission of symmetric tariff shocks under suboptimal policies

Under a suboptimal constant money growth rule (dashed line in Figure 1), a symmetric tariff shock raises inflation and causes a recession---in line with standard results

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

in the recent literature. The price index rises both because of the direct effect of tariffs paid on imported consumption goods, and because the indirect effect of tariffs on imported inputs used by firms---as higher marginal costs of production are passed on by firms to consumption prices.

GDP falls, as higher tariffs depress output via several channels. Perhaps the clearest channel is the rise in the price of imported goods used in the round-about production structure. Higher marginal costs of production drive up prices and reduce demand for firms' output. A different 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. Indirectly, a lower number of firms and product varieties also contributes to raising inflation, measured with the welfare-relevant price index. Observe that the drop in the number of firms is quite persistent, and this conveys a high degree of persistence to the fall in GDP.

Consumption demand also falls sharply and persistently. In part, consumption falls with the loss of real income due to higher prices (real wages tank 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.)

Figure 1 indicates that nominal rigidities can amplify the effect of tariff shocks. Comparing the impulse responses under flexible prices (dot-dash lines in Figure 1) to the no-policy scenario (dashed line), the fall in GDP and the number of firms are smaller for the flexible price case for the first several quarters of the simulation. This difference mainly stems from the fact that, in the presence of nominal rigidities, firms do not pass through lower wage costs on to prices, which in our model environment would work to counteract the direct effect of the tariff. Note that, on impact, inflation is initially higher under sticky prices than under flexible prices, as the tariff is added directly to the price charged to consumers.

Turning to the Taylor rule regime (dotted lines), the first thing to note is that both countries raise the interest rate. Policymakers respond to overall inflation, induced by the effect of a tariff on the price on imported goods. Although the GDP falls, which argues in favor of a fall in interest rate, the Taylor rule places greater weight on the change in inflation. The contractionary monetary policy exacerbates the fall in GDP and firm creation in the initial period relative to the no-policy case, in which the interest rate remains unchanged.

3.1.2 Economic dynamics under optimal monetary expansion

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 Taylor rule, the optimal monetary policy response is expansionary: the nominal interest rate falls markedly in both countries. Compared to the no-policy case, the Ramsey policy response mitigates by half the fall in GDP, while it exacerbates slightly the rise in inflation in the initial period. The overall expansionary monetary stance may seem surprising, in light of the fact that tariff shocks are typically portrayed as supply shocks (see e.g. Barattieri et al., 2021, for a detailed discussion). After all, the impact of the tariff under no policy (a fall in output corresponding to a rise in prices), would seem consistent with such an interpretation. It is well known that the optimal monetary policy prescription in the presence of an inflationary supply shock involves monetary contraction, not an expansion. This argument may have motivated the specification of Taylor rules with a large coefficient on inflation relative to GDP in related literature (Erceg et al. (2018) and Barattieri et al. (2021)). 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.

A monetary contraction is appropriate when the supply shock that drives up inflation is a fall in productivity. In this case, monetary tightening serves to eliminate 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. However, 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 Figure 1, there is a wide gap in impulse responses in the optimal policy and the flexible price allocations. 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.

When the tariff shock is symmetric across countries, it should not come as a surprise that the optimal cooperative monetary response does not eliminate the relative price distortion of the tariff on the relative price of exports and imports---nor aim to manipulate the exchange rate. Rather, the policy focuses on stimulating domestic demand in each country, so as to replace the traded goods in consumption and investment lost because of higher trade costs, with domestically produced goods. In doing so, policymakers tolerate a temporary burst of inflation above the long-run stability target.

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

3.1.3 Distribution of macro variables and welfare

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

The table 2 also reports welfare conditional on a suboptimal policy (Taylor Rule), as a percentage of welfare under the Ramsey optimal policy. A Taylor rule policy lowers welfare relative to Ramsey by 0.082%---modest values are typical of business cycle analysis (experiments to follow will report scenarios where the welfare gain from optimal policy is somewhat higher). 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.

To place our welfare result 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. (1993), and set model parameters adopting standard value in the literature with no roundabout production or firm entry. In this standard setting, the welfare loss from pursuing a Taylor rule rather than following the Ramsey optimal policy is 0.110%, a similar (though slightly larger) loss than for the tariff shock. This is a surprising result. One may expect the overall welfare implications of tariff shocks to be somewhat smaller than 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 is much more inefficient in response to tariff shocks than in response to productivity fluctuations. Moreover, 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.

3.1.4 The role of roundabout production and firm entry

Two of our model's distinctive trade features, roundabout production and firm entry, play a role in driving the quantitative relevance of our results. If we repeat our exercise in a version of the model without roundabout production ($\varsigma = 0$), the impact effect of the tariff on output and consumption under optimal policy is significantly dampened.

(See Appendix Figure 1 for impulse responses.) In 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. Yet we should stress that, regardless of whether domestic production requires imported inputs, and/or there are firm dynamics, the optimal policy prescribes comparable interest rate cuts in response to the tariff shock.

Roundabout production and firm entry are consequential for welfare. As shown in columns 2 and 3 of Table 2, the welfare loss of a Taylor rule relative to the Ramsey optimal policy falls from 0.082% in the benchmark model, to 0.057% if there is no roundabout production, and to 0.024% if firm entry is also eliminated.

3.2 Optimal monetary stabilization of a unilateral tariff shock

We now consider the case in which the foreign country imposes a tariff on home exports, but home does not retaliate. Clearly, an asymmetric shock and possibly asymmetric policy responses are bound to affect variables such as the exchange rate and the trade balance, which do not come into play in response to symmetric shocks. Relative to the previous trade-policy scenario, this new scenario thus raises new issues, regarding the extent to which exchange rate adjustment can help in redressing the undesirable distortions of a tariff on international relative prices. Results are shown in Figure 2.

3.2.1 Transmission under suboptimal policy

For the no-policy case (dashed line in Figure 2), our impulse responses resonate with the headline case for protection in policy debates. A foreign tariff results in a foreign trade surplus (home trade deficit). While the effect of the tariff on home GDP is distinctly contractionary, foreign GDP rises (by a smaller magnitude than the fall in home GDP). Looking deeper into the transmission of the tariff, however, the headline case for protection is not strong. As discussed by Erceg et al. (2018), however, the GDP in the country that imposes the tariff (the foreign country in our experiment) may rise or fall, depending upon whether the fall in consumption demand due to intertemporal incentives is dominated by the rise in export demand due to the expenditure switching effect of relative prices. In our benchmark calibration the expenditure switching effect dominates.[13] In our context, output also reflects investment demand associated with the creation of new firms. The tariff has an undesired contractionary effect on firm entry in the Foreign economy, while it favors entry in the Home economy.

In response to a unilateral tariff on home exports, the home exchange rate depreciates.[14] Observe that, in the no policy response scenario, the rate of depreciation is not large enough to offset the impact of the tariff on the relative price of home exports to home imports. This is in violation of the well-known “Lerner symmetry” result, predicting perfect offset. Linde and Pescatori (2019) have recently pointed out that, in its stronger form, Lerner symmetry fails in many macroeconomic contexts, depending on the structure of financial markets and nominal rigidities. It may nonetheless hold in a weaker form. Our impulse responses indicate that, holding policy constant, endogenous exchange rate movements offset about half of the effect of the tariff on the terms of trade. It is worth noting that, in the no-policy scenario, the currency depreciation reflects exclusively the equilibrium response to the tariff shock of real (as opposed to nominal policy) rates across countries, driven by adjustment in consumption and thus in stochastic discount factors.

3.2.2 Efficient stabilization

In Figure 2, economic dynamics under the optimal policy are depicted with a solid line. Optimal monetary policy is sharply different in the unilateral tariff case relative to the symmetric case studied earlier, highlighting new channels and mechanisms. In response to the tariff, the optimal cooperative policy still prescribes substantial monetary expansion at home (lower home interest rates). But the optimal response abroad is now a contraction. The reason for this asymmetric monetary stance is to offset the impact of the tariff on the terms of trade via currency depreciation. In Figure 2, compared to the no-policy case, the optimal policy significantly dampens the home terms of trade movements in the initial

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

[14] The small magnitude of the currency movement makes it difficult to detect depreciation in Figure 4, given the scaling used in this figure

periods, without however going all the way and restore the Lerner symmetry result for the exchange rate.

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

While the global monetary stance partly restores the Lerner symmetry result, it cannot (and would not) 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 exchange rate 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 required cut in home interest rate tends to over-stimulate home consumption---and cause a significant aggravation of overall inflation in the home country.

As in the symmetric tariff case, the optimal policy response is at odds with strict inflation targeting or a Taylor rule with a large weight on inflation. To engineer the optimal currency adjustment, the optimal monetary stance actually exacerbates home inflation. The optimal policy prescribes a cut in interest rates that is an order of magnitude larger than the one implemented under a Taylor rule (dotted line in Figure 2): 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 2.

3.2.3 Welfare

To compute welfare implications under asymmetric tariff shocks, we simulate the model with home and foreign tariffs uncorrelated. The welfare computations are shown in Table 2. (Given that both countries are equally likely to experience a unilateral tariff shock, the benefits of optimal policy are symmetric across countries.) Relative to the optimal policy, the welfare loss under a Taylor rule, while still modest, is larger in the case of unilateral shocks than in symmetric tariff war: 0.25% (column 4) as opposed to 0.082%. The loss in welfare is associated with a particularly large fall in the mean level of firm entry, as well as with a fall in mean consumption and a rise in labor effort. 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); both features of the model clearly contribute in amplifying the welfare implications of tariff shocks.[15]

To sum up, in all the cases reviewed in this section, the optimal monetary policy responses to tariff shocks trade off higher inflation for higher output. For the home country, this is so whether or not the country retaliates to the foreign tariff. The key lesson is that the effects of tariff shocks are distinct from those of a productivity disturbance---which would call for strict inflation targeting. We further note that a tariff shock is also different from a markup shock, which would also move output and inflation in opposite directions, but would be efficiently stabilized by containing its inflationary consequences.

4. Comparative advantage and monetary policy

Most of the work studying the effects of tariffs in the trade literature emphasizes reallocation between sectors producing tradables as a source of inefficiency and welfare loss. The macroeconomic literature that models sector reallocation, however, typically focuses on the production shift between tradables and nontradables. In this section, we take a step to bring our monetary analysis closer in line with the trade literature. We now rely on the full two-sector macro model specified in section 2, featuring production of both

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

differentiated and non-differentiated tradable goods. In our calibration, the share of differentiated goods in the final goods bundle is $\theta = 0.61$.[16] As our baseline we assume that tariffs are raised on the differentiated goods sector---we will discuss briefly below the case of a tariff shock to the other sector. To highlight the most novel results in the richer version of our model, we begin our discussion with the case of an asymmetric shock to the tariff on home exports, reversing the order of the previous section.

4.1 Unilateral tariff shock

Relative to our analysis so far, our two-sector environment allows us to bring forward the effects of a tariff shock on comparative advantage. As shown in Figure 3, these effects are significant. Here is the key novel result. Relative to the one-sector model (compare Figures 2 and 3), the fall in Home GDP is smaller overall, but the muted effect on activity at the aggregate level corresponds to a large sectoral reallocation. In the no-policy scenario, for instance, the percentage fall in the production of differentiated goods in the home country is three times the percentage fall in GDP. This sectoral contraction is matched by a rise in home production of non-differentiated goods of a similar magnitude. In the foreign country, sectoral productions mirror this adjustment, moving in the opposite direction.

Comparative advantage is an important transmission channel, missed by the simpler (one-sector) standard model. Namely, in response to a targeted tariff on home differentiated goods, the foreign country gains by specializing in the production of non-differentiated goods, the Home country loses out as it ends up producing a larger share of non-differentiated goods. In the model, this normative result reflects the welfare gains from a rise in the share of good varieties produced in a country, that residents can enjoy without paying transportation costs---according to the "home market effect" widely discussed in the literature after Krugman (1980). In the trade literature, similar shifts in comparative

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

advantage have been associated with a reconsideration of the "optimal tariff argument" by Ossa 2007, stressing distinct benefits from specializing in the differentiated goods sector (see Corsetti et al., 2007 and Bergin and Corsetti, 2020, for a discussion).

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

In our baseline, the welfare loss from following a Taylor rule instead of the optimal policy appears to be smaller in the two-sector than in the one-sector model, as shown in Table 2 (see column 8).[17] This is because (a) the differentiated goods sector accounts only for a limited share of the aggregate economy and (b) monetary stabilization is not consequential for the stabilization of the non-differentiated sector, which has flexible prices. The magnitude of the welfare losses is however sensitive to the degree of substitutability between the goods produced in the two sectors, as this crucially impinges on the extent to which a tariff shock (and the policy response to it) can drive a shift in comparative advantage. Figure 4 plots the welfare loss from pursuing a suboptimal Taylor policy rule against the elasticity of substitution between sectors (ξ). The welfare loss in the two-sector model becomes larger than that in the one-sector model, for an elasticity of 1.4 (compared to our benchmark calibration of unity).[18]

4.2 Symmetric tariff war

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

[18] Results for this calibration are detailed in column 9 of Table 2.

In a symmetric tariff war targeting differentiated goods, the aggregate economic dynamics in the two-sector model are seemingly close to the case of the one-sector model; compare Figure 1 with Figure 5. For instance, output falls markedly in either model specification. But this aggregate result masks an important difference: the contraction in activity in the two-sector model is largely driven by the fall in differentiated goods production worldwide (similar to one experience by the home country in Figure 3). The production of non-differentiated goods actually rises. In a symmetric tariff war, there is no shift in comparative advantage across countries---rather, the tariff distortions result in a shift the sectoral composition of output at a global level.

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

4.3. Additional results on sectoral reallocation

The literature that studies inter-sectoral reallocation from tariffs typically assumes that the second sector produces goods that are not internationally traded---a recent instance is Caliendo et al. (2017). For comparison, we modify our model by assuming that the non-differentiated sector produces non-tradables ($\nu = 1$). Simulation results (reported in Appendix Figure 4) indicate that the implications of tariff shocks for the production of differentiated goods are similar to those in Figure 3. The economic transmission is however profoundly different: there is no shift in comparative advantage. The effect on the non-differentiated sector is an order of magnitude smaller if these are not traded internationally.

The welfare loss associated with a Taylor rule relative to the optimal policy is 0.135%, compared to 0.155% for the benchmark two-sector case discussed above.

In the appendix, we also consider the case of a foreign tariff shock targeted to home exports of the non-differentiated goods (see Appendix Figures 2 and 3). Given that this sector has flexible prices, it is not surprising that the impulse responses are much more similar across alternative monetary policies, than for tariff shocks hitting the differentiated sector with sticky prices. The choice of monetary policy is less consequential in dealing with tariff shocks targeting a sector subject to small or no nominal price distortions.[19]

5. 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. The literature has long made clear that the international transmission mechanism and especially optimal policy design are sensitive to the way nominal rigidities constrain pricing of exports and imports. We proceed in steps. First, we assume that export prices are symmetrically sticky in local currencies, as may be the case for trade across, say, US and the EU. Next, we will discuss the case of one dominant currency, introducing a fundamental asymmetry in pricing.

5.1 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 benchmark model. The Rotemberg price setting equations are modified to specify that prices for domestic sales, $p_t(h)$, and exports, $p_t^*(h)$, are set separately in the currencies of the buyers. See section 3 of the online appendix for the modified price-setting equations, counterparts to Eqns. (23) and (24) above. We simulated the LCP model for the four scenarios studied above using our benchmark model specifications: unilateral shock or

[19] In particular, in the case of a unilateral foreign tariff on home non-differentiated goods (Appendix Figure 2) optimal policy implies a fall in interest rate that is an order of magnitude smaller than in the benchmark case of a tariff on differentiated goods, and there is no discernible stabilization of the fall in home GDP. In the case of symmetric tariff war on non-differentiated goods (Appendix Figure 3), the optimal monetary policy is very similar to the Taylor rule, implying a rise rather than fall in interest rate, with no attempt to stabilize the fall in GDP in the two countries.

symmetric tariff war, each in both the one-sector and the two-sector model. Figure 6 reports impulse responses for the case of a unilateral foreign tariff in a two-sector setting; the other three of our usual cases are reported in the appendix (Appendix Figures 5-7).[20]

Relative to the baseline, LCP does not significantly alter the transmission of a tariff to prices or macroeconomic aggregates. By way of example, consider the scenario of a unilateral foreign tariff in the two-sector model with constant money growth policy, depicted for the LCP case in Figure 6. Comparing the corresponding PCP case in Figure 3 discussed earlier, the dynamics of the terms of trade under the no-policy scenario (dashed line) are nearly identical. So are the dynamics of GDP in these figures. This is a first important result, which may be surprising in light of the fact that LCP price stickiness is known to dampen pass-through of exchange rate changes. Tariff shocks, however, are different from exchange rate shocks, in that tariffs are imposed directly on the importer, for any given price charged by the exporter. So even if the exporters ignore the tariff and do not change the price they charge at the dock, the importers still have to set prices after paying the full tariff increase.

Although LCP does not alter tariff transmission in the no-policy case, it has significant implications for the optimal policy in the case of a unilateral tariff. First, comparing the LCP case in Figure 6 with the benchmark PCP case of Figure 3, the optimal monetary policy in the LCP case (solid line) involves a drop in the interest rate that is contained (yet still deeper than dictated by a Taylor rule). Second, the optimal policy now lowers the foreign interest rate instead of raising it---hence the monetary response to the tariff shock is symmetric. This significantly dampens the home currency depreciation relative to the PCP case---the exchange rate hardly moves. The GDP dynamics are correspondingly different. Under PCP, a monetary expansion can buffer the fall in home GDP by improving price competitiveness of Home products via currency depreciation. Under LCP, the optimal policy cannot rely on the exchange rate to contain the fall in economic activity and the shift in home comparative advantage between sectors. Recall that, under LCP, the prices that buyers face in own currency are sticky---there are no short-

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

run benefits in engineering a home currency depreciation: the exchange rate does not affect the allocative relative prices.

A similar conclusion, that LCP price stickiness limits monetary policy's ability to contain the macroeconomic effects of a unilateral tariff, applies to the one-sector environment. Compare the case of LCP (Appendix Figure 6) to the corresponding case of PCP discussed earlier (Figure 2). Although the monetary policy response is similar (a fall in home interest rate drives domestic currency depreciation), the potency of this policy to dampen the fall in home GDP is greatly reduced. The fall in GDP after the foreign tariff under optimal policy remains substantial, similar to the no-policy case, in contrast with the small fall in GDP under optimal policy in the PCP case.

Overall, relative to our PCP benchmark, LCP has limited implications for the optimal stabilization of a symmetric tariff war. (Compare Appendix Figure 7 to Figure 5 for the two-sector environment, and Appendix Figure 5 to Figure 1 for one sector.) As one may anticipate, however, the main difference is that the optimal stabilization cannot work through relative price adjustment induced by currency depreciation.

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

A specification of the model that recently has become standard in open macro literature requires both countries set export prices in one dominant currency. We can develop a dominant currency (DCP) version of our model by designating one of our countries' 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. The analysis will then have to distinguish different cases, depending on whether the dominant currency country is the one imposing the tariffs, or the country whose exports are subjected to the tariffs.

Selected impulse responses for three different cases are summarized in Figure 7, with full results reported in the appendix (Appendix Figures 8-10). 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 (compare column (1) of Figure 7, or Appendix Figure 8 for a more complete set of results, to Figure 3). The optimal policy response calls for a substantial 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 in response to a unilateral foreign tariff now resemble our earlier case where of symmetric LCP price stickiness. The optimal policy is closer to the Taylor rule, with a smaller cut in home interest rate and reduced stabilization of home output fluctuations (compare column (2) of Figure 7 (or Appendix Figure 9) to Figure 6).

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. This country has a clear advantage since PCP price stickiness makes it possible to redress the tariff distortion via a monetary boost and currency depreciation. In the wake of a symmetric tariff shock on the differentiated good sector, the DCP country actually gains a comparative advantage in the production and export of this good.[21] In the simulation reported in column (3) of Figure 7 (or Appendix Figure 10), the home production actually rises relative to the pre-tariff equilibrium. [22]

Remarkably, however, these asymmetric output effects do not necessarily correspond to welfare benefits. (See Appendix Table 3 for welfare analysis of the DCP case.) In a cooperative equilibrium, the large asymmetric expansion in the country issuing the dominant currency contributes to global welfare, but is not a Pareto improvement. In this country, social welfare is higher under a Taylor rule---in line with a well-known result

[21] As is well understood, in the case of dominant currency pricing, both the transmission of shocks across borders and policy stabilization are inherently asymmetric, even when shocks are symmetric. A point in case is the effect of a symmetric tariff war impinging on the exports of both countries.
[22] These results would be missed in exercises imposing a Taylor rule for monetary policy. In this case (as in the case of no-policy response) a dominant currency pricing would not alter a nearly symmetric transmission of the tariff shocks.

in the literature, establishing that, under DCP, cooperation may not be in the interest of the dominant country (see Corsetti and Pesenti 2005).

6. Tariff pass-through

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

6.1 Empirical motivation

The empirical literature on tariff pass-through has flourished after 2016, due to the combined effects of Brexit and the aggressive trade initiatives by the Trump administration. Based on regressions of U.S. import price indexes controlling for inflation, Cavallo et al. (2019) find that, for a typical good imported from China, only 7.5% of a tariff increase is offset by a drop in price set by the exporter: the pass-through to prices at the dock is 92.5%. When additional controls are included in the regression, the change in exporter price is insignificantly different from zero, implying a pass-through indistinguishable from 100%. Looking at retail prices, however, the same authors find mixed results, differentiated by product. By way of example, pass-through appears high for washing machines, initially slow but eventually high pass-through for tires, and low pass-through for bicycles. Flaaen et al. (2020) find a pass-through as low as 21% for washing machines after the 2016 anti-dumping duties on China; and in a range between 58% and 125% after the 2018 tariffs on Chinese exports (depending on estimation method). Both Flaaen et al. (2020) and Cavallo et al. (2019) highlight that tariffs led to a similar degree of price rise across washing machine brands directly affected by the tariffs, and other brands, including domestic brands, not affected directly by the tariff.[23]

Our benchmark model with PCP fits the empirical evidence of nearly complete pass-through of tariffs to import prices at the dock. Price stickiness at the dock increases the degree of tariff pass-through, since it precludes producers from adjusting their export price to offset tariffs imposed on importers. To underscore this point, using as our reference the case of a unilateral foreign tariff in the two-sector sticky-price model with constant money growth, we find that pass-through of the tariff to the import price at the dock is 100%.[24] In the flexible price version of the model, exporters would lower the ex-tariff price by 5.7%, implying a pass-through of 94.3%.

The fit of our benchmark model in terms of pass-through to retail prices is more difficult to evaluate, given the range of estimates in the recent empirical literature. In the reference case of the model singled out above, we find that the pass-through of the tariff to the sectoral consumer price index of differentiated goods in the foreign country (which includes both domestic and imported varieties) is a modest 24.3%, owing largely to home bias in this sector.[25] This compares favorably with the pass-through to consumer prices Flaaen et al. (2020) estimate for 2016 China duties, but is smaller than the pass–through the same authors estimate for the 2018 tariffs. It is higher than the values (close to zero) estimated in Cavallo et al. (2019).

Price stickiness in local currency (LCP) does not reduce tariff pass-through in the model. In the scenario of a unilateral foreign tariff in the two-sector model with constant

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[23] Cavallo et al. (2019) interpret this as evidence that the direct effect of the tariff on import prices was close to zero – estimating regressions based on a comparison of brands directly affected by the tariff and those not affected, they find that a 20 percent tariff is associated with only a 0.9 percent increase in the retail prices of affected household goods, and a 1.4 percent increase in the retail prices of affected electronics products after one year. In contrast, Flaaen et al. (2020) attribute the similarity among affected and unaffected brands to factors such as rising materials costs or to domestic producers using their market power to raise prices.

[24] To measure pass-through to an import price index, we can define a data-consistent import price index that holds constant the number of varieties: $\widehat{P}^*_{Mt} = \left(\overline{n}\left(p^*_t\left(h\right)T^*_{D,t}\right)^{1-\phi}\right)^{\frac{1}{1-\phi}} = \overline{n}^{\frac{1}{1-\phi}} p^*_t\left(h\right)T^*_{D,t}$. The percentage change from steady state for this index will be identical to that simply of the foreign import price of a representative home variety: $p^*_t\left(h\right)T^*_{D,t}$.

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

money growth policy, depicted in Figure 6, home exporters actually *raise* their ex-tariff export price. The pass-through of the tariff to the import price is 108.7%, larger than the 100% found for the PCP model; the pass-through to the consumer price index of differentiated goods is 26.7%, similar but slightly higher than for the PCP model. As noted above, tariffs are imposed directly on the importer: if the exporter leaves its supply price at its pre-tariff level, the importer will have to have to adjust its supply price to the full extent of tariff, or suffer a drop in its margin.

6.2 Low tariff pass-through with production chains and distribution

Hereafter, to account for a moderate degree of tariff pass-through at consumer level, we model the incidence of local production inputs and/or distribution on the price of imports faced by consumers. We extend the model in the spirit of Corsetti and Dedola (2005), positing that, realistically, consumers do not purchase imported differentiated varieties directly from producers. Consumer goods combine imported goods with domestic labor and home differentiated domestic goods as inputs. Analytically, we now specify the consumption index without the direct inclusion of imported varieties:

$C_{D,t} \equiv \left(\int_0^{n_t} c_t(h)^{\frac{\phi-1}{\phi}} dh \right)^{\frac{\phi}{\phi-1}}$, and correspondingly change in the consumer price indexes and demand equations (see section 4 of the online appendix for the full list of modified equations). To be clear: given the roundabout production structure, domestic firms use imported differentiated goods as inputs, hence households do consume foreign differentiated goods indirectly. They purchase them from domestic firms that combine them with home differentiated goods and additional labor inputs, according to the extended production function shown in the appendix. One can interpret this labor and material inputs as part of a domestic distribution cost. Consistently, we recalibrate the trade cost for differentiated goods (τ_D = 0.23) to maintain the same ratio of imports as a share of GDP as in the benchmark version of the model.

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

In light of the similarity of PCP and LCP specifications in terms of matching the empirical pass-through of the tariff, we focus our discussion on the PCP economy, allowing for either unilateral or symmetric shocks. Figure 8 summarizes impulse responses for selected variables, with the full set of variables reported in Appendix Figure 11 (unilateral shock) and Appendix Figure 12 (symmetric shock). In our distribution-augmented two-sector model, the optimal policy and macroeconomics dynamics in response are close to our baseline---i.e., it is only moderately affected by the degree of tariff pass-through to consumer prices. (Compare column (1) of Figure 8 to Figure 3, and column (2) of Figure 8 to Figure 4). Relative to our baseline, a low pass-through to consumer prices only slightly dampens the transmission of the shock to GDP and the interest rate change mandated by optimal policy.

Key to this remarkable result is the use of imports as intermediates. Even if the tariff does not impact consumer prices on a one-to-one basis, it still has large effects on GDP and other macroeconomic aggregates through the demand for imported intermediate goods by domestic producers. On impact, Home GDP falls 1.45% in the low pass-through specification (as shown in the first column of Figure 8 for the no-policy case), compared to 2.06% in the benchmark model (shown in Figure 3). Consequently, the optimal policy calls for a similarly strong expansionary response to moderate the macroeconomic effects of the tariff, with a home interest rate cut (by 0.53 percentage points, compared to a cut of 0.54 percentage points in the benchmark model shown in Figure 3). In a symmetric tariff war shock (Figure 4 and column (2) of Figure 8), a low tariff pass through to consumer prices even amplifies the home contraction: in our no-policy specification, GDP falls by 2.71%, versus 1.86% for the benchmark case. We conclude that a low pass-through to consumer prices does not necessarily moderate the macroeconomic effects of tariff shocks, nor reduces the need for a thorough assessment of the correct monetary policy response.

7. Conclusion

In the wake of Brexit and the Trump tariff war, central banks faced the need to reconsider their role in managing the rise in inflation and economic slowdown possibly induced by unexpected hikes in distortionary trade costs. Given that tariff shocks combine elements of both demand and supply shocks, the main question is whether monetary policy should focus on stabilizing their implications on inflation, rather than the output gap. This paper studies the optimal monetary policy response to tariff shocks in a New Keynesian model that includes elements from the trade literature, including global value chains in production, and comparative advantage between two traded sectors.

The most novel and consequential result from our analysis is that the optimal (cooperative) policy response to tariffs tends to be expansionary, with the goal of stabilizing the output gap at the expense of further aggravating inflation. This optimal response is at odds with the standard Taylor rule assumed in most of the related literature. 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. An important difference is the role of the exchange rate. In the case of unilateral tariff shocks, 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.

Price stickiness can amplify the effects of tariffs on macroeconomic aggregates, as it prevents firms from offsetting tariffs by cutting export prices. But since tariffs distort the economy, the optimal policy does not aim to replicate the flexible price allocation under a tariff shock. Rather, it takes advantage of nominal rigidities to offset the distortions in relative prices and production created by the tariff, and to minimize the associated welfare loss.

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

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

We believe the current focus of this paper addresses the main question that central banks have been asking: how to respond to tariff policy surprises to achieve a goal of business cycle stabilization. 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 ou 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 expansionary in response to a tariff may be even stronger. We leave to future work an analysis of the strategic dimension of non-cooperative policy, and the strategic interactions between optimal monetary and trade policies.

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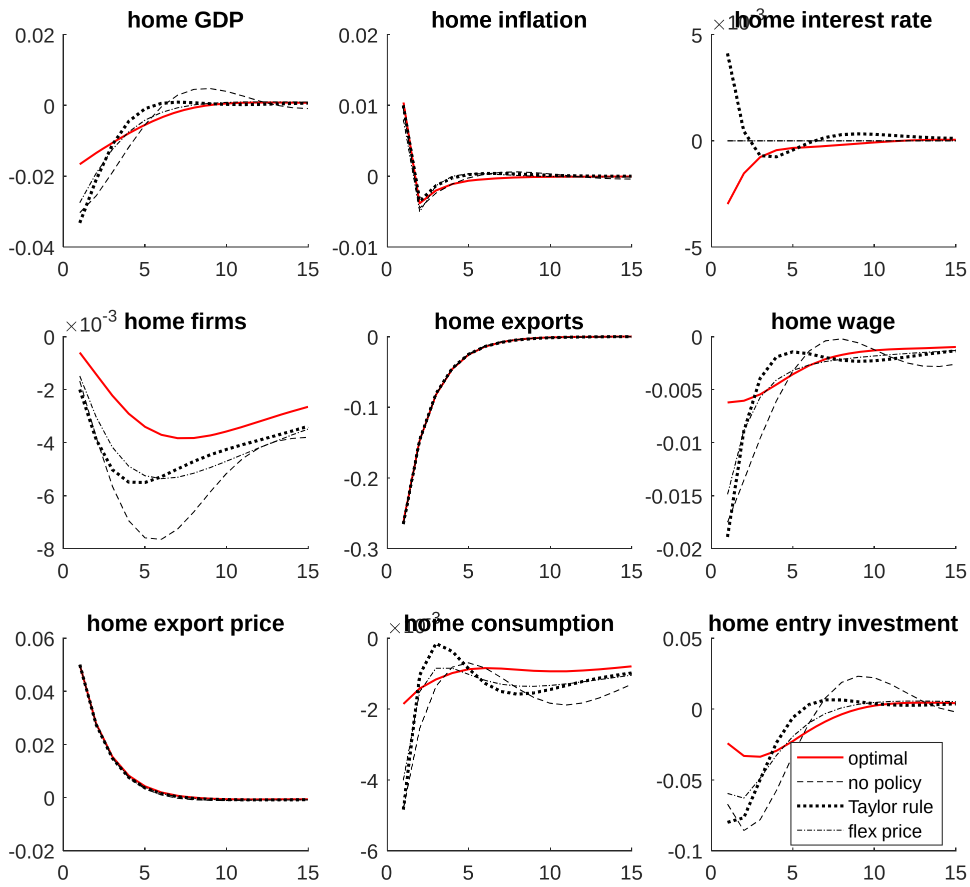
Table 1. Benchmark Parameter Values

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

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

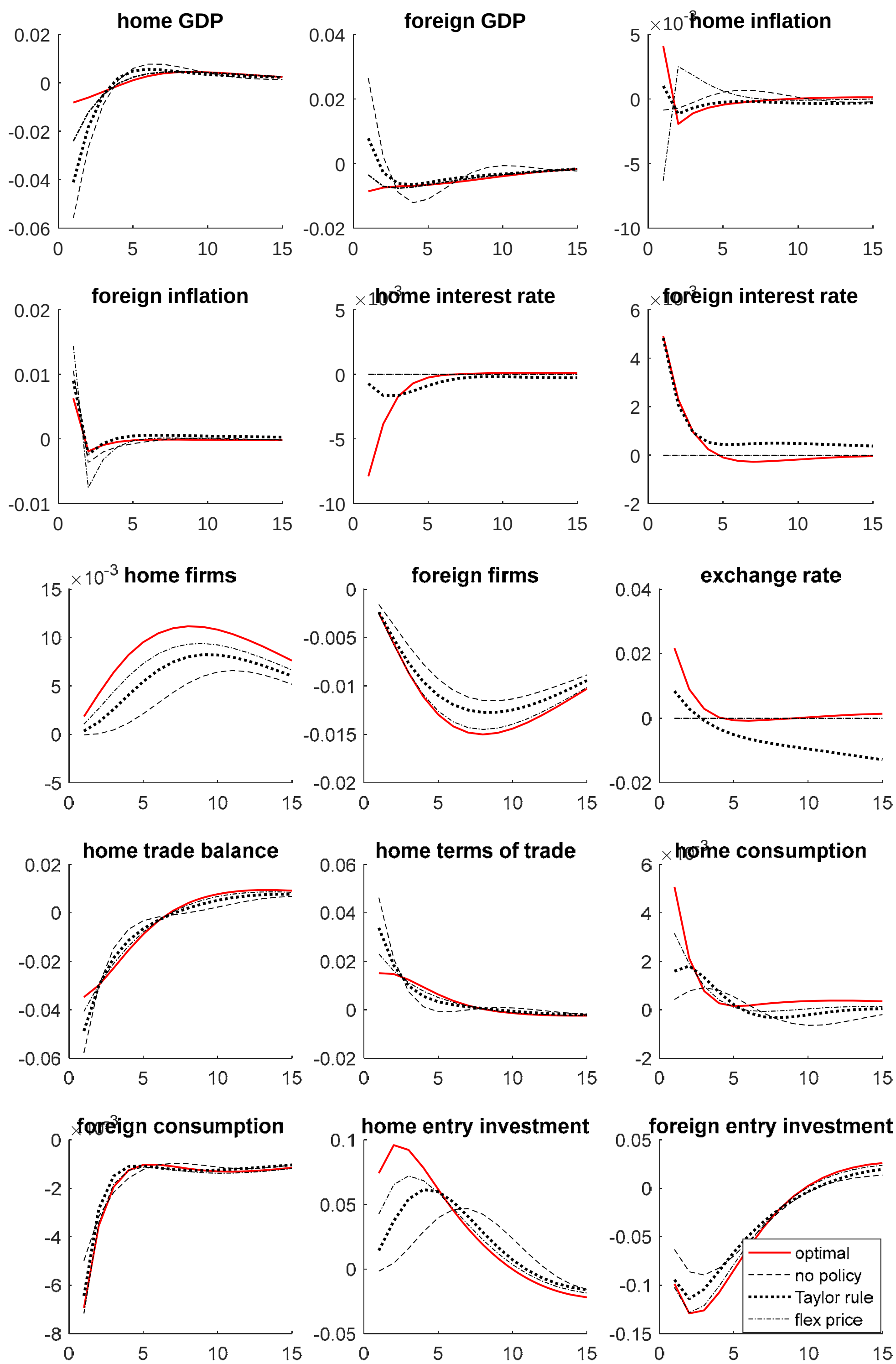
	one-sector model						two-sector model		
	common shock			independent shock			common	independent	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	benchmark	no roundabout	no firm entry or roundabout	benchmark	no roundabout	no firm entry or roundabout	benchmark	benchmark	substitutes
standard deviations in percent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

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



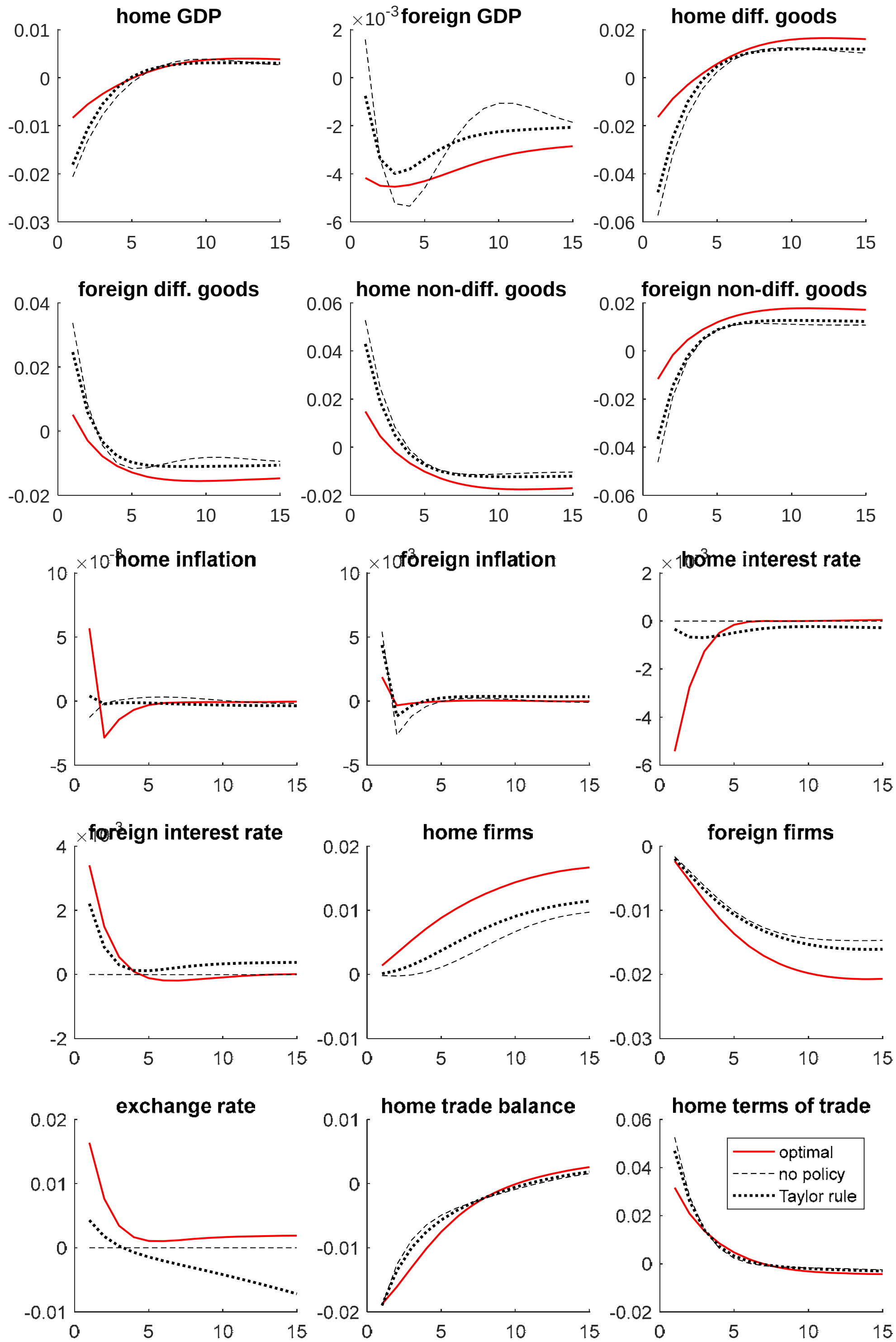
Vertical axis is percent deviation (0.01=1%) from steady state levels. Horizontal axis is time (in quarters).

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



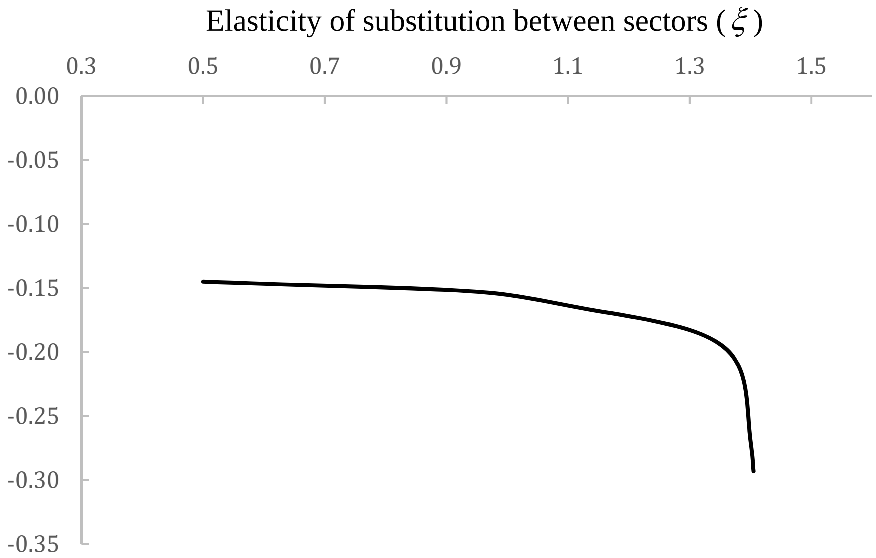
Vertical axis is percent deviation (0.01=1%) from steady state levels. Horizontal axis is time (in years).

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



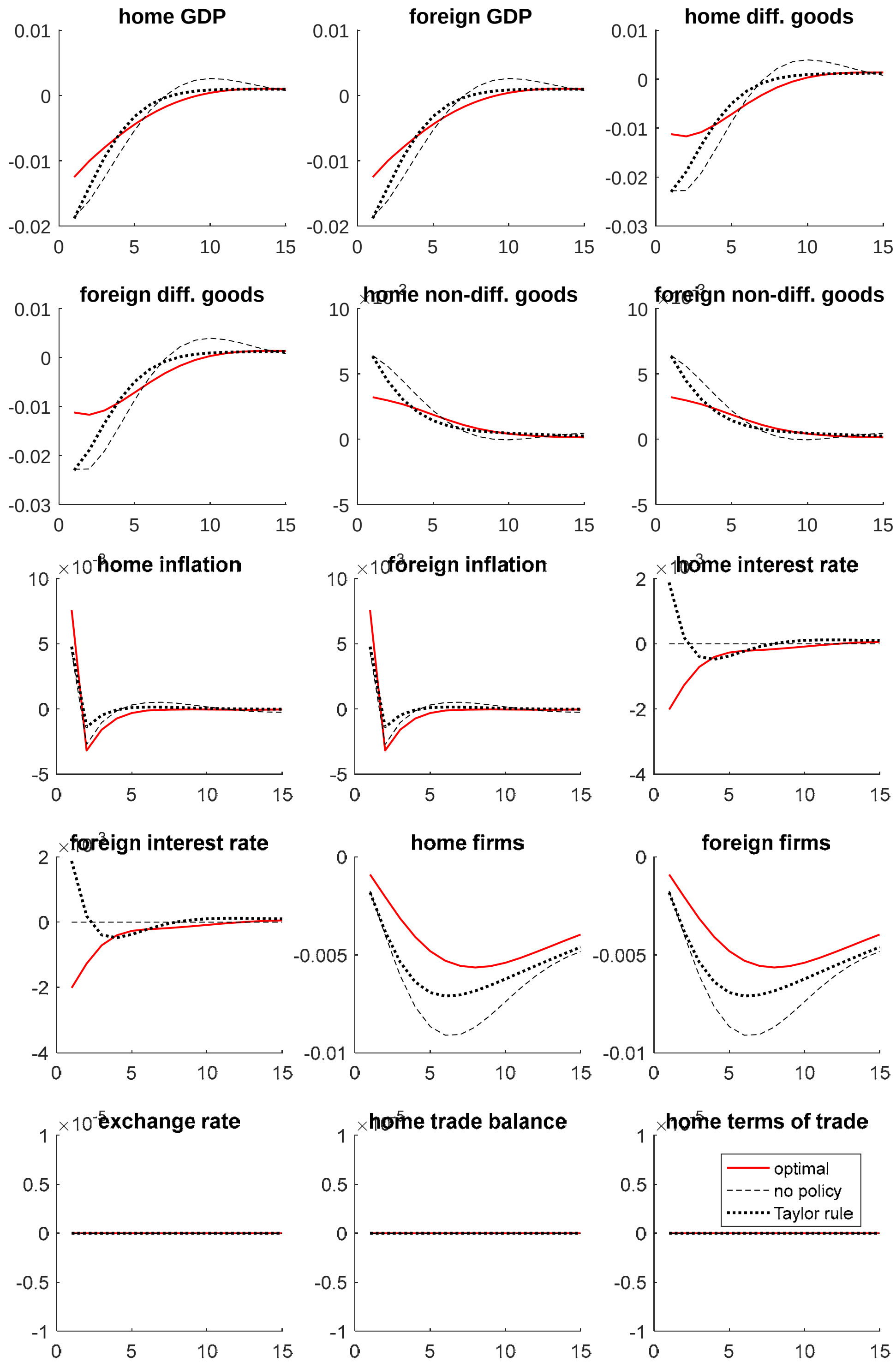
Vertical axis is percent deviation (0.01=1%) from steady state levels. Horizontal axis is time (in years).

Figure 4. Welfare loss for varoius substitution elasticities between sectors



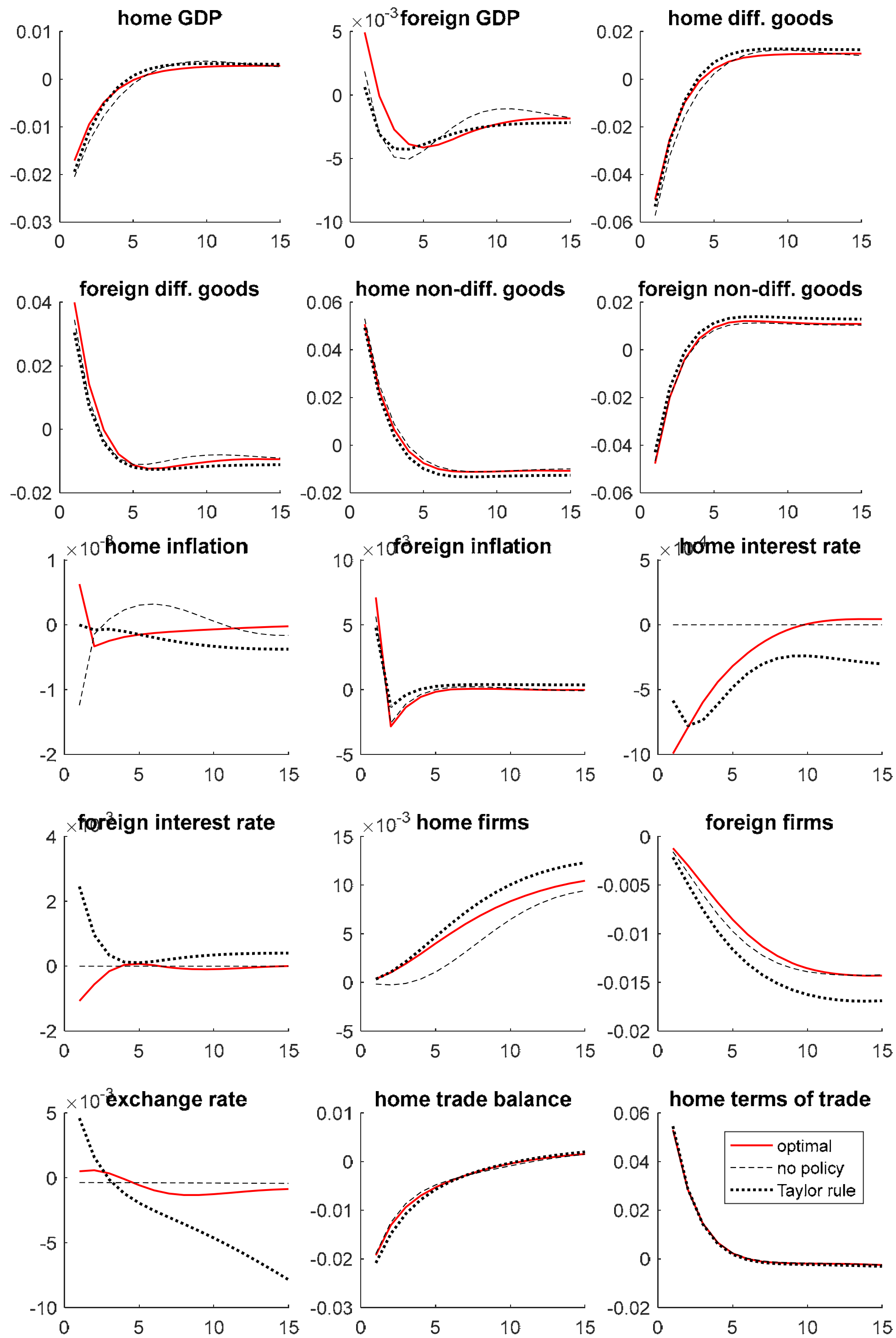
Vertical axis reports percentage change in welfare loss from Taylor rule relative to Ramsey Optimal policy, in units of state consumption.

Figure 5. Impulse responses to a rise in tariff on differentiated goods in both countries, two-sector model



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

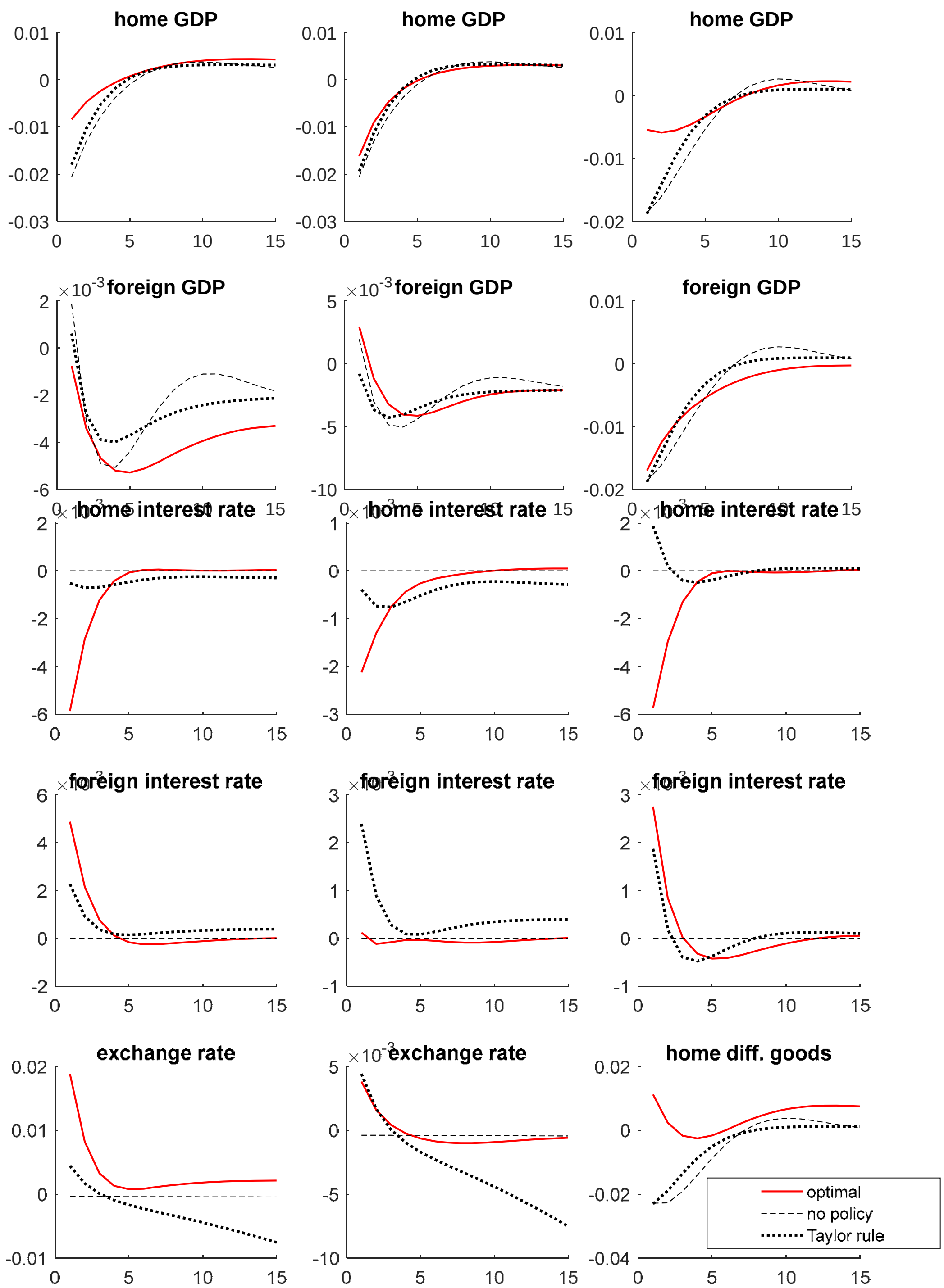
Figure 6. Impulse responses to a rise in foreign tariff on home differentiated exports, two-sector model, LCP



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

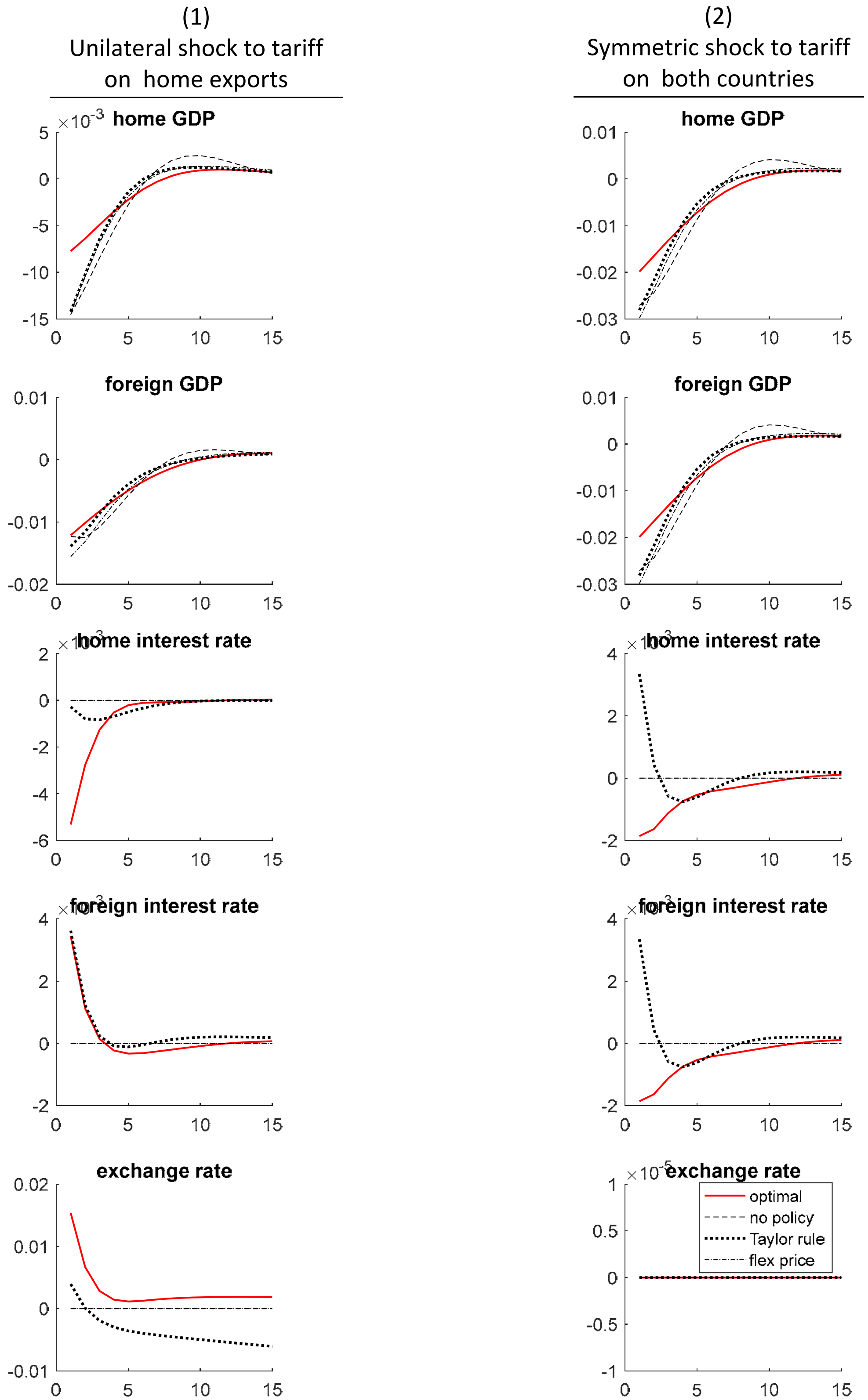
Figure 7. Impulse responses under various specifications of dominant currency pricing (tariff on differentiated goods in two-sector model)

(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 years). Column (1) highlights selected results from Appendix Figure 8; column (2) from Appendix Figure 9, and column (3) from Appendix Figure 10.

Figure 8. Impulse responses for two cases under the low pass-through model (tariff on differentiated goods in two-sector model)



Vertical axis is percent deviation (0.01=1%) from steady state levels. Horizontal axis is time (in years). Column (1) highlights selected results from Appendix Figure 11; column (2) from Appendix Figure 12.