

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

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## Abstract

In the wake of Brexit and the Trump tariff war, central banks have had to reconsider the role of monetary policy in managing the economic effects of tariff shocks, which may induce a slowdown while raising inflation. This paper studies the optimal monetary policy responses using a New Keynesian model that includes elements from the trade literature, including global value chains in production, firm dynamics, and comparative advantage between two traded sectors. We find that, in response to a symmetric tariff war, the optimal policy response is generally expansionary: central banks stabilize the output gap at the expense of further aggravating short-run inflation---contrary to the prescription of the standard Taylor rule. In response to a tariff imposed unilaterally by a trading partner, it is optimal to engineer currency depreciation up to offsetting the effects of tariffs on relative prices, without completely redressing the effects of the tariff on the broader set of macroeconomic aggregates.

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

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## 1. Introduction

Brexit and the Trump trade wars have ignited a debate over the economic effects of tariffs, and the appropriate monetary policy response to the economic slowdown potentially induced by these shocks. Much of recent research on the macroeconomic effects of trade policy shocks has been conducted in the context of real trade models, or in empirical exercises without consideration of monetary policy.<sup>1</sup> In the classical literature, there are examples of studies focusing on trade policy also as a tool of macroeconomic management. But the question facing numerous central banks has been how to respond to a trade policy that is either imposed by a foreign country over which it has no control, or reflects a domestic government political agenda best modeled as an exogenous shock.

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 (possibly reflecting a fall in activity). In recent theoretical research on the topic, however, monetary policy is modelled using Taylor rules, without deriving them from optimal policy exercises. This approach is tantamount to assuming that monetary authorities would focus on countering the inflationary effects of a tariff with monetary contraction, possibly exacerbating the associated fall in output (See Barattieri et al. (2018), Caldara et al. (2020), and Linde and Pescatori (2019) for examples.) However, given the mix of demand and supply implications of tariffs, it is far from clear that the optimal monetary policy response can be approximated by the standard mold of inflation targeting.

This paper studies Ramsey optimal monetary policy responses to tariff shocks in a New Keynesian model that exhibits nominal rigidities, along with several other features borrowed from the trade literature particularly relevant for understanding the effects of tariffs. 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 raising tariff protection of domestic exporters can also raise the cost of production for domestic firms.

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<sup>1</sup> 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. (2018), which goes on to consider two alternative monetary regimes of a zero lower bound and a fixed exchange rate.

The model also 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, where a country's comparative advantage between sectors is endogenous. As shown in the trade literature, optimal tariff policy can be designed with the goal to manipulate comparative advantage. In previous work of ours, we have reconsidered the same goal in relation to the optimal design of monetary and exchange rate policy (see Bergin and Corsetti, 2019). In this paper, we bring our two-country model to bear on both the macroeconomic effects of tariff shocks, and the optimal response of monetary policy to such a shock. We carry out our analysis numerically, at first focusing on a version of our model with one sector only, then extending our exercises to the richer setting.

Our results are as follows. A symmetric tariff war, in which countries impose symmetric tariffs on exports from each other, implies that output falls and inflation rises in both countries. The optimal (cooperative) monetary policy response is distinctly expansionary. Central banks lower interest rates to stimulate flagging export demand, consumption demand, and investment demand. Stabilizing the output gap comes at the expense of further aggravating inflation. The characterization of the optimal monetary response as expansionary may be surprising, in light of the fact that an unexpected hike in tariffs is commonly seen as a supply shock, because of its effect on marginal costs and thus on the price of domestic goods. The Ramsey solution is also at odds with the prescription arising from imposing a standard Taylor rule with a large inflation coefficient.

The optimal domestic response to the alternative scenario of a unilateral tariff shock imposed by a trading partner is similarly expansionary. In this scenario, however, the optimal home monetary stance engineers currency depreciation with the primary goal to offset the impact of the tariff on relative prices, thus containing the distortions impinging on efficient production and trade. Yet the optimal policy only imperfectly redresses the effects of the tariff on the broader set of macroeconomic aggregates.

The above results are qualitatively similar in the one- and two-sector versions of our model. Quantitatively, however, the two models have different implications. When we allow tariff shocks to induce shifts in comparative advantage between multiple sectors, our model predicts a significant amplification of their macroeconomic effects, in particular in

terms of firm entry dynamics. In this case, monetary policy has a much larger role to play in counteracting trade policy distortions.

Our work is related to a number of recent papers studying macroeconomic effects of trade policies in dynamic stochastic general equilibrium models. Barrattieri et al. (2017) and Erceg et al. (2018) study whether tariffs or combinations of trade policies can potentially serve as effective tools of macroeconomic stimulus in environments with nominal frictions. Caldara et al. (2018) study how trade policy uncertainty can have contractionary macroeconomic implications. Linde and Pescatori (2019) study the degree to which endogenous exchange rate movements in a macroeconomic environment work to offset the real effects of tariffs and export subsidies. These papers share with our work a nominal dimension that goes beyond the standard trade literature, in that they have nominal rigidities and specify monetary policy behavior. However, we differ in that our focus is on the monetary policy choice. These papers focus on the design and efficacy of tariff policies, in an environment that includes a given, standard Taylor monetary policy rule in the background. In contrast, we compute the design of the welfare-optimizing monetary policy response of a central bank faced by a given, exogenous tariff shock. We also differ in considering 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. Section 3 presents simulation experiments for scenarios in a one-sector version of the model, including a symmetric tariff war and a unilateral foreign tariff. Section 4 then shows how results change in the full two-sector model, and section 5 concludes.

## **2. Model**

The theoretical framework builds upon the monetary comparative advantage model developed in Bergin and Corsetti (2019), wherein two countries, home and foreign, each produce two types of tradable goods. The first type comes in differentiated varieties produced under monopolistic competition. Firms in this sector face a sunk investment cost to enter the market with a new variety, and set prices subject to nominal rigidities;

moreover, production may require intermediates in a round-about production structure. 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

Households consume goods produced in both sectors, of 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  $\phi$ . The non-differentiated goods come in a home and foreign version, which are imperfect substitutes with elasticity  $\eta$ . 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:

$$C_t \equiv C_{D,t}^\theta C_{N,t}^{1-\theta},$$

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

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

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

$$(1) \quad P_t \equiv \frac{P_{D,t}^\theta P_{N,t}^{1-\theta}}{\theta^\theta (1-\theta)^{1-\theta}},$$

where

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

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

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

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.

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

$$(4,5) \quad C_{D,t} = \theta P_t C_t / P_{D,t} \quad C_{N,t} = (1-\theta) P_t C_t / P_{N,t}$$

$$(6,7) \quad c_t(h) = (p_t(h) / P_{D,t})^{-\phi} C_{D,t} \quad c_t(f) = (p_t(f) T_{D,t} / P_{D,t})^{-\phi} C_{D,t}$$

$$(8,9) \quad C_{H,t} = \nu (P_{H,t} / P_{N,t})^{-\eta} C_{N,t} \quad C_{F,t} = (1-\nu) (P_{F,t} T_{N,t} / P_{N,t})^{-\eta} C_{N,t}$$

## 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  $(\Pi_t)$  in real terms and defined below, as well as interest income on bonds in home currency  $(i_{t-1}B_{H,t-1})$  and foreign currency  $(i_{t-1}^*B_{F,t-1})$ , where  $e_t$  is the nominal exchange rate in units of home currency per foreign. Income 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:

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

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

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

scaled by  $\psi_B$ , 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 equation (4)-(9).

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

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

a labor supply condition:

$$(11) \quad W_t = l_t^\psi \mu_t$$

a money demand condition:

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

and a home interest rate parity condition:

$$(13) \quad E_t \left[ \frac{\mu_t}{\mu_{t+1}} \frac{e_{t+1}}{e_t} (1+i_t^*) \left( 1 + \psi_B \left( \frac{e_t B_{ft}}{P_{Ht} y_{Ht}} \right) \right) \right] = E_t \left[ \frac{\mu_t}{\mu_{t+1}} (1+i_t) \right].$$

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

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

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, and given that the index is the same as for consumption, this implies demands for differentiated goods varieties analogous to equations (6)–(7).

$$(15,16) \quad d_{G,t}(h) = (p_t(h) / P_{D,t})^{-\phi} G_t \quad d_{G,t}(f) = (p_t(f) T_{D,t} / P_{D,t})^{-\phi} G_t$$

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

$$(17) \quad AC_{P,t}(h) = \frac{\psi_p}{2} \left( \frac{p_t(h)}{p_{t-1}(h)} - 1 \right)^2 \frac{p_t(h) y_t(h)}{P_t},$$

where  $\psi_p$  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.<sup>3</sup>

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

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<sup>3</sup> The price index for adjustment cost is identical to the overall consumption price index, implying demands analogous to those for consumption in equations (4)–(9). See the supplementary online appendix for the full list of equations.



same exogenous probability of exit  $\delta$ , a fraction  $\delta$  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:

$$(18) \quad n_{t+1} = (1 - \delta)(n_t + ne_t),$$

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:

$$(19) \quad K_t = \left( \frac{ne_t}{ne_{t-1}} \right)^\lambda \bar{K},$$

where  $\bar{K}$  indicates the steady state level of entry cost, and the parameter  $\lambda$  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,  $\lambda$ , to match data on the dynamics of new firm entry.<sup>4</sup> Entry costs are specified either in units of labor (if  $\theta_K = 1$ ) or in units of the differentiated good (if  $\theta_K = 0$ ). If entry costs are in units of differentiated goods, the investment-driven demand is distributed analogously to demands for consumption of differentiated goods:

$$(20) \quad d_{K,t}(h) = (p_t(h)/P_{D,t})^{-\phi} ne_t (1 - \theta_K) K_t$$

$$(21) \quad d_{K,t}(f) = (p_t(f)T_{D,t}/P_{D,t})^{-\phi} ne_t (1 - \theta_K) K_t.$$

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

$$(22) \quad d_t(h) = c_t(h) + d_{G,t}(h) + d_{K,t}(h) + d_{AC,P,t}(h) + d_{AC,B,t}(h)$$

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

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<sup>4</sup> The value of steady state entry cost  $\bar{K}$  has no effect on the dynamics of the model, and so will be normalized to unity.

$(d_{AC,B,t}(h))$ . There is an analogous demand from abroad  $d_t^*(h)$ . We assume iceberg trade costs  $\tau_D$  for exports, so that market clearing for a firm's variety is:

$$(23) \quad y_t(h) = d_t(h) + (1 + \tau_D) d_t^*(h),$$

Firm profits are computed as:

$$(24) \quad \pi_t(h) = p_t(h) d_t(h) + e_t p_t^*(h) d_t^*(h) - mc_t y_t(h) - P_t AC_{p,t}(h).$$

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:

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

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:

$$(25) \quad v_t(h) = (\theta_K W_t + (1 - \theta_K) P_{D,t}) K_t,$$

recalling  $\theta_K = 1$  is the case of entry costs in labor units, and  $\theta_K = 0$  the case of goods units.

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

$$(26) \quad \frac{P_{D,t} G_t(h)}{W_t l_t(h)} = \frac{\zeta}{1 - \zeta}.$$

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

$$(27) \quad p_t(h) = \frac{\phi}{\phi-1} mc_t + \frac{\psi_P}{2} \left( \frac{p_t(h)}{p_{t-1}(h)} - 1 \right)^2 p_t(h) - \psi_P \frac{1}{\phi-1} \left( \frac{p_t(h)}{p_{t-1}(h)} - 1 \right) \frac{p_t(h)^2}{p_{t-1}(h)} \\ + \frac{\psi_P}{\phi-1} E_t \left[ \beta \frac{\Omega_{t+1}}{\Omega_t} \left( \frac{p_{t+1}(h)}{p_t(h)} - 1 \right) \frac{p_{t+1}(h)^2}{p_t(h)} \right]$$

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

$$\Omega_t = \left[ \left( \frac{p_t(h)}{P_{D,t}} \right)^{-\phi} (C_{D,t} + G_t + n e_t (1 - \theta_K) K_t + A C_{P,D,t} + A C_{B,D,t}) \right. \\ \left. + \left( \frac{(1 + \tau_D) T_{D,t}^* p_t(h)}{e_t P_{D,t}^*} \right)^{-\phi} (1 + \tau_D) (C_{D,t}^* + G_t^* + n e_t^* (1 - \theta_K) K_t^* + A C_{P,D,t}^* + A C_{B,D,t}^*) \right] / \mu_t$$

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:

$$(28) \quad p_t^*(h) = (1 + \tau_D) p_t(h) / e_t,$$

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:

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

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

## 2.4 Home firm problem in the undifferentiated goods sector

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

$$(29) \quad y_{H,t} = \alpha_{N,t} l_{H,t},$$

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:

$$(30) \quad p_{H,t} = W_t / \alpha_{N,t}.$$

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

$$(31) \quad p_{H,t}^* = p_{H,t} (1 + \tau_N) / e_t.$$

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.

We also study a “no-policy” case with a constant money growth rule:

$$(32) \quad \frac{M_t}{M_{t-1}} = \nu.$$

as well as a Taylor rule of the form

$$(33) \quad 1 + i_t = (1 + \bar{i}_{t-1})^{\gamma_i} \left[ (1 + \bar{i}) \left( \frac{p_t(h)}{p_{t-1}(h)} \right)^{\gamma_p} \left( \frac{Y_t}{\bar{Y}} \right)^{\gamma_Y} \right]^{1-\gamma_i},$$

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:<sup>5</sup>

$$(34) \quad Y_t = \left( (1 + n_t)^{-(1/(1-\sigma))} \int_0^{n_t} p_t(h) y_t(h) dh - P_{D,t} G_t + p_{H,t} y_{H,t} \right) / P_t.$$

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:

$$(35) \quad T_t = (M_{t-1} - M_t) + (T_{D,t} - 1) n_{t-1}^* d_t(f) + (T_{N,t} - 1) (C_{F,t} + A C_{P,F,t} + A C_{B,F,t}).$$

## 2.6 Market clearing

<sup>5</sup> 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.

The market clearing condition for the manufacturing goods market is given in equation (22) above. Market clearing for the non-differentiated goods market requires:

$$(36) \quad y_{H,t} = C_{H,t} + AC_{P,H,t} + AC_{B,H,t} + (1 + \tau_N)(C_{H,t}^* + AC_{P,H,t}^* + AC_{B,H,t}^*)$$

$$(37) \quad y_{F,t} = (1 + \tau_N^*)(C_{F,t} + AC_{P,F,t} + AC_{B,F,t}) + C_{F,t}^* + AC_{P,F,t}^* + AC_{B,F,t}^*.$$

Labor market clearing requires:

$$(38) \quad \int_0^{n_t} l_t(h) dh + l_{H,t} + \theta_K n e_t K_t = l_t.$$

Bond market clearing requires:

$$(39) \quad B_{Ht} + B_{Ht}^* = 0$$

$$(40) \quad B_{Ft} + B_{Ft}^* = 0.$$

Balance of payments requires:

$$(41) \quad \int_0^{n_t} p_t^*(h)(d_t^*(h)) dh - \int_0^{n_t^*} p_t(f)(d_t(f)) df + P_{Ht}^*(C_{H,t}^* + AC_{P,H,t}^* + AC_{B,H,t}^*) - P_{F,t}(C_{F,t} + AC_{P,F,t} + AC_{B,F,t}) - i_{t-1} B_{H,t-1}^* + e_t i_{t-1}^* B_{F,t-1} = (B_{H,t}^* - B_{H,t-1}^*) + e_t (B_{F,t} - B_{F,t-1}).$$

## 2.7 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  $\rho_A$ , and the covariance matrix  $E[\varepsilon_{At} \varepsilon_{At}']$ . 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  $\rho_T$ , and the covariance matrix  $E[\varepsilon_{Tt} \varepsilon_{Tt}']$ .

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 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). Parameter values are chosen to be consistent with an annual frequency—the frequency at which sectoral productivity data are available. Accordingly, time preference is set at  $\beta = 0.96$ .

To choose parameters for the differentiated and non-differentiated sectors we draw on Rauch (1999). We choose  $\theta$  so that differentiated goods represent 55 percent of U.S. trade in value. 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 for the differentiated and non-differentiated goods 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  $\phi = 5.2$  (the sample period is 1972-1988). The corresponding elasticity of substitution for non-differentiated commodities is  $\eta = 15.3$ .

The price stickiness parameter is set at  $\psi_p = 40$ , a value implies in simulations of a productivity shock that approximately half the firms resetting price during the first year. The firm death rate is set at  $\delta = 0.1$ , which is four times the standard rate of 0.025 to reflect the annual frequency. The mean sunk cost of entry is normalized to the value  $\bar{K} = 1$ . The share of intermediates in differentiated goods production is set to a modest value of  $\zeta = 1/3$ .<sup>6</sup>

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<sup>6</sup> There is a wide range of views regarding the appropriate calibration for this parameter. Jones (2007) suggests a value of 0.43 for the share of intermediates, and it is common in the related literature to use a value at 1/2. We will consider a range of values for this parameter in sensitivity analysis, but we use a modest value of this parameter for our benchmark model.

To set trade costs, we calibrate  $\tau_D$  so that exports represent 26% of GDP, as is the average in World Bank national accounts data for OECD countries from 2000-2017.<sup>7</sup> This requires a value of  $\tau_D = 0.33$ .<sup>8</sup> This is similar to the value of trade costs typically assumed by macro research, such as 0.25 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). As shown later on, sensitivity analysis to a wide range of values for the trade cost suggests that our results are robust to calibrations implying trade shares both much higher and much lower than in our benchmark calibration. We begin with the standard assumption of trade models that the homogeneous good is traded frictionlessly ( $\tau_N$ ), but we will consider a range of values for this parameter also in sensitivity analysis.

The benchmark simulation model specifies entry costs in units of goods ( $\theta_K = 0$ ) but we will also report results for entry costs in labor units in our sensitivity analysis (see the discussion in Cavallari, 2013). The adjustment cost parameter for new firm entry,  $\lambda$ , is taken from Bergin and Corsetti (2019), chosen to match the standard deviation of new firm entry in the benchmark simulation to that in data.

Currently all tariff variables are calibrated with a mean value of 1.05 (5 percentage point mean tariff rate). A shock raises the tariff rate 2 percentage points, with an autoregressive parameter of 0.9.

### 3. Optimal policy in the one-sector version of the 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. We assume that both countries produce differentiated goods, and shut down the non-differentiated goods sector by setting  $\theta = 1$ . We will report simulations 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, in order to gain insight on the response of the exchange rate and trade balance.<sup>9</sup> In all cases we

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<sup>7</sup> See <https://data.worldbank.org/indicator/NE.EXP.GNFS.ZS?locations=OE>.

<sup>8</sup> 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.

<sup>9</sup> 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

consider a rise in tariffs by 2 percentage points above their 5% steady state level, with an autoregressive coefficient of 0.9.

### **3.1 Optimal stabilization in a tariff war with full retaliation**

In figure 1, we report impulse responses to an unexpected rise in tariffs in both countries, contrasting the cases of “no-policy” (dashed), “flexible prices” (dotted), and “optimal policy” (solid), where the “no policy” case is obtained by imposing a constant money growth rule. The first two cases allow us to set the stage for our main contribution, characterizing economic dynamics under efficient stabilization of the shock.

#### **3.1.1 The transmission of symmetric tariff shocks**

Under a suboptimal money growth rule (“no policy”), a symmetric tariff shock raises inflation and causes a recession---a standard result 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 by more than a full percentage point. 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, household smooth spending intertemporally, acting on expectations that tariffs will abate in

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variance, with all other elements zero. The autoregressive matrix is diagonal. The case of a unilateral shock is specified by setting just the second diagonal element of the covariance matrix as nonzero.



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.)

Nominal rigidities do amplify the effect of tariff shocks. Focus on impulse responses under flexible prices, marked with dotted lines in Figure 1. Relative to the no-policy scenario, the fall in GDP and the number of firms is about a third lower. This difference mainly stems from the fact that, in the presence of nominal rigidities, firms do not pass through lower wage costs on prices, counteracting the direct effect of the tariff. Note that, on impact, inflation is initially higher under sticky prices than under flexible prices (inflation rises by 0.39 versus 0.34 percentage points)---as the tariff is added directly to the price charged to consumers.

### **3.1.2 Economic dynamics under optimal monetary expansion**

We now come to the main contribution of this paper, characterizing the optimal monetary policy response to the tariff-induced macroeconomic slowdown cum inflation. As shown by the solid lines in Figure 1, the cooperative optimal monetary policy response is expansionary: the nominal interest rate falls markedly in both countries. This policy response mitigates by half the fall in GDP compared to the no-policy case, while it exacerbates slightly the rise in inflation in the initial period (from 0.39% to 0.41%). 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., 2018, for a detailed discussion). After all, the impact of the tariff under no-policy, where a fall in output corresponds to a rise in prices, would seem consistent with such an interpretation. But the optimal monetary policy prescription in the presence of an inflationary supply shock involves monetary contraction, not an expansion. Perhaps this argument has 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. (2018)). 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. Note that, in Figure 1, there is a wide gap in impulse responses in the optimal policy and the flexible price allocations. The optimal policy most definitely 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 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, as to replace the exports lost because of higher trade costs.

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---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. In the case of a symmetric tariff war, monetary policy cannot directly redress the relative price distortion. However, it can indirectly offset the distortion by pushing demand and overall production up, closer to their efficient, higher levels.

The optimality of a monetary expansion is a robust result. In Figure 2, we redo our analysis using alternative versions of our model, shutting down, respectively, roundabout production and firm entry. Regardless of whether domestic production requires imported inputs, and whether there are firm dynamics, the optimal policy prescribes a similar degree of interest rate cuts in response to the tariff shock. Dynamic adjustment is understandably

different across these exercises. Note that without firm entry the persistence of the shock is visibly lower. The policy rate, in this case, dynamically rises after the initial fall, reflecting a stronger concern with the inflationary impact of the optimal response to the tariff. Besides the case shown in Figure 2, under no calibration using the one-sector version of our model did we find a case in which the optimal monetary policy is contractionary. We will return to this point later, when we use our complete model.

### 3.2 Responding to a unilateral tariff shock

We now consider the case when the tariff shock is unilateral, i.e. 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 trade balance, which did not come into play in response to symmetric shocks across countries. But would the home monetary response switch from expansionary to contractionary, redressing inflation rather than the output gap in the short run?

The economic dynamics under the no-policy scenario (dashed line) in Figure 3 show that the foreign tariff results in a foreign trade surplus (home trade deficit). The effect on home GDP is distinctly contractionary: the fall in home export demand (to a large extent driven by expenditure switching effects of higher post-tariff prices) impacts on consumption and firm entry investment demand. Note that the response of foreign GDP is an order of magnitude smaller than the response of home GDP---and the sign of the response is quite sensitive to calibration. As discussed by Erceg et al. (2018), foreign GDP may rise or fall, depending upon whether the fall in consumption demand due to intertemporal incentives is dominated by the rise in foreign export demand due to the expenditure switching effect of relative prices. In our benchmark calibration, foreign GDP actually rises, as the expenditure switching effect dominates. We should note in this respect that 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. The experiments reported in Figure 4 (dashed line) 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.

In response to a unilateral tariff on home exports, the home exchange rate depreciates, as shown in Figure 3. But the rate of depreciation in our environment is not large enough to offset the impact of the tariff on the relative price of home exports to home imports, as predicted by the well-known “Lerner symmetry result.” In a recent discussion of this result, Linde and Pescatori (2019) point out that, in its stronger form, the Lerner symmetry fails to be complete in many macroeconomic contexts, due to factors such as nominal rigidities and asset market spillovers. Our impulse responses indicate that endogenous exchange rate movements offset about half of the effect of the tariff on the terms of trade. In the no-policy scenario, the currency depreciation is not driven by movements in the short run policy rates, but by the equilibrium response in nominal and real rates across countries, reflecting the change in consumption and thus in stochastic discount factors.

Optimal monetary policy is sharply different in the unilateral tariff case relative to the symmetric case studied earlier, highlighting new channels and mechanisms. In Figure 3, economic dynamics under the optimal policy is depicted with a solid line. In response to the tariff, the optimal cooperative policy prescribes substantial monetary expansion at home (lower home interest rates) but a rise in the foreign interest rate, although by an order of magnitude smaller than the change in the home interest rate. The reason for this asymmetric monetary stance is to engineer enough home currency depreciation, to offset optimally the impact of the tariff on the terms of trade. Note that, in Figure 3, the home terms of trade remain virtually unaffected on impact. If only temporarily, the optimal policy restores the Lerner symmetry result for the exchange rate!

As in the previous subsection, the optimal policy response moves opposite to strict inflation targeting or to a Taylor rule with a large weight on inflation: as it engineers a large depreciation, it actually exacerbates home inflation. In pursuing the optimal trade-offs among objectives, the optimal policy clearly does not aim to replicate the flexible price allocation. On the contrary, it brings most macro aggregates to overshoot their flex-price levels (dotted lines in the figure) substantially. By way of instance, the optimal monetary policy is not limited by the need to keep home GDP in line with the contraction the home country would experience under the “natural rate”: on impact, it almost fully reverses the negative effect of the tariff on activity. Similarly, the rise in foreign GDP under the no-

policy scenario is completely reversed. Foreign GDP falls well below the flexible price level. Note that, in either country, despite moving economic activity in opposite directions, the optimal policy nearly eliminates the large drops in firm entry experienced in the no-policy case. 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.

It may be worth noting that monetary policy cannot (and would not) replicate the pre-tariff allocation, i.e. undo the trade distortion, via currency depreciation. On 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.

All these results are qualitatively robust to various alternative specifications of our model---a sample of which is shown in Figure 5. Note that, barring firm entry (dotted line), the need for foreign monetary contraction at an optimum becomes much smaller.

### **3.3 Discussion**

In all the cases reviewed in this section, in response to tariffs that result in higher prices and lower economic activity, the optimal monetary policy trades off higher inflation for higher output. For the home country, this is so whether or not the country retaliates to the foreign tariff, or whether or not we allow for firm entry. While the tariff shock has both demand and supply effects, these effects are distinct from those of a productivity disturbance---which would call for strict inflation targeting. A tariff shock is also different from a markup shock, which would also move output and inflation in opposite directions, but would typically be stabilized by containing its inflationary consequences.

We derive our results assuming 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 from the above. Yet, because of the trade cost externality analyzed in our previous paper (see Bergin and Corsetti, 2019), policymakers will have a strong incentive to keep the

production of a large number of varieties within their borders. If anything, the monetary expansionary response to a tariff will be stronger

#### **4. Dealing with tariffs in a two-sector environment**

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 losses. In the macroeconomic literature, sector reallocation is typically envisioned as a production shift between tradables and nontradables. In recent work (Bergin and Corsetti 2019) we have proposed a macro model with two tradable sectors, one producing differentiated, the other non-differentiated goods, to bring the study of optimal monetary policy to bear on comparative advantage. In this section, we build on this early work, and reconsider the transmission of foreign tariffs imposed on home exports, assuming that these fall on the differentiated goods only.<sup>10</sup>

Relative to our previous result, our new model allows us to track the shift in comparative advantage following tariff shocks---which, as depicted in Figure 6, are large. The production of differentiated goods in the home country falls by 2.5 percentage points, which is twice the size of the fall in output observed in earlier scenarios. This is matched by a rise in home production of non-differentiated goods of a similar magnitude. In the foreign country, sectoral productions also move, in opposing direction. This result highlights that foreign tariffs targeted to home differentiated goods can have significant consequences on comparative advantage. At the margin, the foreign country specializes in the production of non-differentiated goods, reflecting the “home market effect” widely discussed in the trade literature. In this literature such shifts in comparative advantage have been associated with an “optimal tariff argument,” by which there are distinct welfare gains from specializing in the differentiated goods sector (see Corsetti et al., 2007 and Bergin and Corsetti, 2019, for a discussion).

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<sup>10</sup>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 available from the authors upon request.

The shift in comparative advantage coincides with a significant redistribution of differentiated goods firms between countries. The percentage fall in the number of home firms is an order of magnitude larger than in the one-sector scenario, and there is a correspondingly large rise in the number of foreign firms. We should stress that, compared to our results for the one-sector version of the model, the rise in foreign investment demand for creating firms fully reverses the implications of the tariff for the trade balance. The foreign country now runs a trade deficit and borrows from the foreign country in order to facilitate its investment in the differentiated goods sector.

The optimal monetary policy for this scenario is qualitatively similar to that in the one-sector model. However, the optimal monetary expansion and currency depreciation are smaller in magnitude. As a result, under the optimal policy the effects of the tariff on macroeconomic aggregates is more pronounced---especially in later periods when price stickiness wanes. The large swing in the number of active firms confers a high degree of persistence to the effects of the tariff on production allocation, and monetary policy is progressively less effective beyond the range of price stickiness. It also appears that a parallel objective of monetary policy to promote international risk sharing may be competing with the goal of compensating for the relative price distortion of the tariff. As shown in Figure 5, the optimal policy serves in this case to raise home consumption relative to the no-policy case, while at the same time lowering foreign consumption. The improvement in home terms of trade helps shift consumption from foreign to home. While a home currency depreciation lowering the price of home exports helps reduce the tariff relative price distortion, it works against the home gains arising from the terms of trade.

As already mentioned, the literature that emphasizes inter-sectoral reallocation assumes that the second sector produces goods that are not internationally traded---a recent instance is Caliendo et al. (2017) specifically studying the effect of a tariff. For comparison, we can consider this case using our model, by assuming that our non-differentiated sector produces non-tradables ( $\nu = 1$ ). Simulation results in Figure 7 indicate that shifts in comparative advantage are qualitatively similar to those in Figure 6, but about half the magnitude. Further, the dynamics in firm entry are much smaller than the two-traded sector model, and instead are more similar in magnitude to those of the one sector model.

## **5. Conclusion**

In the wake of Brexit and the Trump tariff war, central banks have questioned what role monetary policy should play in managing economic slowdowns induced by tariff shocks. Given that tariff shocks combine elements of both demand and supply shocks, it is unclear whether monetary policy should focus on stabilizing the changes in prices induced by a tariff, or stabilizing the output gap implications. This paper studies optimal monetary policy responses 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. Simulations indicate that the optimal (cooperative) policy response to a symmetric tariff-war tends to be expansionary, stabilizing the output gap at the expense of further aggravating inflation, contrary to the standard Taylor rule imposed in most of the related literature. In the case of a unilateral tariff shock imposed by a trading partner, optimal policy prescribes a currency depreciation to offset the effects of tariffs on relative prices, though it only imperfectly offsets effects of the tariff on a broader set of macroeconomic aggregates.



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Table 1. Benchmark Parameter Values

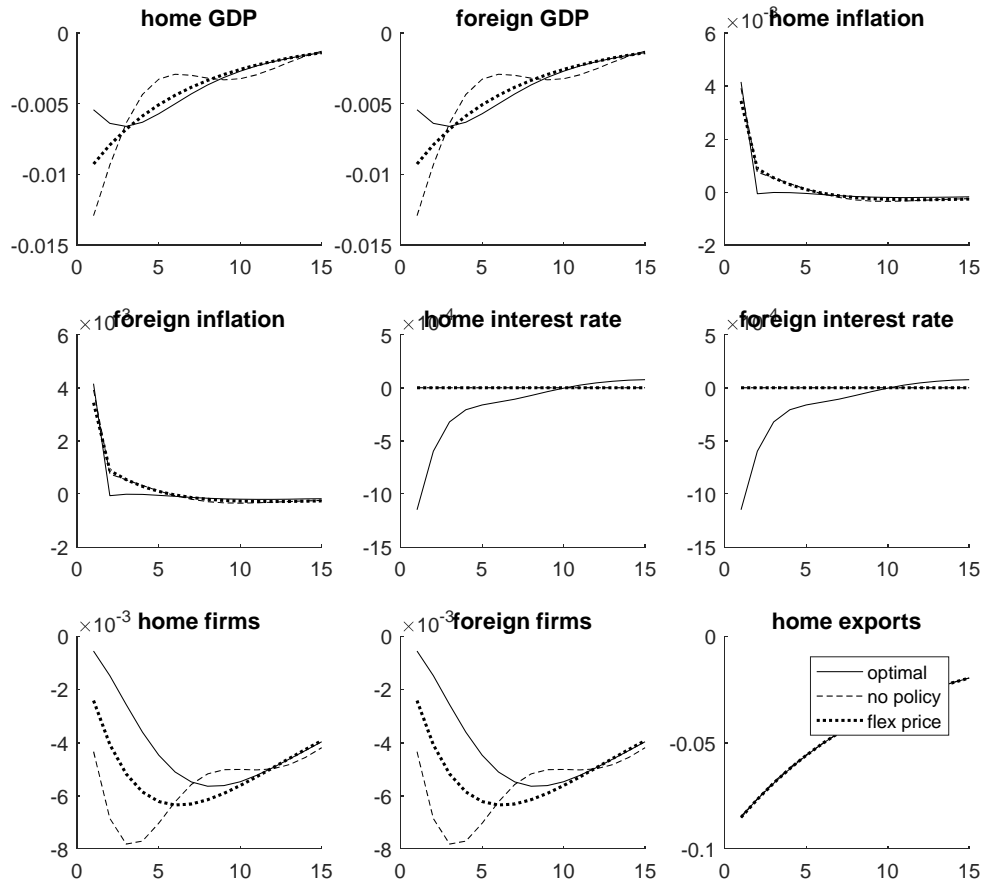
Preferences

Risk aversion	$\sigma = 2$
Time preference	$\beta = 0.96$
Labor supply elasticity	$1/\psi = 1.9$
Differentiated goods share	$\theta = 1, 0.61$
Non-differentiated goods home bias	$\nu = 0.5$
Differentiated goods elasticity	$\phi = 5.2$
Non-differentiated goods elasticity	$\eta = 15.3$

Technology

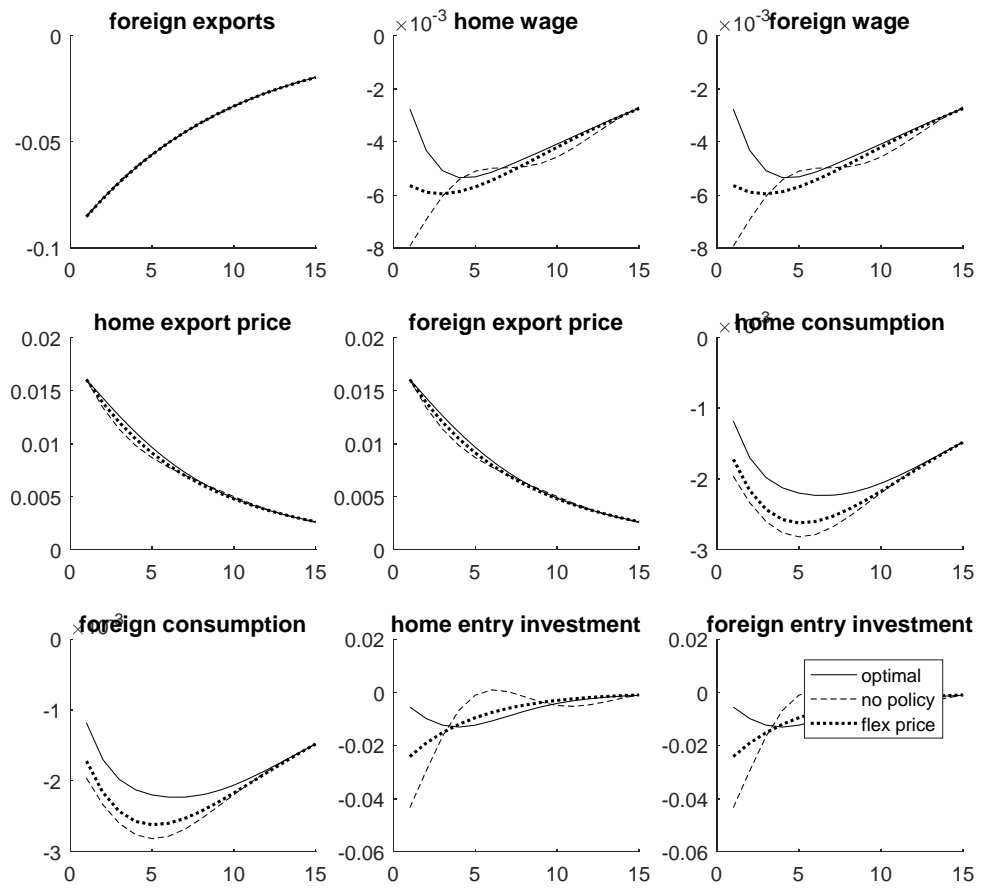
Firm death rate	$\delta = 0.1$
Price stickiness	$\psi_p = 40$
Intermediate input share	$\zeta = 1/3$
Differentiated goods trade cost	$\tau_D = 0.33$
Non-differentiated goods trade cost	$\tau_N = 0$
Mean sunk entry cost	$\bar{K} = 1$
Firm entry adjustment cost	$\lambda = 0.10$
Bond holding cost	$\psi_B = 1 \times 10^{-6}$
Tariff means	$\bar{T}_D = \bar{T}_N = 1.05$

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



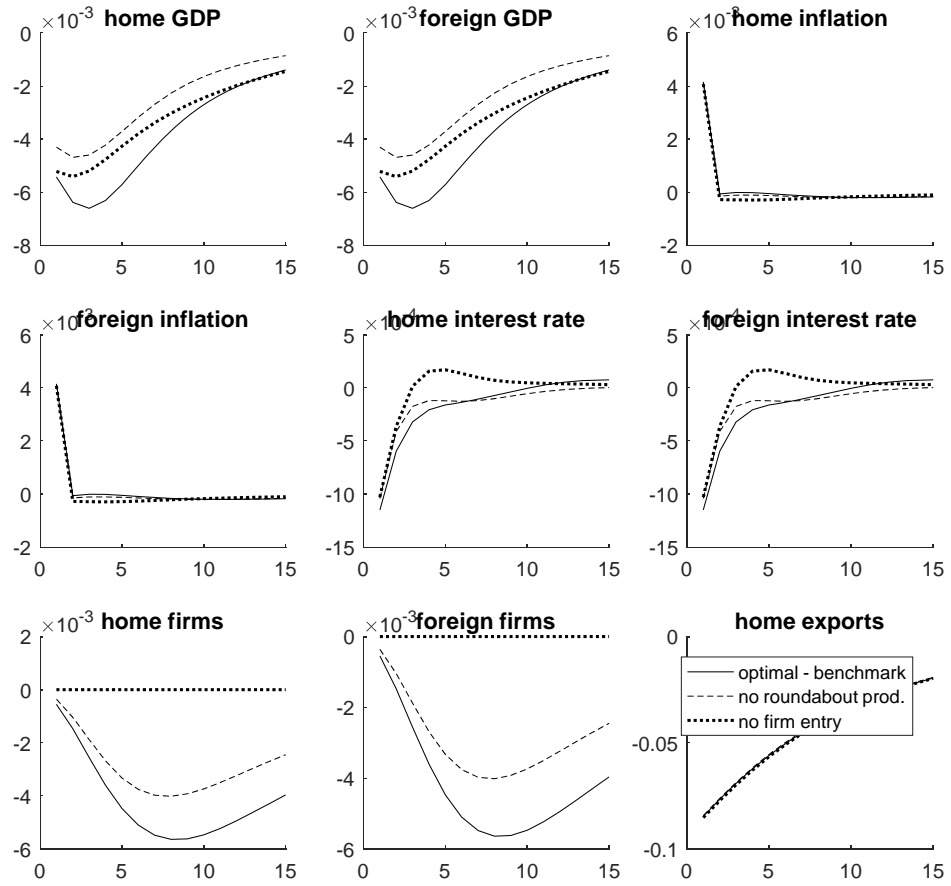
Vertical axis is percent deviation (0.01=1%) from steady state levels. Horizontal axis is time (in years).

Figure 1 continued



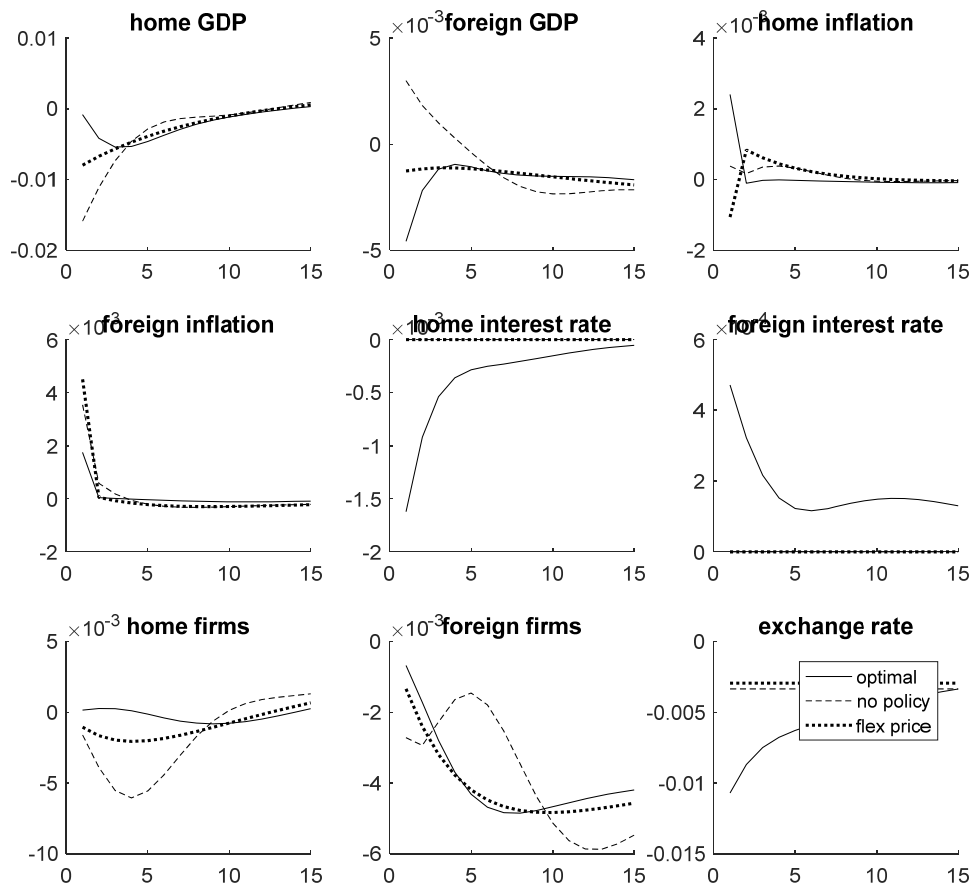
Vertical axis is percent deviation (0.01=1%) from steady state levels. Horizontal axis is time (in years).

Figure 2. Impulse responses to a rise in tariff in both countries, one-sector model, optimal policy for various model specifications



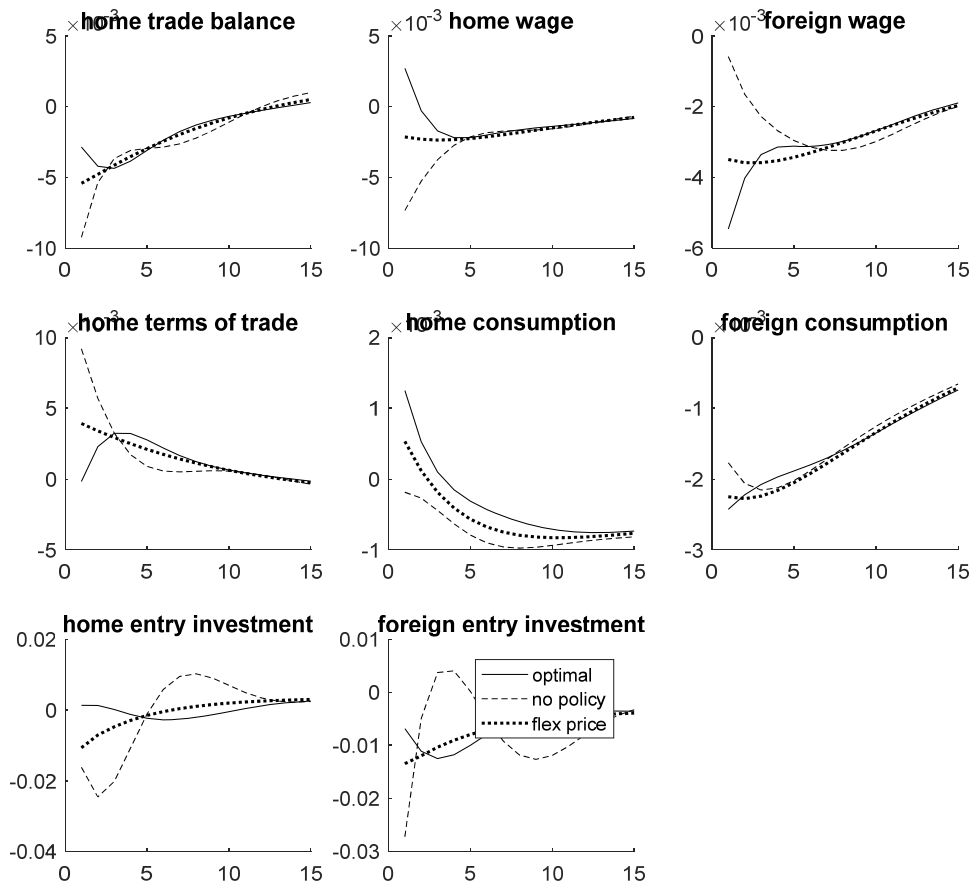
Vertical axis is percent deviation (0.01=1%) from steady state levels. Horizontal axis is time (in years).

Figure 3. 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).

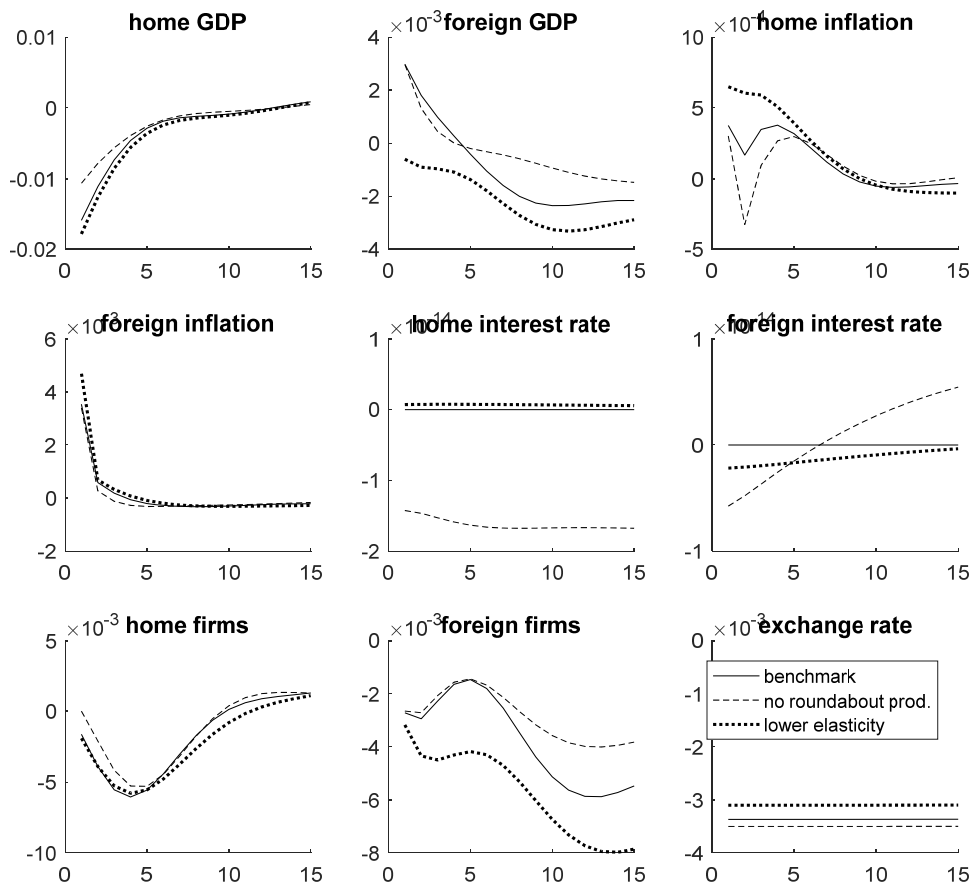
Figure 3 continued



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

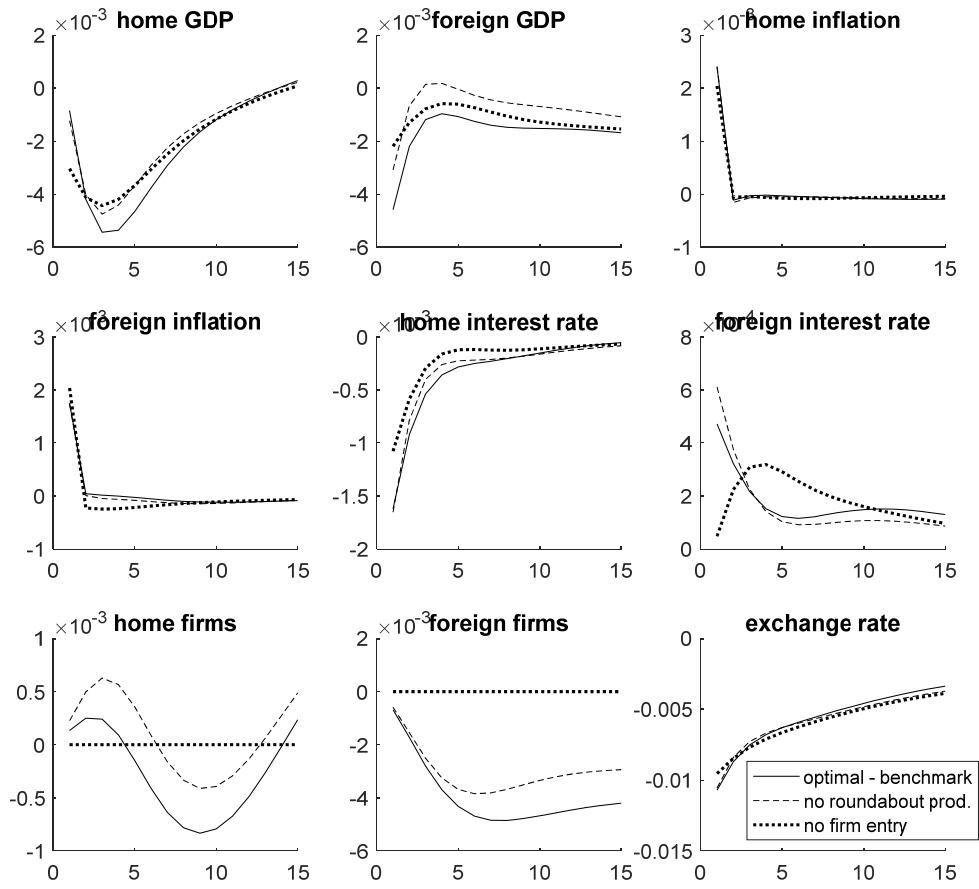


Figure 4. Impulse responses to a rise in foreign tariff on home exports, one-sector model, various model specifications



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

Figure 5. Impulse responses to a rise in foreign tariff on home exports, one-sector model, optimal policy for various model specifications



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

Figure 6. Impulse responses to a rise in foreign tariff, two-sector model

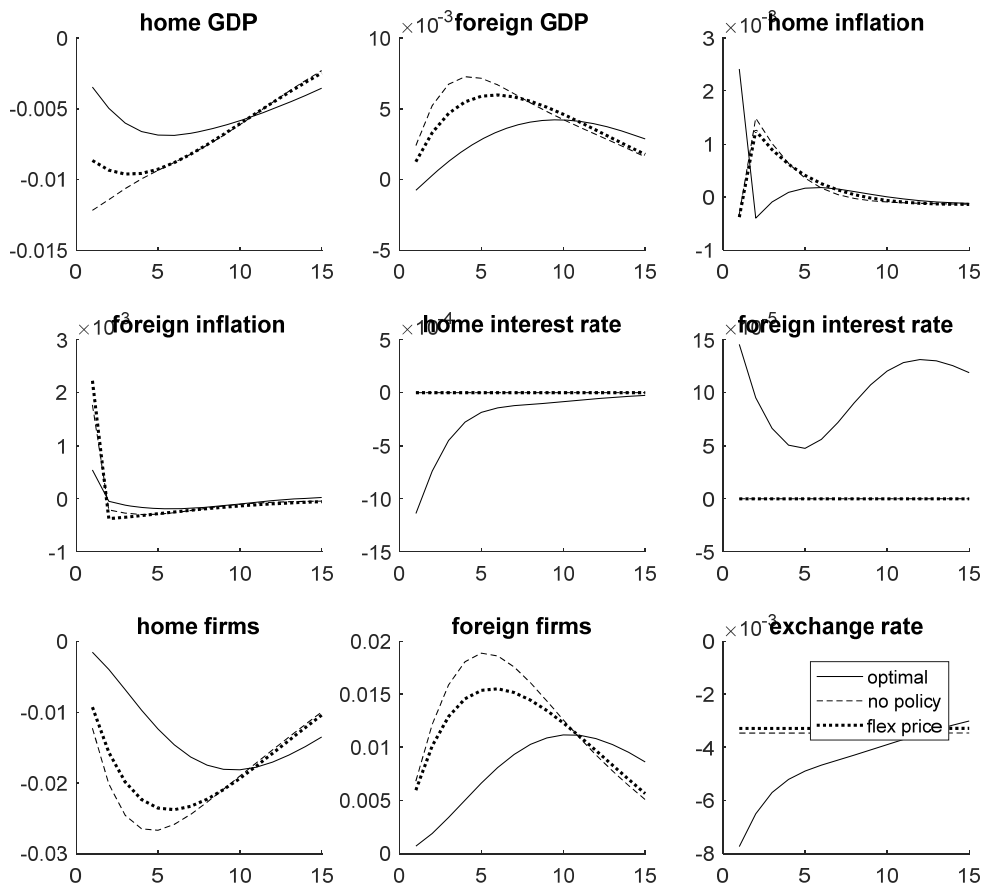
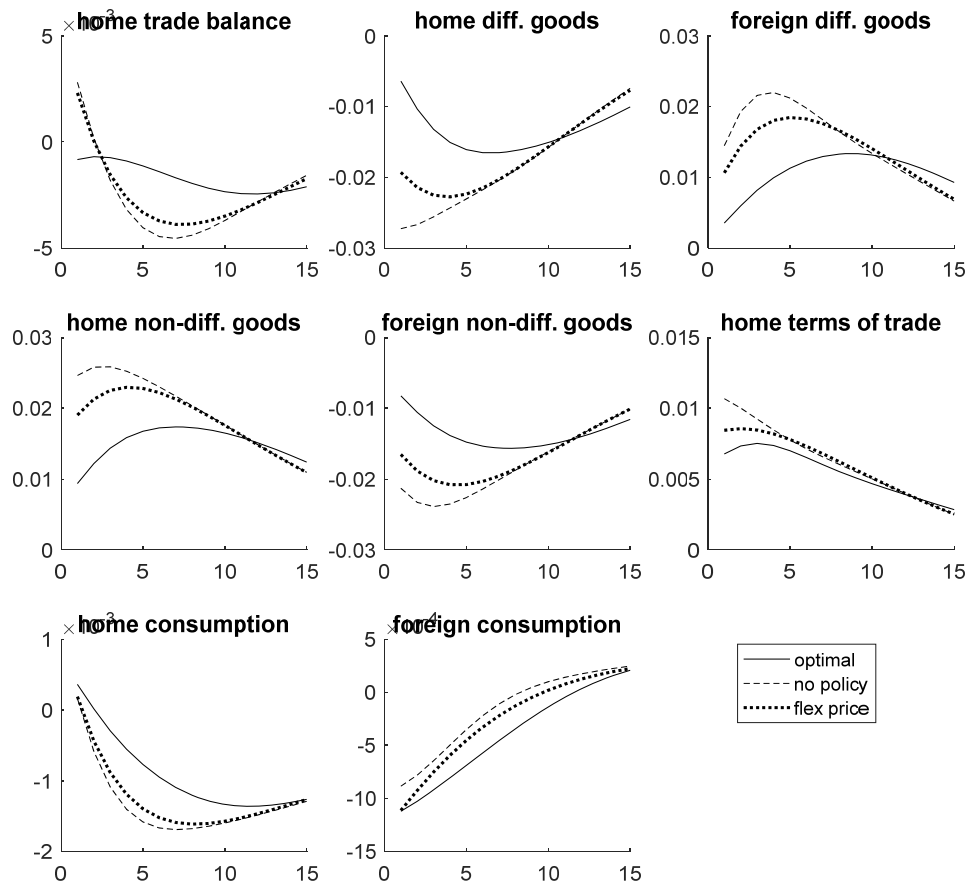
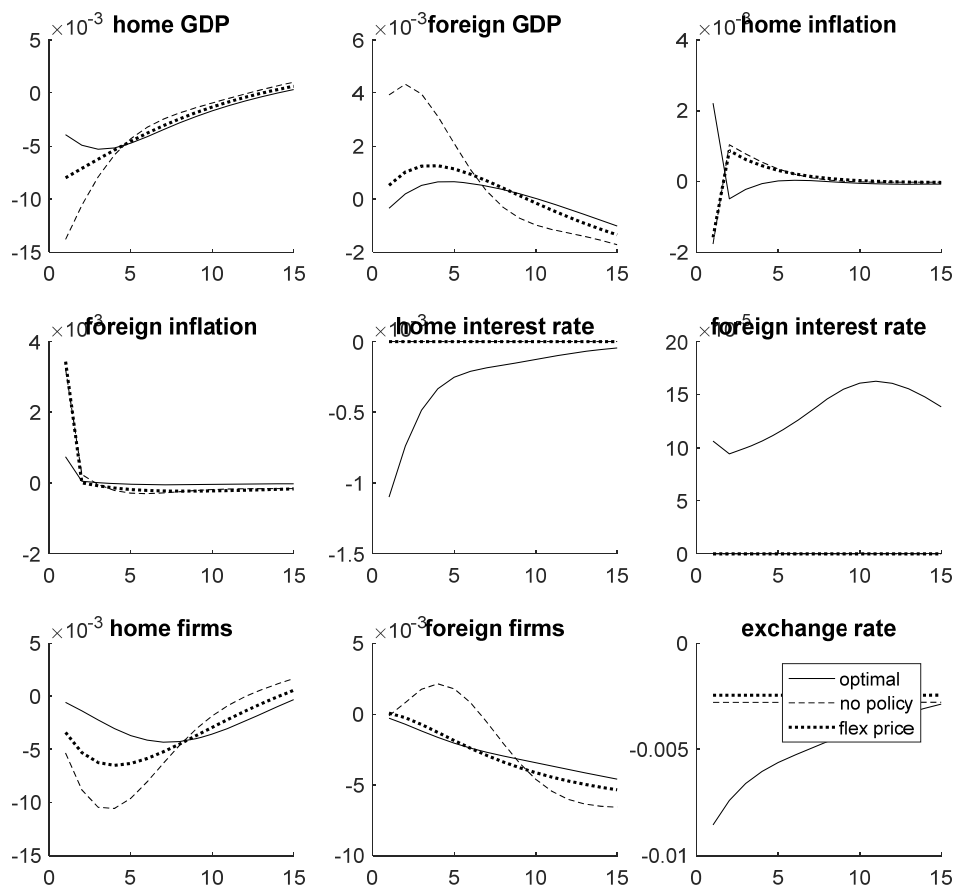


Figure 6 continued



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

Figure 7. Impulse responses to a rise in foreign tariff, two-sector model, one nontraded



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