Online Appendices

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

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Appendix A. Derivations for analytical model

This section derives the optimal monetary policy rule for the analytical model specified in section 2 of the main text.

1. Deriving firm price setting:

In this version of the simplified model, we also introduce taxes to represent price markup shocks, following Corsetti et al. (2010). For clarity, these taxes are not reported in the analytical results in the main text, since they cancel out of the optimal monetary policy rule in this simplified environment. We report this fact in the main text, and rely instead upon simulations of the general model to compare tariff shocks to the markup shocks. In particular, specify that a tax of $1-T_{MX,t}$ is levied on the home firm on each unit of export revenue, and a tax of $1-T_{MD,t}$ is levied on the home firm on each unit of domestic sales revenue. Tax revenue from taxes imposed on home firms is rebated back to the home household. The rest of the model is the same as specified in section 2 of the main text, including a tariff shock, where T_t represents the value of 1 plus the time-varying ad valorem tariff rate.

To derive optimal price setting under the assumption of producer currency pricing, maximize expected discounted profit computed as

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

where demands are $c_t(h)=\left(p_t(h)/P_{H,t}\right)^{-\phi}C_{H,t}$ and $c_t^*(h)=\left(p_t(h)T_t/P_{H,t}^*\right)^{-\phi}C_{H,t}^*$

and $C_{H,t}=\frac{1}{2}\frac{P_tC_t}{P_{H,t}}$, $C_{F,t}=\frac{1}{2}\frac{P_tC_t}{T_tP_{F,t}}$, $C_{Ht}^*=\frac{1}{2}\frac{e_tP_t^*}{T_t^*P_{Ht}}C_t^*=\frac{1}{2T_t^*}\frac{P_t}{P_{Ht}}C_t$, so $C_{Ht}^*=\frac{1}{T_t^*}C_{Ht}$.

Differentiating with respect to firm price:

$$E_{t-1}\beta\left[\frac{\mu_{t-1}}{\mu_t}\left(p_t(h)/P_{H,t}\right)^{-\phi}T_{MD,t}C_{H,t}\right]-E_{t-1}\beta\left[\phi\left(p_t(h)/P_{H,t}\right)^{-\phi-1}\frac{1}{P_{Ht}}\frac{\mu_{t-1}}{\mu_t}\left(p_t(h)T_{MD,t}-\frac{W_t}{\alpha_t}\right)C_{H,t}\right]$$
$$+E_{t-1}\beta\left[\frac{\mu_{t-1}}{\mu_t}\left(p_t(h)/P_{H,t}\right)^{-\phi}T_{MX,t}C^*{}_{H,t}\right]-E_{t-1}\beta\left[\phi\left(p_t(h)/P_{H,t}\right)^{-\phi-1}\frac{1}{P_{Ht}}\frac{\mu_{t-1}}{\mu_t}\left(p_t(h)T_{MX,t}-\frac{W_t}{\alpha_t}\right)C^*{}_{H,t}\right]=0$$

$$P_{Ht}=\frac{\phi}{\phi-1}\frac{E_{t-1}\left[\frac{1}{\mu_t}\frac{W_t}{\alpha_t}\left(C_{H,t}+C^*{}_{H,t}\right)\right]}{E_{t-1}\left[\frac{1}{\mu_t}\left(T_{MD,t}C_{H,t}+T_{MX,t}C^*{}_{H,t}\right)\right]}.$$

Substituting in demands

$$P_{Ht}=\frac{\phi}{\phi-1}\frac{E_{t-1}\left[\frac{1}{\mu_t}\frac{W_t}{\alpha_t}\left(\frac{1}{2}\frac{\mu_t}{P_{H,t}}+\frac{1}{2T_t^*}\frac{\mu_t}{P_{H,t}}\right)\right]}{E_{t-1}\left[\frac{1}{\mu_t}\left(\frac{1}{2}T_{MD,t}\frac{\mu_t}{P_{H,t}}+\frac{T_{MX,t}}{2T_t^*}\frac{\mu_t}{P_{H,t}}\right)\right]}.$$

Note that tariff enters the price-setting condition only through its effect on overall demand for home products. Simplifying:

$$P_{Ht}=\frac{\phi}{\phi-1}\frac{E_{t-1}\left[\left(1+\frac{1}{T_t^*}\right)\frac{\kappa\mu_t}{\alpha_t}\right]}{E_{t-1}\left[T_{MD,t}+\frac{T_{MX,t}}{T_t^*}\right]}. \tag{A1}$$

Price setting for foreign firm, by analogy:

$$P_{Ft}^*=\frac{\phi}{\phi-1}\frac{E_{t-1}\left[\left(1+\frac{1}{T_t}\right)\frac{\kappa\mu_t^*}{\alpha_t^*}\right]}{E_{t-1}\left[T_{MDt}^*+\frac{T_{MXt}^*}{T_t}\right]}. \tag{A2}$$

2. Deriving aggregate supply block

Write the resource constraint:

$$C_{Ht}+C_{Ht}^*=\alpha_t l_t \tag{A3}$$

$$C_{Ft}+C_{Ft}^*=\alpha_t^* l_t^*. \tag{A4}$$

Note tariff does not enter this resource constraint, since tariff revenue is rebated to domestic households, and does not use real resources. Substitute in demands into the home resource constraint:

$$\frac{1}{2}\frac{P_t}{P_{Ht}}C_t + \frac{1}{2T_t^*}\frac{P_t}{P_{Ht}}C_t = \alpha_t l_t,$$

so
$$2\alpha_t l_t P_{Ht}\left(1+\frac{1}{T_t^*}\right)^{-1} = P_t C_t = \mu_t.$$

Substituting in price setting:

$$2\alpha_t l_t \frac{\phi}{\phi-1}\frac{E_{t-1}\left[\left(1+\frac{1}{T_t^*}\right)\frac{\kappa\mu_t}{\alpha_t}\right]}{E_{t-1}\left[T_{MD,t}+\frac{T_{MX,t}}{T_t^*}\right]}\left(1+\frac{1}{T_t^*}\right)^{-1} = \mu_t.$$

Solving for labor:

$$l_t = \frac{\phi-1}{\phi}\frac{E_{t-1}\left[T_{MD,t}+\frac{T_{MX,t}}{T_t^*}\right]}{E_{t-1}\left[\left(1+\frac{1}{T_t^*}\right)\frac{\kappa\mu_t}{\alpha_t}\right]}\left(1+\frac{1}{T_t^*}\right)\frac{\mu_t}{2\alpha_t}. \qquad \text{(A5)}$$

3. Computing welfare:

Substitute solution for labor into welfare.

$$W_t = E_{t-1}\ln C_t - E_{t-1}\kappa l_t$$

$$= E_{t-1}\left[\ln\mu_t - \ln P_t\right] - E_{t-1}\left[\kappa\frac{\phi-1}{\phi}\frac{E_{t-1}\left[T_{MD,t}+\frac{T_{MX,t}}{T_t^*}\right]}{E_{t-1}\left[\left(1+\frac{1}{T_t^*}\right)\frac{\kappa\mu_t}{\alpha_t}\right]}\left(1+\frac{1}{T_t^*}\right)\frac{\mu_t}{2\alpha_t}\right]$$

$$W_t = E_{t-1}\left[\ln\mu_t\right] - E_{t-1}\left[\ln P_t\right] - \frac{\phi-1}{2\phi}E_{t-1}\left[T_{MD,t}+\frac{T_{MX,t}}{T_t^*}\right].$$

Recall the CPI price index as $P_t = 2P_{Ht}^{1/2}T_t^{1/2}e_t^{1/2}P_{Ft}^{1/2}$,

so

$$P_t = 2\left(\frac{\phi}{\phi-1}\frac{E_{t-1}\left[\left(1+\frac{1}{T_t^*}\right)\frac{\kappa\mu_t}{\alpha_t}\right]}{E_{t-1}\left[T_{MD,t}+\frac{T_{MX,t}}{T_t^*}\right]}\right)^{1/2}\left(\frac{\phi}{\phi-1}\frac{E_{t-1}\left[\left(1+\frac{1}{T_t}\right)\frac{\kappa\mu_t^*}{\alpha_t^*}\right]}{E_{t-1}\left[T_{MDt}^*+\frac{T_{MXt}^*}{T_t}\right]}\right)^{1/2}T_t^{1/2}e_t^{1/2}$$

$$P_t = 2\left(\frac{\phi}{\phi-1}\frac{E_{t-1}\left[\left(1+\frac{1}{T_t^*}\right)\frac{\kappa\mu_t}{\alpha_t}\right]}{E_{t-1}\left[\left(1+\frac{1}{T_t^*}\right)\right]}\right)^{1/2}\left(\frac{\phi}{\phi-1}\frac{E_{t-1}\left[\left(1+\frac{1}{T_t}\right)\frac{\kappa\mu_t^*}{\alpha_t^*}\right]}{E_{t-1}\left[\left(1+\frac{1}{T_t}\right)\right]}\right)^{1/2} T_t^{1/2}\left(\frac{\mu_t}{\mu_t^*}\right)^{1/2}.$$

Substitute into welfare:

$$W_t = E_{t-1}\left[\ln\mu_t\right] - E_{t-1}\left[\ln\left(2\frac{\phi}{\phi-1}\left(\frac{E_{t-1}\left[\left(1+\frac{1}{T_t^*}\right)\frac{\kappa\mu_t}{\alpha_t}\right]}{E_{t-1}\left[T_{MD,t}+\frac{T_{MX,t}}{T_t^*}\right]}\right)^{1/2}\left(\frac{E_{t-1}\left[\left(1+\frac{1}{T_t}\right)\frac{\kappa\mu_t^*}{\alpha_t^*}\right]}{E_{t-1}\left[T_{MDt}^*+\frac{T_{MXt}^*}{T_t}\right]}\right)^{1/2} T_t^{1/2}\left(\frac{\mu_t}{\mu_t^*}\right)^{1/2}\right)\right]$$
$$-\frac{\phi-1}{2\phi}E_{t-1}\left[T_{MD,t}+\frac{T_{MX,t}}{T_t^*}\right]$$

$$W_t = E_{t-1}\left[\ln\mu_t\right] - \ln\left(2\frac{\phi}{\phi-1}\right) - \frac{1}{2}\ln E_{t-1}\left[\left(1+\frac{1}{T_t^*}\right)\frac{\kappa\mu_t}{\alpha_t}\right] + \frac{1}{2}\ln E_{t-1}\left[T_{MD,t}+\frac{T_{MX,t}}{T_t^*}\right] - \frac{1}{2}\ln E_{t-1}\left[\left(1+\frac{1}{T_t}\right)\frac{\kappa\mu_t^*}{\alpha_t^*}\right]$$
$$+\frac{1}{2}\ln E_{t-1}\left[T_{MDt}^*+\frac{T_{MXt}^*}{T_t}\right] - \frac{1}{2}E_{t-1}\left[\ln\left(T_t\right)\right] - \frac{1}{2}E_{t-1}\left[\ln\mu_t\right] + \frac{1}{2}E_{t-1}\left[\ln\mu_t^*\right] - \frac{\phi-1}{2\phi}E_{t-1}\left[T_{MD,t}+\frac{T_{MX,t}}{T_t^*}\right]$$

By analogy the foreign counterpart is:

$$W_t^* = E_{t-1}\left[\ln\mu_t^*\right] - \ln\left(2\frac{\phi}{\phi-1}\right) - \frac{1}{2}\ln E_{t-1}\left[\left(1+\frac{1}{T_t}\right)\frac{\kappa\mu_t^*}{\alpha_t^*}\right] + \frac{1}{2}\ln E_{t-1}\left[T_{MD,t}^*+\frac{T_{MX,t}^*}{T_t}\right] - \frac{1}{2}\ln E_{t-1}\left[\left(1+\frac{1}{T_t^*}\right)\frac{\kappa\mu_t}{\alpha_t}\right]$$
$$+\frac{1}{2}\ln E_{t-1}\left[T_{MDt}+\frac{T_{MXt}}{T_t^*}\right] - \frac{1}{2}E_{t-1}\left[\ln\left(T_t^*\right)\right] - \frac{1}{2}E_{t-1}\left[\ln\mu_t^*\right] + \frac{1}{2}E_{t-1}\left[\ln\mu_t\right] - \frac{\phi-1}{2\phi}E_{t-1}\left[T_{MD,t}^*+\frac{T_{MX,t}^*}{T_t}\right]$$

4. Optimal policy

To find the optimal policy in a Nash equilibrium, differentiate home welfare with respect to home policy stance, μ:

$$\frac{1}{\mu_t} - \frac{\left(1+\frac{1}{T_t^*}\right)\frac{\kappa}{\alpha_t}}{2E_{t-1}\left[\left(1+\frac{1}{T_t^*}\right)\frac{\kappa\mu_t}{\alpha_t}\right]} - \frac{1}{2\mu_t} = 0$$

$$\left(1+\frac{1}{T_t^*}\right)\frac{\mu_t}{\alpha_t} = E_{t-1}\left[\left(1+\frac{1}{T_t^*}\right)\frac{\mu_t}{\alpha_t}\right].$$

Conjecture the solution: $\mu_t = a\alpha_t\left(1+\frac{1}{T_t^*}\right)^{-1}$ for some constant a.

Verify the solution:

$$\left(1+\frac{1}{T_t^*}\right)\frac{a\alpha_t\left(1+\frac{1}{T_t^*}\right)^{-1}}{\alpha_t}=E_{t-1}\left[\left(1+\frac{1}{T_t^*}\right)\frac{a\alpha_t\left(1+\frac{1}{T_t^*}\right)^{-1}}{\alpha_t}\right]$$

$$a=E_{t-1}[a].$$

Confirmed.

The interpretation of this optimal policy is provided in the main text. We note here, in addition, that the price markup shocks, $T_{MD,t}$ and $T_{MX,t}$, have no bearing on optimal monetary policy in this simplified environment of one-period price predetermination.

By analogy, the solution for foreign optimal policy is:

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

To find the cooperative optimal policy, differentiate the average of home and foreign welfare with respect to both home and foreign policy stances, μ and μ_t^*. These derivatives are identical to those in the Nash case, since under the specification of preferences assumed, the home policy stance variable enters the combined welfare function multiplied only by domestic α and tariff on its exports, T_t^*. This indicates that optimal polices are the same in as the cooperative case as the Nash case.

Applying the monetary stance specification to Eq. (A5) we can derive labor under optimal monetary policy:

$$l_t=\frac{\phi-1}{\phi}E_{t-1}\left[T_{MD,t}+\frac{T_{MX,t}}{T_t^*}\right]\frac{1}{2\kappa}$$

which is constant and does not fluctuate with a tariff. Substituting labor into the production function we solve for output:

$$Y_{Ht}=\frac{\phi-1}{\phi}E_{t-1}\left[T_{MD,t}+\frac{T_{MX,t}}{T_t^*}\right]\frac{\alpha_t}{2\kappa}$$

which does fluctuate with productivity shocks, but again, does not fluctuate with tariff shocks.

5. 'No policy' allocation

Suppose a policy stance of $\mu = 1$. Substitute this into the supply block Eq. (A5):

$$l_t = \frac{\phi - 1}{\phi} \frac{E_{t-1}\left[T_{MD,t} + \frac{T_{MX,t}}{T_t^*} \right]}{E_{t-1}\left[\left(1 + \frac{1}{T_t^*} \right) \frac{\kappa \mu_t}{\alpha_t} \right]} \left(1 + \frac{1}{T_t^*} \right) \frac{1}{2\alpha_t}.$$

And use the production function to find output:

$$Y_{H,t} = \frac{\phi - 1}{2\phi} \frac{E_{t-1}\left[T_{MD,t} + \frac{T_{MX,t}}{T_t^*} \right]}{E_{t-1}\left[\left(1 + \frac{1}{T_t^*} \right) \frac{\kappa \mu_t}{\alpha_t} \right]} \left(1 + \frac{1}{T_t^*} \right),$$

which shows that when a tariff increase dampens foreign demand for home goods, home output falls.

6. Social planner allocation

For comparison, now suppose a social planner that maximizes

$$\frac{1}{2}\left(U_t + U_t^* \right) = \frac{1}{2}\left(\ln C_t - \kappa L_{Ht} + \ln C_t^* - \kappa L_{Ft}^* \right) = \frac{1}{2}\left(\frac{1}{2} \ln C_{H.t} + \frac{1}{2} \ln C_{F.t} - \kappa L_{Ht} + \frac{1}{2} \ln C_{H.t}^* + \frac{1}{2} \ln C_{F.t}^* - \kappa L_{Ft}^* \right)$$

subject only to the resource constraints (A3) and (A4). Note that tariff does not enter the constraints for this problem since they are rebated and hence have no real resource cost. The first order conditions with respect to $C_{H.t}$ and $C_{H.t}^*$ are

$$C_{H.t} = \frac{\alpha_t}{2\kappa}$$

$$C_{H.t}^* = \frac{\alpha_t}{2\kappa}.$$

Substituting back into the (A3), efficient production and labor are specified as:

$$y_{H.t} = \frac{\alpha_t}{\kappa}$$

$$l_{H.t} = \frac{1}{\kappa}.$$

So it is efficient for production not to change in response to a change in tariff. See the text for discussion and comparison with alternative policies.

Appendix B. Additional equations from the full model not listed in text

This appendix lists equilibrium conditions for the full model not listed in section 3 of the main text.

1. demand conditions

The composition of expenditure on adjustment costs, both for prices and bond holding, follows the same preferences as for consumption, and the associated demands mirror Eqs. (16)-(17). Adjustment costs for bond holding are as follows:

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

$$d_{AC,B,t}(f) = \left(p_t(f)T_t/P_t\right)^{-\phi} AC_{B,t}.$$

The economy-wide demand for goods arising from price adjustment costs sums across the demand arising among n_{t-1} home firms: $AC_{P,t} = n_{t-1}AC_{P,t}(h)$. This is allocated as follows:

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

$$d_{AC,P,t}(f) = \left(p_t(f)T_t/P_t\right)^{-\phi} AC_{P,t}.$$

The demand for varieties for use as intermediates in production also mirrors Eqs. (16)-(17):

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

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

Similarly, the demand for varieties for use in the sunk entry investment of new firms is:

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

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

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

Labor market clearing requires:

$$\int_0^{n_t} l_t(h)dh = l_t.$$

Bond market clearing requires:

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

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

Balance of payments requires:

$$\int_0^{n_t} p_t^*(h)\left(d^*{}_t(h)\right)dh - \int_0^{n_t^*} p_t(f)\left(d_t(f)\right)df - i_{t-1}B^*_{H,t-1} + e_t i^*{}_{t-1}B_{F,t-1} = \left(B^*_{H,t} - B^*_{H,t-1}\right) + e_t\left(B_{F,t} - B_{F,t-1}\right).$$

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

$$\begin{bmatrix} \log T_t - \log \overline{T} \\ \log T_t^* - \log \overline{T^*} \end{bmatrix} = \rho_T \begin{bmatrix} \log T_{t-1} - \log \overline{T} \\ \log T_{t-1}^* - \log \overline{T^*} \end{bmatrix} + \varepsilon_{Tt}$$

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

$$\begin{bmatrix} \log \alpha_t - \log \overline{\alpha} \\ \log \alpha_t^* - \log \overline{\alpha^*} \end{bmatrix} = \rho_A \begin{bmatrix} \log \alpha_{t-1} - \log \overline{\alpha} \\ \log \alpha_{t-1}^* - \log \overline{\alpha^*} \end{bmatrix} + \varepsilon_{At}$$

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

In the case of markup shocks:

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

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

Under the assumption that firms set separate prices in the two markets, in units of domestic currency for sale in the domestic market, and in units of foreign currency for sale in the foreign market, the price setting equations (Eqs. 31-32) are replaced by the following:

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

and

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

where $\Omega_{H,s} = \left(\frac{p_s(h)}{P_s} \right)^{-\phi} \left(C_s + G_s + n e_s (1-\theta_K) K_s + AC_{P,s} + AC_{B,s} \right) \frac{1}{\mu_s}$, and

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

5. Modifications of model for alternative versions of markup shock

To specify that markup shocks only affect export prices, the firm budget constraint (28) is modified as follows:

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

which implies that the price setting equation for domestic sales (31) does not include a markup shock, but the equation for exports (32) does, as follows:

$$p^*_t(h) = \frac{\phi}{(\phi-1) T_{MU,t}} \frac{(1+\tau) mc_t}{e_t} + \frac{\psi_P}{2} \left(\frac{p^*_t(h)}{p^*_{t-1}(h)} - 1 \right)^2 p^*_t(h) - \psi_P \frac{1}{\phi - 1} \left(\frac{p^*_t(h)}{p^*_{t-1}(h)} - 1 \right) \frac{p^*_t(h)^2}{p^*_{t-1}(h)}$$
$$+ \frac{\psi_P}{\phi - 1} E_t \left[\beta \frac{\Omega^*_{t+1}}{\Omega^*_t} \left(\frac{p^*_{t+1}(h)}{p^*_t(h)} - 1 \right) \frac{p^*_{t+1}(h)^2}{p^*_t(h)} \right]$$

In addition, the government budget constraint (35) becomes:

$$\Gamma_t = (M_t - M_{t-1}) + (T_t - 1) n^*_{t-1} d_t(f) + (1 - T_{MU,t}) n^*_{t-1} d_t(f).$$

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

$$\Gamma_t = (M_t - M_{t-1}) + (T_t - 1) n^*_{t-1} d_t(f) + (1 - T^*_{MU,t}) n_{t-1} d^*_t(h).$$

Finally, specifying that markup shocks for exports are placed outside of price stickiness implies the price setting rule (32) becomes the following (conditional on maintaining the specification above that markup shocks do not affect domestic prices):

$$p^*_t(h) = \frac{(1+\tau)}{e_t T_{MU,t}} p_t(h).$$

Appendix C. Model with wage stickiness

Suppose monopolistic suppliers of differentiated labor indexed by *h* on the unit interval, where the overall demand for labor by firm *i* is an aggregate over labor varieties *h*:

$$L_t(i) = \left(\int_0^1 l_t(h,i)^{\frac{1}{1+\eta}} \right)^{1+\eta} dh \cdot$$

This implies demand for labor variety *h*:

$$l_t(h,i) = L_t(i) \left(\frac{w_t(h)}{W_t} \right)^{-\frac{1+\eta}{\eta}} dh \cdot$$

Labor suppliers choose their wage subject to this demand and a cost of adjusting labor:

$$AC_{W,t}(h) = \frac{\psi_W}{2} \frac{\left(w_t(h) - w_{t-1}(h) \right)^2}{w_{t-1}(h)} \, l_t(h) \cdot$$

The home household optimization problem becomes:

$$\max E_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{1-\sigma} C_t^{1-\sigma} + \ln \frac{M_t}{P_t} - \frac{1}{1+\psi} \left(l_t \left(\frac{W_t(h)}{W_t} \right)^{-\frac{1+\eta}{\eta}} \right)^{1+\psi}$$

subject to

$$P_t C_t + \left(M_t - M_{t-1} \right) + \left(B_{Ht} - B_{Ht-1} \right) + e_t \left(B_{Ft} - B_{Ft-1} \right)$$

$$= W_t l_t \left(\frac{W_t(h)}{W_t} \right)^{\frac{1+\eta}{\eta}} + \Pi_t + i_{t-1} B_{Ht-1} + i_{t-1}^* B_{Ft-1} - P_t AC_{Bt} - \frac{\psi_W}{2} \frac{\left(w_t(h) - w_{t-1}(h) \right)^2}{w_{t-1}(h)} \, l_t(h) + \Gamma_t$$

This implies the following wage setting condition:

$$E_t \left[\beta \left(\frac{C_{t+1}^{-\sigma}}{P_{t+1}} \Big/ \frac{C_t^{-\sigma}}{P_t} \right) \frac{l_{t+1}}{l_t} \frac{\psi_W}{2} \left(\frac{W_{t+1}^2}{W_t^2} - 1 \right) \right] - \psi_W \left(\frac{W_t}{W_{t-1}} - 1 \right) + \frac{1+\eta}{\eta} \left(\frac{l_t^{\psi} C_t^{\sigma}}{W_t / P_t} + \frac{\psi_W}{2} \frac{\left(W_t - W_{t-1} \right)^2}{W_t W_{t-1}} - 1 \right) = 0 \cdot$$

Calibration of benchmark wage stickiness parameters mimics that of price stickiness, with η =5.2 and ψ_W =49, though a version with extreme wage stickiness will also be considered, ψ_W =10000.

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

In this section, we investigate the sensitivity of our results to the degree of pass-through of tariffs to consumer prices. The motivation for 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.

1. Empirical motivation for low tariff pass-through

The empirical literature on tariff pass-through has flourished after 2016, due to the combined effects of Brexit and the aggressive trade initiatives by the Trump administration. Based on regressions of U.S. import price indexes controlling for inflation, Cavallo et al. (2021) 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. (2021) 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.[1]

[1] Cavallo et al. (2021) 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.

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 sticky-price model with constant money growth, we find that exporters lower the ex-tariff price by 2.4%, implying pass-through of the tariff to the import price at the dock is 97.6%.[2]

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 consumer price index in the foreign country (which includes both domestic and imported varieties) is a modest 17.5%, owing largely to home bias in this sector.[3] This compares favorably with the pass-through to consumer prices Flaaen et al. (2020) estimate for 2016 China duties, and even is lower than the pass–through the same authors estimate for the 2018 tariffs. However, it is higher than the values (close to zero) estimated in Cavallo et al. (2021).

2. Modified model with distribution

Hereafter, to account for a moderate degree of tariff pass-through at consumer level, we model the incidence of local production inputs and/or distribution on the price of imports faced by consumers. We extend the model in the spirit of Corsetti and Dedola (2005), positing that, realistically, consumers do not purchase imported varieties directly from producers. Consumer goods combine imported goods with domestic labor and domestic goods as inputs. Analytically, we now specify the consumption index without the direct inclusion of imported varieties: $C_t \equiv \left(\int_0^{n_t} c_t(h)^{\frac{\phi-1}{\phi}} dh \right)^{\frac{\phi}{\phi-1}}$, and correspondingly change in the consumer price indexes and demand equations in the main text (Eqs. 14-15) as follows:

[2] 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: $\hat{P}_t^* = \left(\bar{n} \left(p_t^*(h) T_t^* \right)^{1-\phi} \right)^{\frac{1}{1-\phi}} = \bar{n}^{\frac{1}{1-\phi}} p_t^*(h) T_t^*$. The percentage change from steady state for this index will be identical to that simply of the foreign import price of a representative home variety: $p_t^*(h) T_t^*$.

[3] Price stickiness in local currency (LCP) does not reduce tariff pass-through in the model, since, as noted above, tariffs are imposed directly on the importer.

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

$$c_t(f) = 0,$$

where we define additional price indexes specific to consumption:

$$P_t^C = \left(n_t p_t(h)^{1-\phi} \right)^{\frac{1}{1-\phi}}$$

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

3. Simulation results for modified model with low tariff pass-through

This version of the model is able to reconcile the empirical evidence of a near zero pass-through to consumers, with a near perfect pass-through at the dock. Simulating a foreign tariff shock on home exports with a constant money growth policy rule, we find that pass-through at the dock is 97.9% for a given imported variety; pass-through to the consumer price index of is actually negative, and equal to -19.5%, in the initial period of the shock. Under a suboptimal constant money growth rule, the tariff has the counterintuitive effect of lowering the prices of goods faced by consumers, since, for lack of stabilization, the economic slow-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 20.4%.

Simulation results are reported in Appendix Figure 9 (unilateral shock) and Appendix Figure 10 (symmetric shock). In our distribution-augmented model, the optimal policy and macroeconomic dynamics in response are close to our baseline---i.e., it is only moderately affected by the degree of tariff pass-through to consumer prices. Relative to our baseline, a low pass-through to consumer prices only slightly dampens the transmission of the shock to GDP and the interest rate change mandated by optimal policy.

Key to this remarkable result is the use of imports as intermediates. Even if the tariff does not impact consumer prices on a one-to-one basis, it still has large effects on GDP and other macroeconomic aggregates through the demand for imported intermediate goods by domestic producers. Consequently, the optimal policy calls for a similarly strong expansionary

response to moderate the macroeconomic effects of the tariff (comparing Appendix Figure 9 to Figure 4 in the main text). Results are similar in the symmetric tariff war scenario (comparing Appendix Figure 10 to Figure 1 in the main text). 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.

Appendix Table 1. Moments of variables and welfare: Foreign tariff shock, Comparing Taylor Rule policy to Ramsey

	home	foreign
standard deviations in percent (difference from Ramsey case)		
GDP	3.04	0.67
employment	2.43	0.47
consumption	-0.28	-0.13
firm entry investment	-5.85	-5.03
number of firms	-1.12	-0.78
inflation	-0.24	0.31
real exch. rate	-0.73	--
unconditional means of variables (percent change from Ramsey case)		
GDP	0.510	0.024
employment	0.050	0.067
consumption	-0.074	-0.044
firm entry investment	-0.391	-0.333
number of firms	-0.419	-0.340
Welfare (percent change from Ramsey case, conditional, in consumption units):		
	-0.165	-0.181

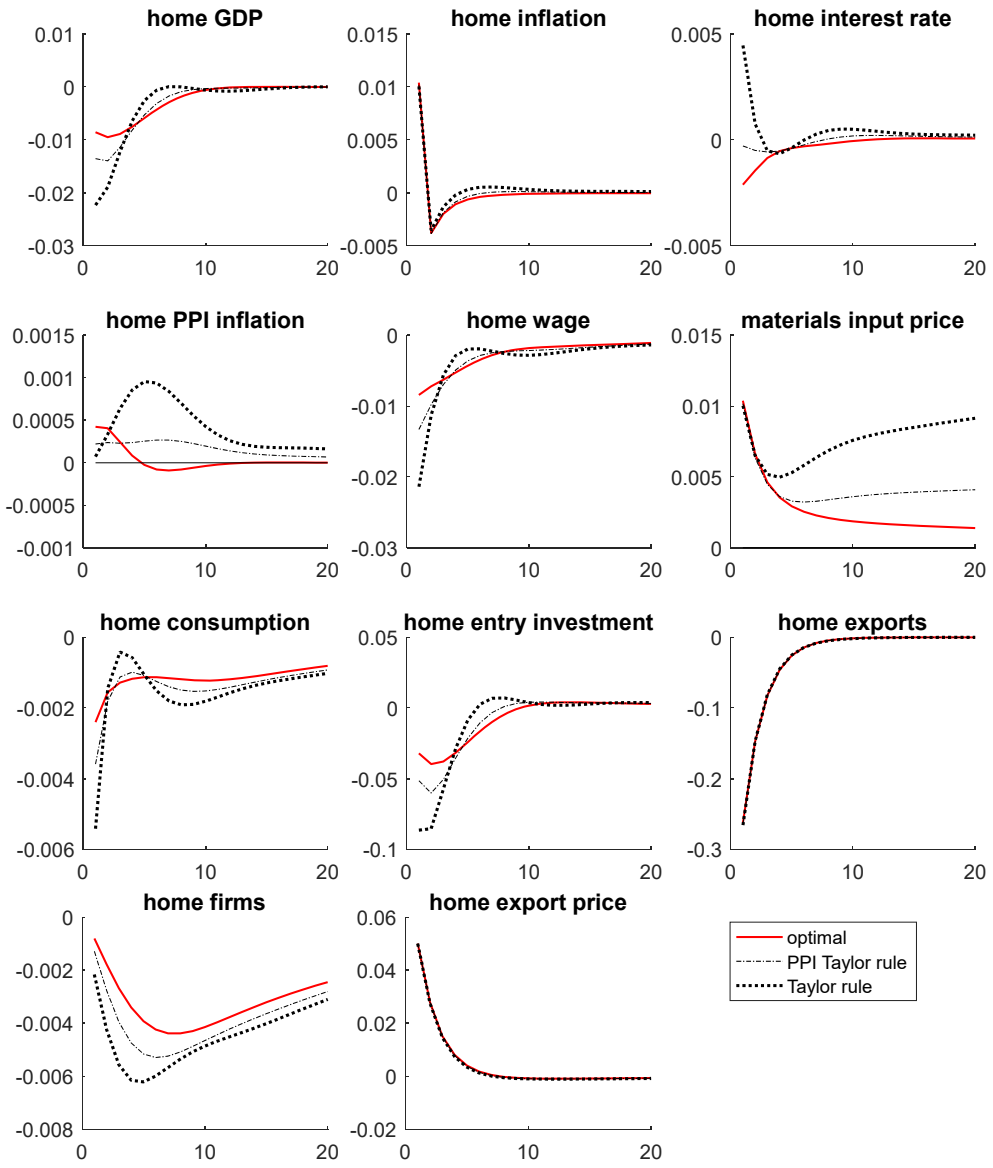
Appendix Table 2. Moments of variables and welfare: LCP version.
Comparing Taylor Rule policy to Ramsey

	Common shock	Independent shock
standard deviations in percent (difference from Ramsey case)		
GDP	1.49	0.84
employment	1.07	0.49
consumption	0.22	-0.13
firm entry investment	4.89	-3.60
number of firms	0.42	-0.79
inflation	-0.05	0.03
real exch. rate	0.00	-0.79
unconditional means of variables (percent change from Ramsey case)		
GDP	0.047	0.019
employment	0.025	0.042
consumption	-0.014	-0.067
firm entry investment	-0.053	-0.280
number of firms	-0.053	-0.280
Welfare (percent change from Ramsey case, conditional, in consumption units):		
	-0.100	-0.172

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

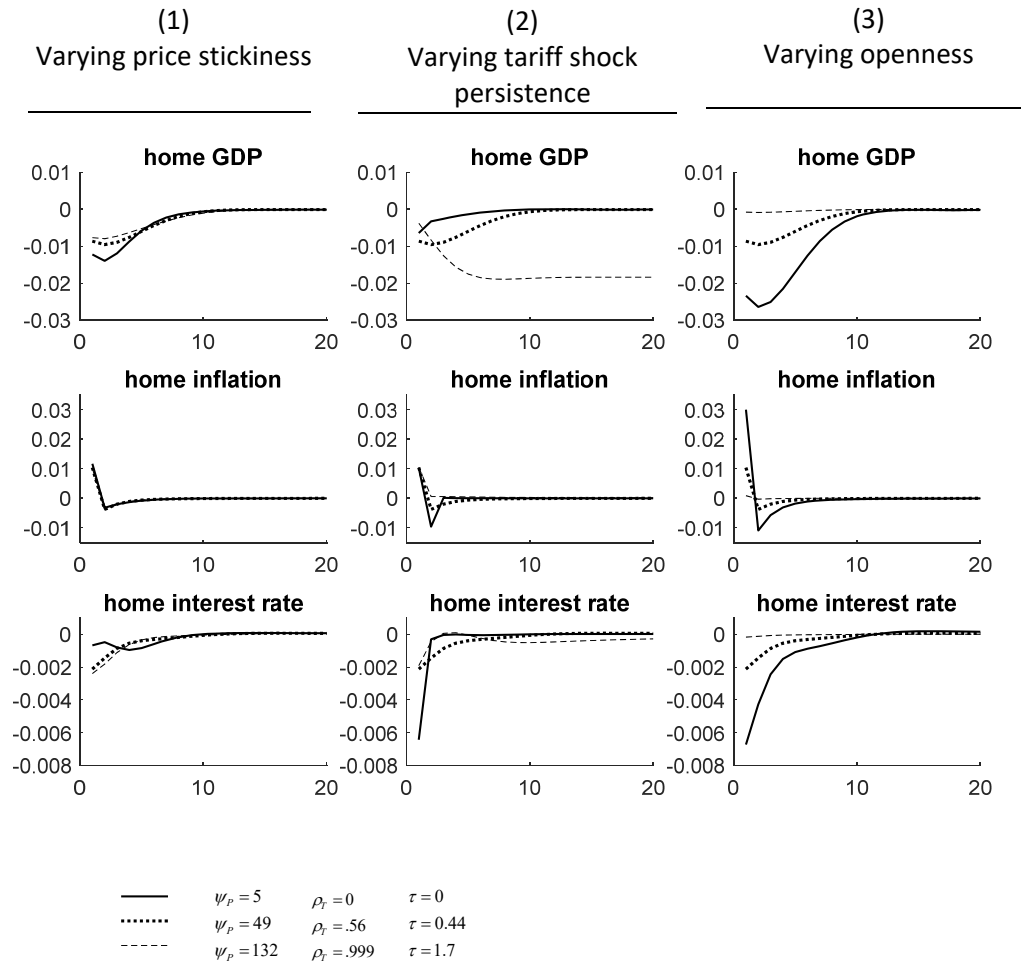
	common shock		independent shock	
	home	foreign	home	foreign
standard deviations in percent (difference from Ramsey case)				
GDP	2.72	0.01	2.29	1.50
employment	1.36	-0.06	1.82	1.57
consumption	0.36	0.03	-0.33	-0.34
firm entry investment	9.71	-2.17	-9.98	-10.56
number of firms	0.97	-0.59	-1.71	-1.81
inflation	-0.08	0.18	0.03	0.32
real excn. rate	-0.89	-0.89	-1.51	-1.51
unconditional means of variables (percent change from Ramsey case)				
GDP	0.084	0.000	0.054	-0.023
employment	0.063	0.055	0.078	0.093
consumption	0.011	-0.034	-0.123	-0.089
firm entry investment	0.063	-0.300	-0.817	-0.462
number of firms	0.063	-0.300	-0.817	-0.462
Welfare (percent change from Ramsey case, conditional, in consumption units):				
	-0.064	-0.199	-0.278	-0.308

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



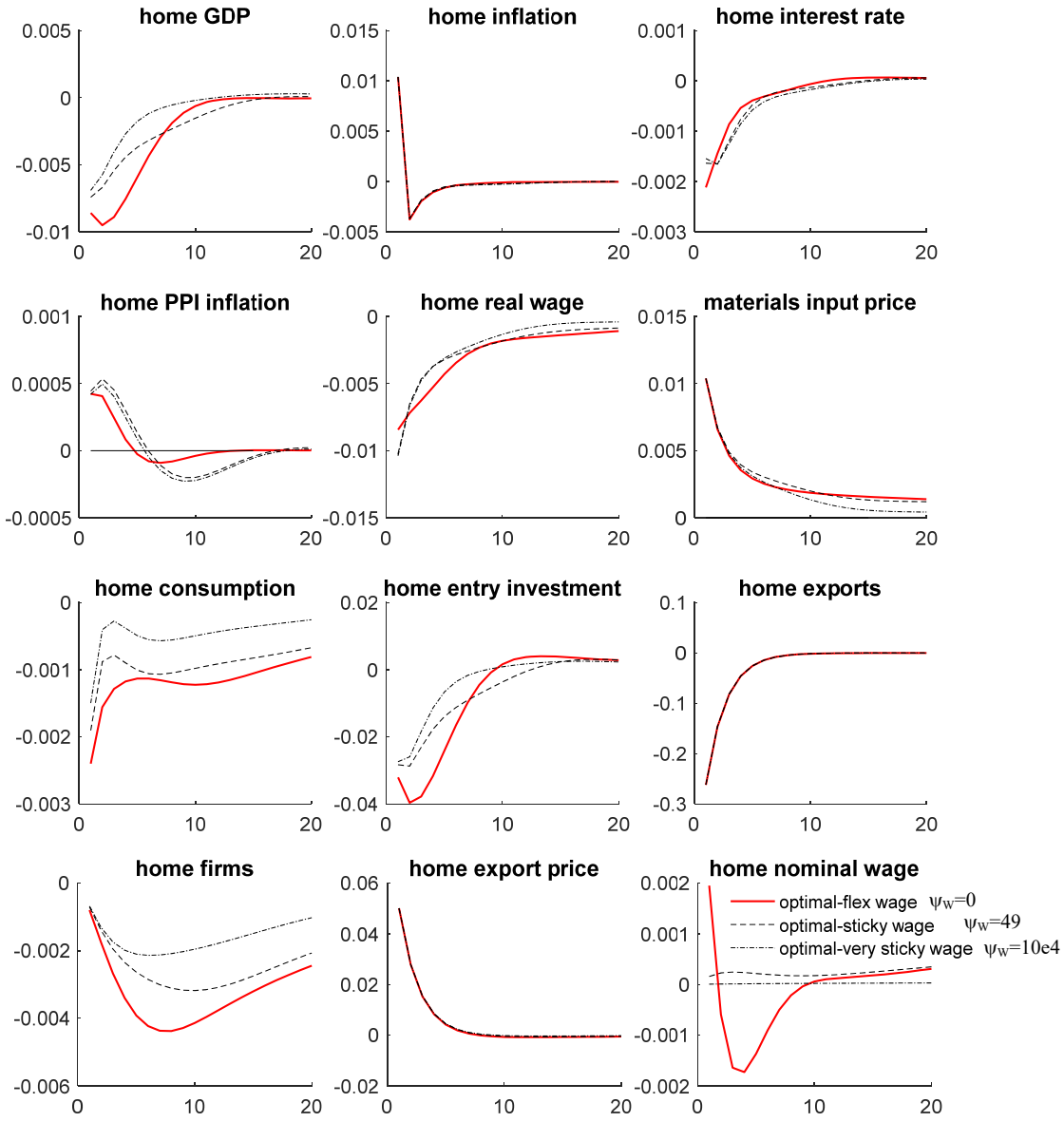
Vertical axis is percent deviation (0.01=1%) from steady state levels. Horizontal axis is time (in quarters).

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



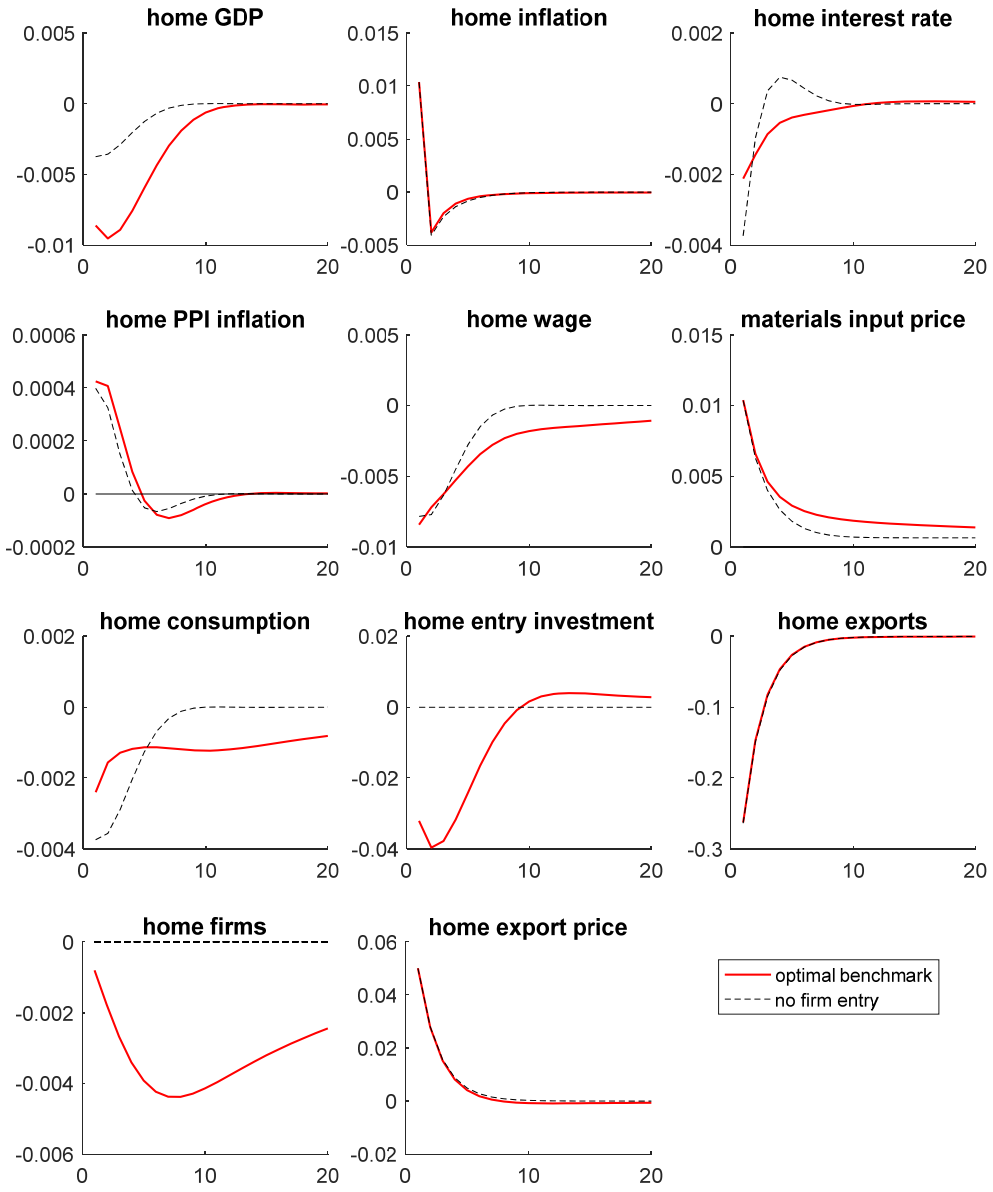
Vertical axis is percent deviation (0.01=1%) from steady state levels. Horizontal axis is time (in quarters).

Appendix Figure 3. Wage stickiness: impulse responses to a symmetric tariff shock



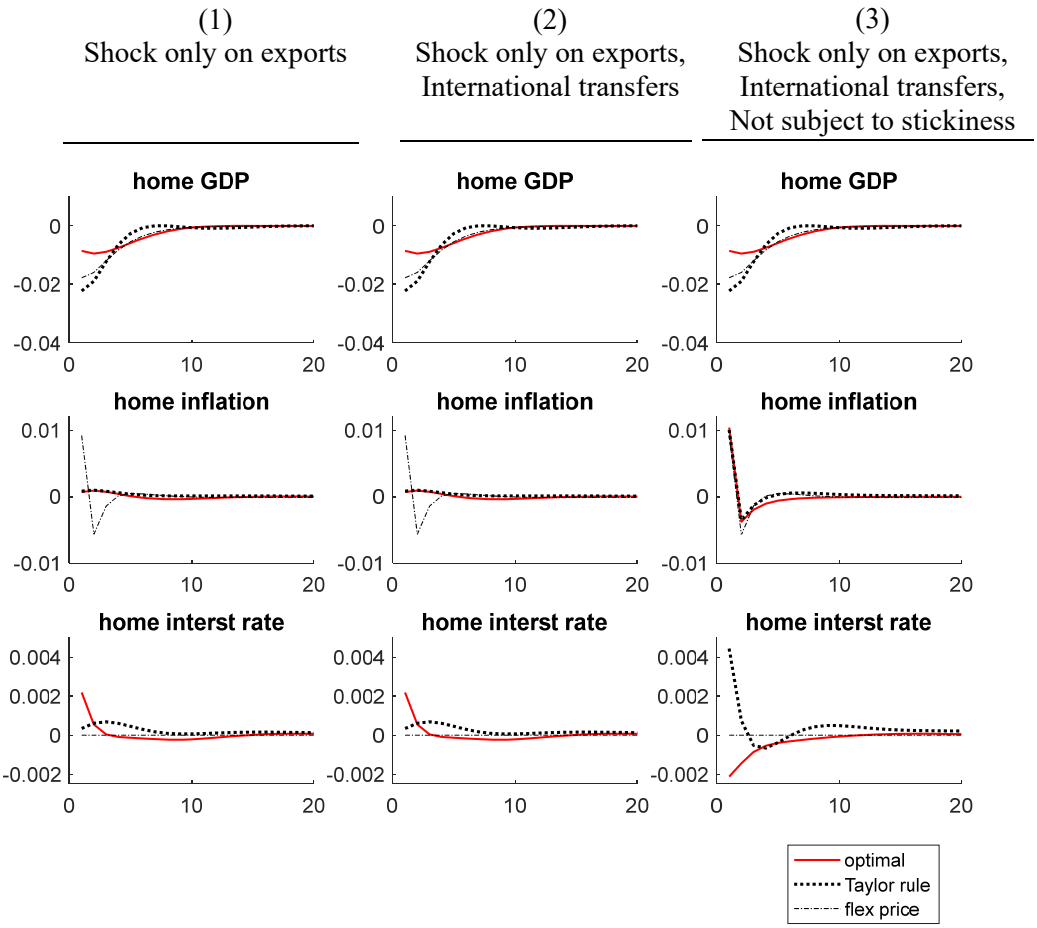
Vertical axis is percent deviation (0.01=1%) from steady state levels. Horizontal axis is time (in quarters).

Appendix Figure 4. Impulse responses to a rise in tariff in both countries, optimal policy for case with no firm entry



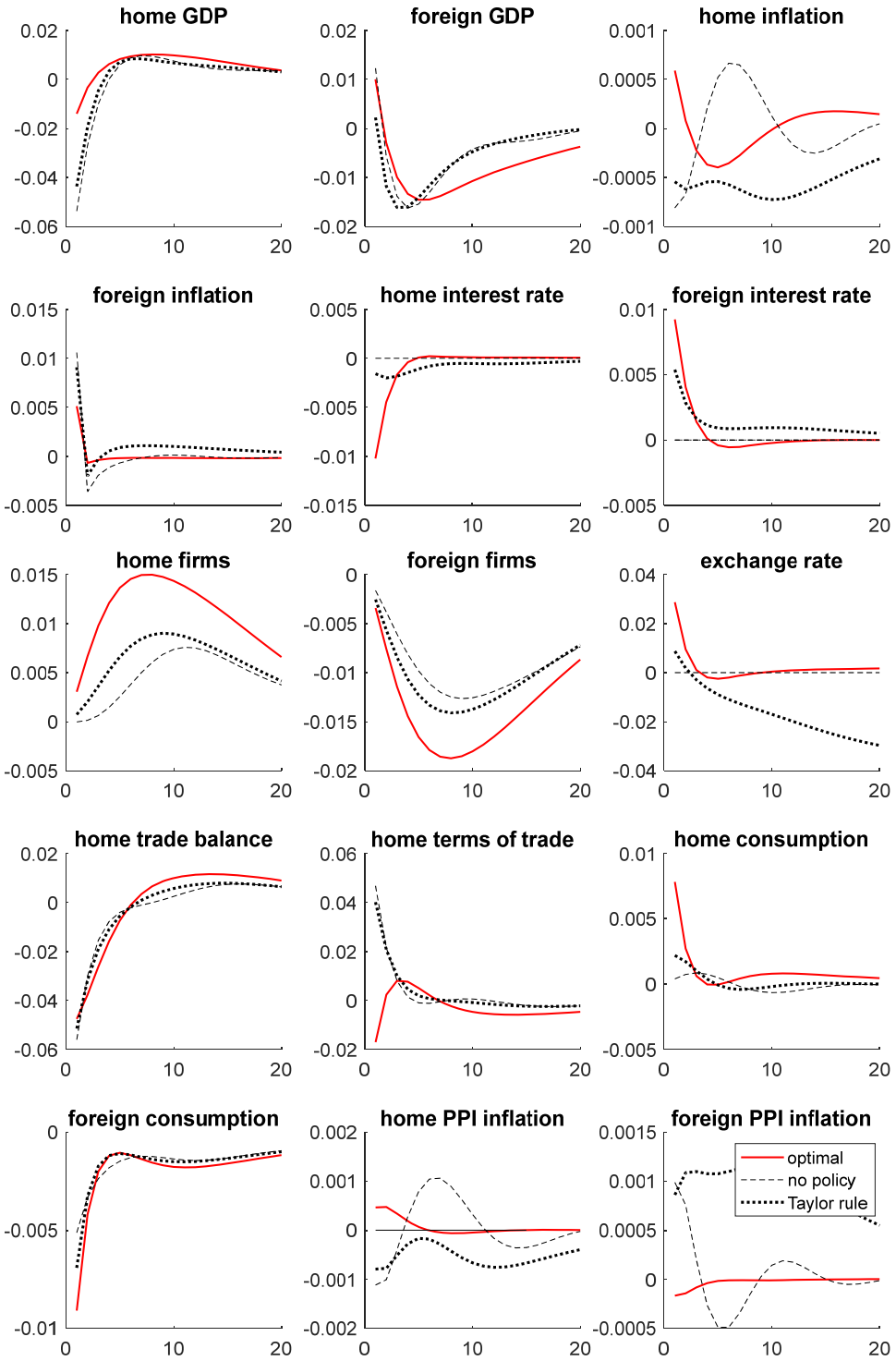
Vertical axis is percent deviation (0.01=1%) from steady state levels. Horizontal axis is time (in quarters).

Appendix Figure 5. Impulse responses to a markup shock with varying specifications

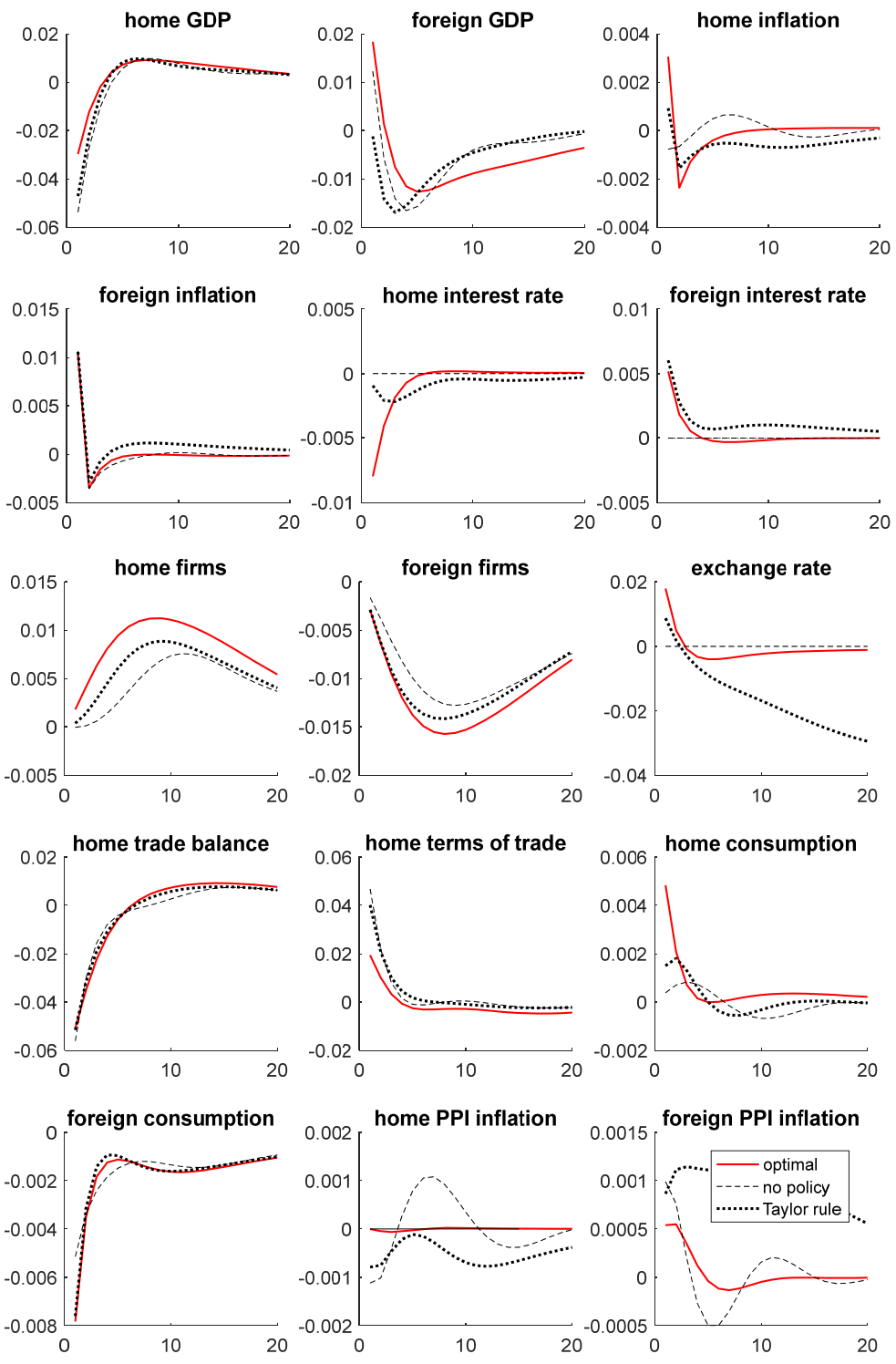


Vertical axis is percent deviation (0.01=1%) from steady state levels. Horizontal axis is time (in quarters).

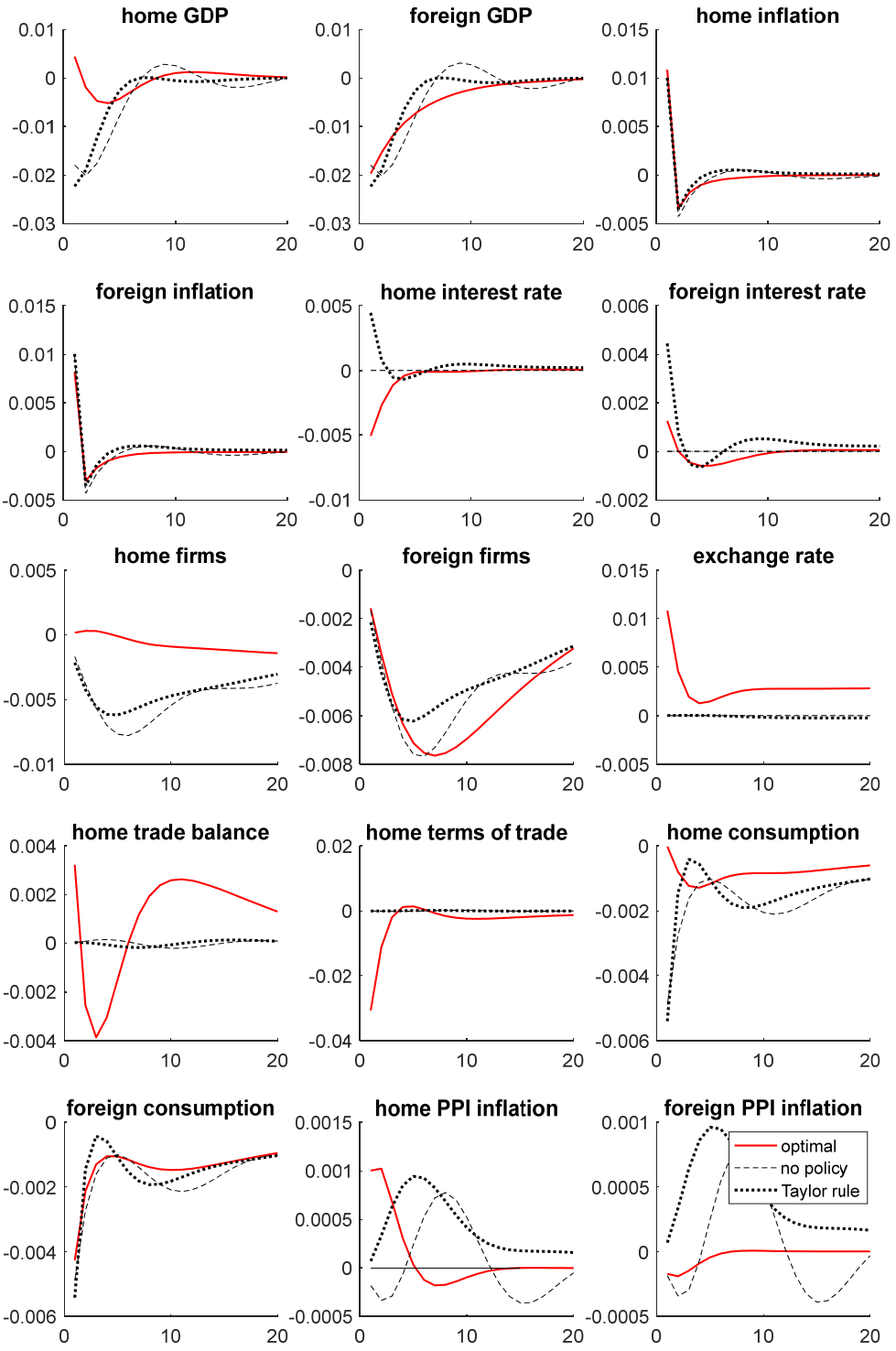
Appendix Figure 6. Impulse responses to a rise in foreign tariff on home exports, home country dominant currency (home PCP and foreign LCP)



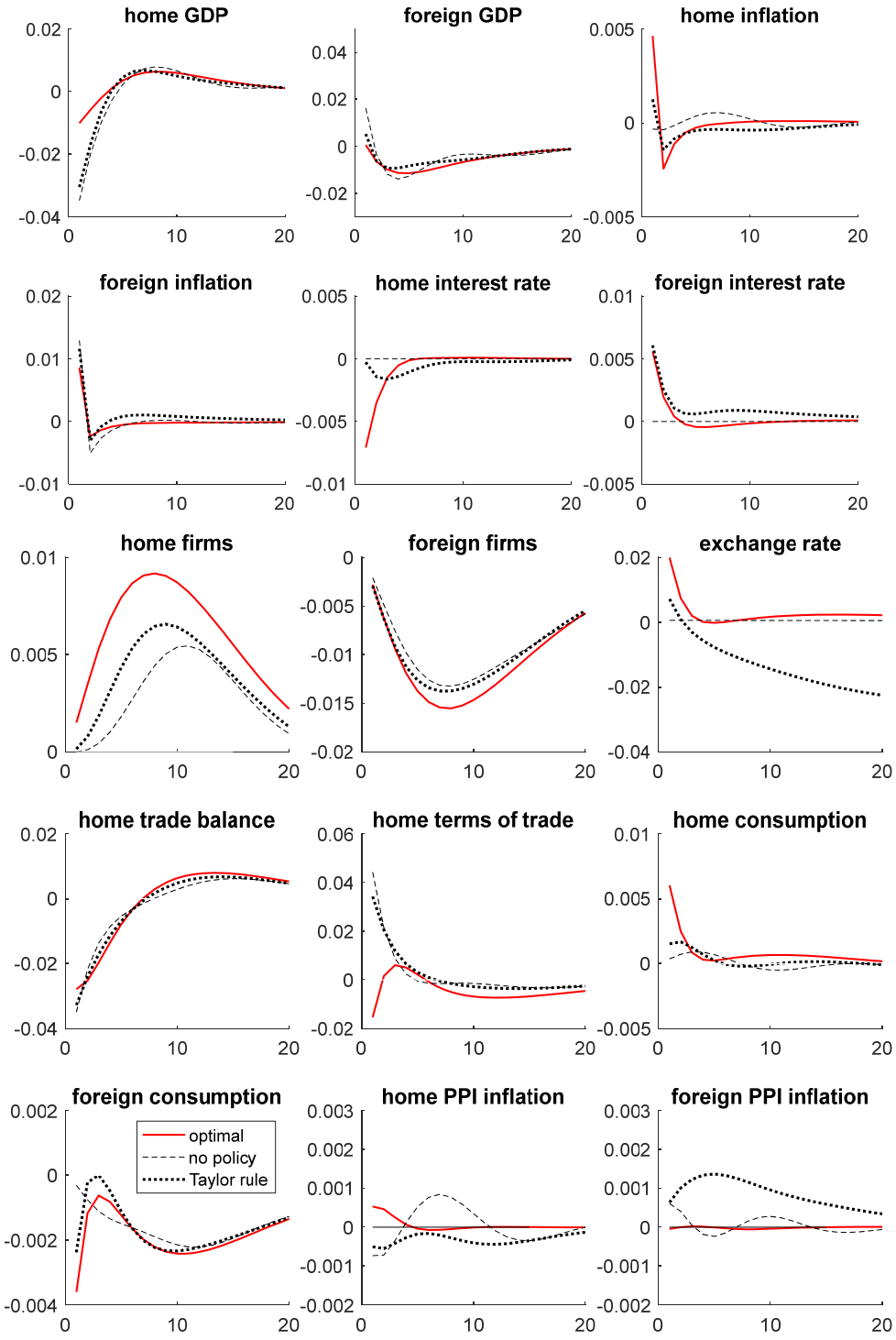
Appendix Figure 7. Impulse responses to a rise in foreign tariff on home exports, foreign currency dominant (home LCP and foreign PCP)



Appendix Figure 8. Impulse responses to a symmetric rise in tariff in both countries, home currency dominant (home PCP and foreign LCP)



Appendix Figure 9. Impulse responses to a rise in foreign tariff on home exports, low pass-through model



Appendix Figure 10. Impulse responses to a symmetric rise in tariff on goods in both countries, low pass-through model