The Macroeconomics of Tariff Shocks

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Abstract

We study the short-run effects of import tariffs on GDP and the trade balance in an open-economy New Keynesian model with intermediate input trade. We find that temporary tariffs cause a recession whenever the import elasticity is below an openness-weighted average of the export elasticity and the intertemporal substitution elasticity. We argue this condition is likely satisfied in practice because durable goods generate great scope for intertemporal substitution, and because it is easier to lose competitiveness on the global market than to substitute between home and foreign goods. Unilateral tariffs tend to improve the trade balance, but when other countries retaliate the trade balance worsens and the recession deepens. Taking into account the recessionary effect of tariffs dramatically lowers the optimal unilateral tariff derived in standard trade theory.

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The views expressed herein are those of the authors and not necessarily those of the Federal Reserve Bank of Minneapolis or the Federal Reserve System.

1 Introduction

Since its inauguration in January 2025, the Trump Administration has proposed and partially implemented import tariffs of a magnitude unprecedented since World War II. Following the "Liberation Day" announcement on April 2, 2025, these plans have continued to shift, with some tariffs being cut or suspended, and others being raised further.

There is an extensive literature in international trade on the long-run effects of tariffs. Tariffs impose efficiency costs by distorting patterns of comparative advantage, but they can also benefit the country setting tariffs by improving its terms of trade. The tradeoff between these two forces is the traditional focus of the "optimal tariff" literature (Kaldor 1940, Johnson 1953, Dixit 1985).

For the recent tariffs, however, the long-run outlook is unclear. There are many ways in which these tariffs may be reversed in the next weeks, months, or years: either deals reached by the administration, litigation invalidating the tariffs, or the arrival of a new administration.[1] Over time, importers may also learn how to avoid tariffs, or be granted exceptions. At least a large share of the tariffs, therefore, are plausibly temporary. Further, in the media and financial markets, the concern about tariffs is typically not about long-run efficiency loss, but rather about the possibility of a more immediate recession brought on by the tariff shock—a question not typically considered by trade models.

In this paper, we lay out a benchmark sticky-wage New Keynesian model with trade, and derive a simple condition for when a unilateral short-run tariff shock causes a domestic recession, in the absence of monetary easing:

$$(1-\alpha)\sigma + \alpha\gamma > \eta. \tag{1}$$

Here, α is the steady-state trade share, σ is the elasticity of intertemporal substitution, γ is the elasticity of demand for exports, and η is the import substitution elasticity. On the left of (1), a rise in tariffs has two contractionary effects: it raises the cost of goods today, decreasing consumer demand in proportion to σ, and also makes exports less competitive, decreasing export demand in proportion to γ. On the right of (1), there is an expansionary effect, as consumers and businesses substitute away from imports toward domestic output in proportion to η.

We argue that condition (1) is likely to hold, and thus that a tariff shock is likely to cause a downturn. In the short run, σ is plausibly high, since there is great scope to sub-

[1] Several lawsuits have already been filed, raising questions about executive power to set such broad tariffs, and also about the specific statutory authority being invoked. See, e.g., Queen (2025).

stitute the timing of durable goods purchases, such as cars or equipment.[2] γ is also likely to be higher than η, since it is easier to lose competitiveness on the global market than to substitute between home and foreign goods. If, in addition, there are equal retaliatory tariffs from abroad, then this adds another γ to the left of (1) and makes recession all but certain. The size of any implied recession is simple to calculate, and equals the trade share α times the gap between the left and right of (1).

Tariffs are often motivated by a desire to improve the trade balance. In the absence of retaliation, we find that the trade balance is indeed likely to improve, thanks both to substitution away from imports and to the likely recession. Retaliatory tariffs, however, directly hit exports and make the trade balance likely to deteriorate instead.

If monetary policy responds, it can potentially avoid a recession by cutting nominal rates, in line with the falling natural interest rate. This, however, causes a depreciation of the home currency, which aggravates the inflationary impact of the shock. Such a depreciation is in stark contrast to the usual long-run analysis, where the exchange rate typically appreciates to enforce long-run trade balance—part of the classic "Lerner symmetry" result (Lerner 1936, Costinot and Werning 2019) that breaks down in our setting. One difficulty facing monetary policy here is that tariff shocks are inherently stagflationary: unlike cost-push shocks in the standard New Keynesian model, they are contractionary even in the absence of a monetary reaction.

Relative to the traditional trade literature, our short-run emphasis brings a new perspective on welfare. The standard welfare analysis of tariffs emphasizes the tradeoff between improving the terms of trade and the costs of distortion, with the optimal tariff balancing the two effects. For tariff shocks, we show that a third effect, the "output-gap effect" associated with recession, is generally equal to or larger than either of the other two effects. This implies a much lower optimal tariff, and a clear welfare loss from any tariff if there is retaliation.

We consider a number of variations on our basic model, including unbalanced trade, hand-to-mouth households, and incomplete pass-through. Although our focus is on the effects of short-run tariff shocks, we also show that the transitional effects from imposing large, permanent tariffs can be contractionary: the inability to substitute quickly between domestic and foreign inputs makes goods more expensive in the short run, leading to a decline in output.

We conclude by building a quantitative version of our model, featuring dynamic wage

[2] In one early indicator of this substitution, the Philadelphia Fed's index of new manufacturing orders experienced its largest-ever one-month decline (excluding the covid period) in April 2025, from 8.7 to -34.2. See `https://fred.stlouisfed.org/series/NOCDFSA066MSFRBPHI`.

adjustment, durable goods, firm inventories, and persistent tariffs. This corroborates our main insights, and also allows us to consider some new questions: for instance, we find that an anticipated shock can lead to a temporary boom in economic activity, as durable purchases are pulled forward prior to a tariff-induced crash.

Our analysis leaves out some potentially important channels through which tariff policy may have an impact. We do not, for instance, consider the effects of tariff uncertainty (Caldara, Iacoviello, Molligo, Prestipino and Raffo 2020) or financial frictions, both of which are likely to aggravate any contraction. A possible loss of confidence in the US dollar as a reserve currency, which may have driven a decline in the dollar beyond what one would expect from relative bond yields, is also outside the scope of our analysis. Our aim is to show how, even in a very simple environment, tariff shocks can trigger substitution that leads to a downturn; we view these other channels as complementary.

Relation to literature. Our model builds on the canonical Gali and Monacelli (2005) New Keynesian open economy framework, with a few key modifications: we assume sticky wages and flexible prices, allow for trade in intermediate inputs, and replace complete with incomplete international markets.[3]

A number of recent papers have explored the effects of tariffs in New Keynesian models. This literature finds conflicting effects of unilateral tariffs on GDP in the absence of a monetary policy response. Bergin and Corsetti (2023) calibrate to $\sigma = 0.5$ and find that unilateral tariffs are expansionary. Barattieri, Cacciatore and Ghironi (2021), on the other hand, feature an investment channel and find a recessionary effect, consistent with a high effective σ from the elastic response of investment. Monacelli (2025), in a model without intermediate goods trade, calibrates to $\sigma = 1$ and finds that a condition for recession is $\eta < 1$.[4] Relative to this literature, our paper features a more stylized framework, which allows us to derive analytical formulas that show the role of underlying elasticities, including the pivotal role of σ.

Several papers, including Kalemli-Özcan, Soylu and Yildirim (2025), Cuba-Borda, Queralto, Reyes-Heroles and Scaramucci (2025), and Nispi Landi and Moro (2024), study the

[3] A literature dating back to Mundell (1961) studies the effect of tariff shocks in old Keynesian models. This literature generally finds that tariffs can reduce employment, because they drive exchange rate appreciation and increase savings via the so-called Laursen-Metzler effect (Eichengreen 1981, Krugman 1982). As Krugman (1982) acknowledges, this effect "rests on weak microfoundations". In our model, tariffs reduce employment even if monetary policy does not respond and the exchange rate does not move; moreover, the exchange rate depreciates rather than appreciates in the natural allocation.

[4] In the original Gali and Monacelli (2005) model without intermediate inputs, condition (1) becomes simply $\sigma > \eta$, as we show in section 4.4. This condition, in turn, is the same as Guerrieri, Lorenzoni, Straub and Werning (2022)'s condition for when shutting down a sector (here, imports) leads to a recession in the other sector (here, domestic production).

effects of tariffs in models with multi-country trade networks. Although we abstract from networks, we do allow for intermediate inputs, and like these papers we find an important role for the transmission of tariffs to input costs.

There is also a literature studying the implications of tariffs for optimal policy. Several papers, including Bergin and Corsetti (2023), Bianchi and Coulibaly (2025), and Monacelli (2025), take tariffs as given and study the optimal monetary policy response. For Bergin and Corsetti (2023), optimal policy depends on the nature of the shock, and is contractionary for unilateral tariffs but expansionary with retaliation. Both Bianchi and Coulibaly (2025) and Monacelli (2025), by contrast, find a clear role for expansionary policy in response to unilateral tariffs, with Bianchi and Coulibaly showing that optimal policy allows inflation to rise above the direct effects of tariffs. Other work, including Auray, Devereux and Eyquem (2024) and Jeanne (2021), endogenizes tariffs and studies the interaction between tariff choice and monetary policy. Our paper, by contrast, does not solve for optimal monetary policy, although our welfare analysis does highlight the interaction between tariffs and the monetary policy regime, and we revisit the optimal tariff literature in light of short-run recessionary effects.

The paper is also part of a set of recent efforts at analyzing the new Trump administration's tariff announcements. Much of this literature focuses on the long-run effect of tariffs on the trade deficit (Itskhoki and Mukhin 2025, Werning and Costinot 2025), welfare and the terms of trade (Ignatenko, Lashkaripour, Macedoni and Simonoska 2025), or capital accumulation (Baqaee and Malmberg 2025). Alessandria, Ding, Yar Khan and Mix (2025) look at both short and long-run effects, with an emphasis on the benefits of tariff revenue in lowering distortionary taxation. Cavallo, Llamas and Vazquez (2025) track the effect of tariffs on both import and domestic prices.[5]

Outline of paper. The paper is structured as follows. Section 2 introduces our core model, section 3 analyzes the effect of tariff shocks in that model, and section 4 considers a variety of extensions. Section 5 conducts the optimal tariff analysis taking into account the costs of recession. Section 6 simulates an extended version of the model to study the effects of persistent and possibly anticipated tariff shocks. Section 7 concludes.

[5]This question of pass-through was central to a literature studying the earlier Trump administration tariffs (Amiti, Redding and Weinstein 2019, Flaaen, Hortaçsu and Tintelnot 2020, Fajgelbaum, Goldberg, Kennedy and Khandelwal 2020, Cavallo, Gopinath, Neiman and Tang 2021). A rapidly growing recent literature has also studied the role of trade policy as a way of projecting geoeconomic power (Clayton, Maggiori and Schreger 2023, Becko and O'Connor 2025).

2 Baseline model

We center our analysis on a baseline model, which we keep simple to illustrate the key transmission mechanisms of tariff shocks. The model is based on Gali and Monacelli (2005), with three modifications. First, we assume incomplete rather than complete international markets, so that countries do not hedge the effects of tariff shocks. This is important for our welfare analysis. Second, we assume that imports are also used in the production of exports, not just domestic consumption. This is to reflect the important role of intermediate inputs and cross-border production chains in trade (e.g. Di Giovanni and Levchenko 2010, Johnson 2014).

Third, we assume sticky wages and flexible prices, rather than sticky prices and flexible wages. This is consistent with an empirical literature that documents much more rigidity in nominal wages than in prices—especially goods prices.[6] In our model, this assumption implies full pass-through of tariffs to prices. This is consistent with recent evidence on tariffs and border prices, although border prices do not always transmit fully to retail prices (Amiti et al. 2019, Flaaen et al. 2020, Fajgelbaum et al. 2020, Cavallo et al. 2021). We argue that retail margins are unlikely to be able to absorb a large share of a broad tariff shock like the U.S. 2025 shock, making full pass-through a plausible assumption in such cases.[7] We relax this assumption, however, and allow for imperfect pass-through into import prices in section 4.3. Importantly, we find that our condition for a recession is unchanged in this case, although the magnitude of a recession is attenuated.

In section 4, we will study several variations of the baseline model, including extensions to a large open economy, unbalanced trade, and durables.

2.1 Setup

We first study the problem of a small open economy ("home", "domestic") that is surrounded by a continuum of symmetric small economies ("rest of the world", "foreign"). Variables describing the rest of the world have a star superscript. The home economy produces a single home good, and the rest of the world produces a single basket of foreign goods. The model is set in discrete time $t = 0, \ldots, \infty$, with perfect foresight from date 0 onward, but where an unexpected shock may perturb the steady-state economy at date 0.

[6] For instance, Bils and Klenow (2004) document a 30% monthly frequency of price adjustment for goods, while Grigsby, Hurst and Yildirmaz (2021) document a less-than-7% monthly frequency of wage adjustment, with virtually no nominal wage declines (0.4% monthly).

[7] See also Cavallo, Lippi and Miyahara (2024) on why large shocks may transmit to prices more quickly.

Domestic households. Domestic households consume home goods C_t, and invest in domestic nominal bonds B_t paying interest i_t and foreign nominal bonds A_t paying interest i_t^*. We assume the latter to be a constant i^*.[8] Household utility is

$$\sum_{t=0}^{\infty} \beta^t \frac{C_t^{1-1/\sigma}}{1-1/\sigma}, \tag{2}$$

where $\beta \in (0,1)$ denotes the discount factor and $\sigma > 0$ the elasticity of intertemporal substitution. The budget constraint in units of domestic currency is given by

$$P_t C_t + A_t + B_t = W_t N_t + \frac{\mathcal{E}_t}{\mathcal{E}_{t-1}} \left(1 + i^*\right) A_{t-1} + \left(1 + i_{t-1}\right) B_{t-1} + T_t. \tag{3}$$

P_t is the price of domestic gross output, which coincides with the domestic consumer price index (CPI), and $\mathcal{E}_t$ is the nominal exchange rate. B_t is in zero net supply and hence also zero initially ($B_{-1} = 0$). A_t is also the net foreign asset position (NFA) of the home economy, and, for now, also assumed to be zero initially ($A_{-1} = 0$). T_t is a transfer from the government.

Labor market. Domestic households supply labor $N_t \leq \overline{N}$, up to some labor endowment $\overline{N}$, to domestic firms, earning the nominal wage W_t. We assume that there is a downward nominal wage rigidity that restricts W_t to stay above W_{t-1}. We thus have that whenever $W_t > W_{t-1}$, households supply their full labor endowment $N_t = \overline{N}$; otherwise, it is possible that N_t falls short of $\overline{N}$, in which case there is involuntary unemployment (see, e.g., Schmitt-Grohé and Uribe 2016). Labor N_t is the only source of domestic value added, and it is therefore equal to domestic real GDP, leading us to write $N_t = GDP_t$.

Domestic production and imports. Domestic gross output Y_t, which is used both for consumption and exports, is produced by a representative firm from domestic labor N_t and imports M_t,

$$Y_t = \left((1-\alpha)^{1/\eta} N_t^{\frac{\eta-1}{\eta}} + \alpha^{1/\eta} M_t^{\frac{\eta-1}{\eta}} \right)^{\frac{\eta}{\eta-1}}. \tag{4}$$

Here, $\alpha \in (0,1)$ is the openness of the economy and $\eta > 0$ the elasticity of import substitution. By having imports enter into the production function for exports, (4) effectively allows for imported intermediate goods.[9]

[8] Except in section 4.7, we take rest-of-the-world aggregates to be constant in our analysis, since the home economy's tariff shock is too small to affect any of them.

[9] We do not explicitly model within-country intermediate goods linkages, and instead view them as part of the production technology (4). We generalize to allow for distinct production technologies for consumption and exports in section 4.4.

With a price P_t^F of imported foreign goods, we can write the domestic price index as

$$P_t = \left[(1-\alpha) W_t^{1-\eta} + \alpha \left(P_t^F\right)^{1-\eta}\right]^{\frac{1}{1-\eta}} \tag{5}$$

and demands for labor and imports as

$$N_t = (1-\alpha) Y_t \left(\frac{W_t}{P_t}\right)^{-\eta} \qquad M_t = \alpha Y_t \left(\frac{P_t^F}{P_t}\right)^{-\eta}. \tag{6}$$

Exchange rate. We denote the nominal exchange rate by $\mathcal{E}_t$, with a higher value for $\mathcal{E}_t$ representing a depreciation. No arbitrage implies that an uncovered interest parity (UIP) condition holds between all periods $t \geq 0$ and $t+1$,

$$\mathcal{E}_t = \frac{1+i^*}{1+i_t}\mathcal{E}_{t+1}. \tag{7}$$

Pricing and tariffs. All prices, with the exception of the nominal wage W_t, are flexible. Foreign goods prices are thus given by

$$P_t^F = (1+\tau_t)\,\mathcal{E}_t, \tag{8}$$

where we normalize foreign goods prices P_t^* in the rest of the world to 1. τ_t is the import tariff and is the main shock of interest in this paper. The government transfers the proceeds of the tariffs to the household:

$$T_t = \tau_t \mathcal{E}_t M_t. \tag{9}$$

Exports. The rest of the world demands X_t domestically produced goods according to

$$X_t = \alpha Y^* \cdot \left(\frac{P_t}{\mathcal{E}_t}\right)^{-\gamma}, \tag{10}$$

where production in the rest of the world is constant at Y^*, and, with our normalization $P_t^* = 1$, the relevant relative price of home goods abroad is $P_t/\mathcal{E}_t$. Following Gali and Monacelli (2005), the elasticity of export demand γ is distinct from η, as γ characterizes substitution between different countries' exports, while η characterizes substitution between domestically produced goods and the entire import basket. We will generally assume that $\gamma > 1$; that is, that the home economy as a whole does not possess infinite market power.

Monetary policy. The nominal interest rate i_t is controlled by the domestic central bank. We assume that in all dates $t \geq 1$, the domestic central bank implements the full-employment allocation $N_t = \bar{N}$. At date $t = 0$, we will consider the polar cases of a "passive" central bank, which leaves i_0 at its steady state value unless there is wage inflation; and a "stabilizing" central bank, which adjusts i_0 to achieve full employment. In all cases, we assume that the central bank stabilizes wage inflation, so that $W_t = W$ is fixed.

Equilibrium. Given a sequence of import tariff shocks $\{\tau_t\}$ and monetary policy, a *competitive equilibrium* in our economy is a sequence of quantities $\{C_t, Y_t, N_t, M_t, X_t, A_t, B_t, T_t\}$ and prices $\{P_t, P_t^F, \mathcal{E}_t, W_t\}$ such that: (a) domestic households maximize (2) s.t. (3), (b) $N_t = \overline{N}$ if $W_t > W_{t-1}$, (c) equations (4)–(10) hold, (d) the domestic asset market clears, $B_t = 0$, (e) the balance of payments is satisfied,

$$A_t = \frac{\mathcal{E}_t}{\mathcal{E}_{t-1}} (1 + i^*) A_{t-1} + \mathcal{E}_t TB_t, \tag{11}$$

where TB_t is the trade balance in units of foreign goods

$$TB_t \equiv \frac{P_t}{\mathcal{E}_t} X_t - M_t, \tag{12}$$

and (f) the goods market clears,

$$Y_t = X_t + C_t. \tag{13}$$

Steady state. We assume the economy starts at $t = -1$ in a *steady-state equilibrium*, in which all quantities and prices are constant, with a zero import tariff $\tau = 0 = T$. We denote the steady-state values of all time-varying objects without any subscripts. We normalize all steady-state prices to 1,

$$P = P^F = \mathcal{E} = W = \underline{W} = 1,$$

and also normalize production to 1, $Y = Y^* = 1$, which pins down

$$M = X = \alpha \qquad C = N = 1 - \alpha.$$

Thus, for now, trade is assumed to be balanced in the initial steady state; we relax this in section 4.1. The steady-state interest rates are $i = i^* = \beta^{-1} - 1$.

Model summary. We summarize the model in figure 1, with arrows indicating spending flows.

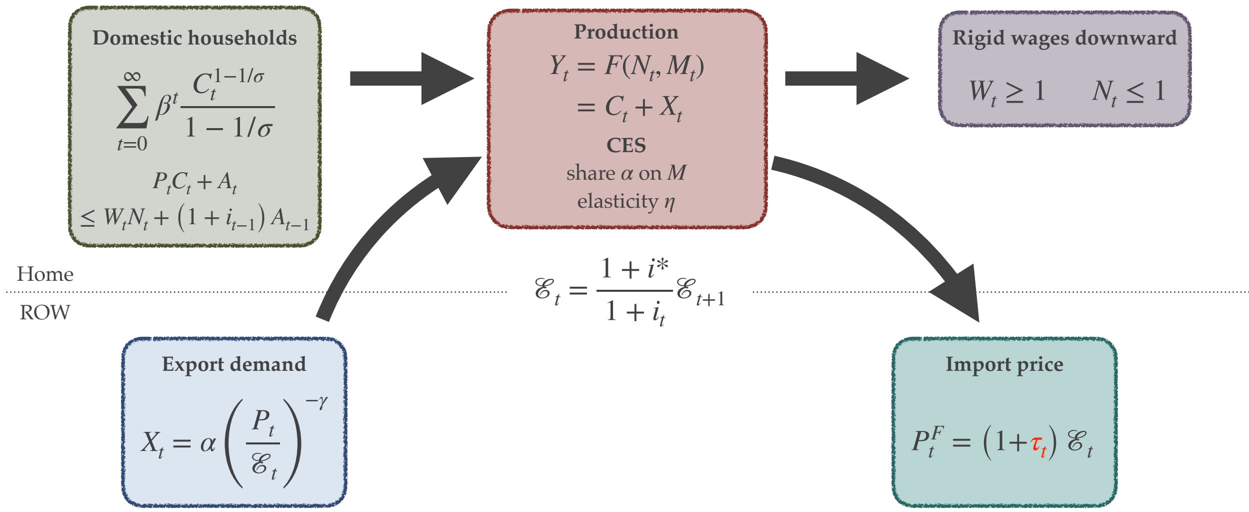


Figure 1: Summary of the spending flows in the baseline model

2.2 Long-run effects of tariffs

We will compare our results for temporary tariff shocks to a benchmark where there is a permanent shift in tariffs. In this case, the economy adjusts immediately to the new long-run equilibrium.

Proposition 1. *In response to a first-order permanent tariff increase, $d\tau > 0$, with either passive or stabilizing monetary policy, there is no change in GDP, $N_t = \overline{N}$, and no change in the trade balance. Exports and imports both decline by*

$$dX = dM = -\frac{\gamma\eta}{(\gamma-1)(1-\alpha)+\eta}d\tau \tag{14}$$

and the exchange rate changes by

$$d\log\mathcal{E} = -\frac{\eta-\alpha(\gamma-1)}{(\gamma-1)(1-\alpha)+\eta}d\tau. \tag{15}$$

The denominator in (14)–(15) is the sensitivity of the trade balance to the exchange rate. In equilibrium, the exchange rate moves to offset the shock to the trade balance from higher tariffs, resulting in an equal decline in exports and imports.

In principle, the exchange rate can go either way: if $\alpha(\gamma-1) > \eta$, export demand is so elastic that a decline in export competitiveness overwhelms substitution away from imports, weakening the trade balance and forcing the exchange rate to depreciate ($\mathcal{E}\uparrow$). For countries like the U.S. with small α, however, this is implausible, and the exchange rate is likely to appreciate. This appreciation limits the increase in relative import prices P^F/P from the tariff. This is the conventional view in the trade literature about the effect of tariffs on the exchange rate.

2.3 Reference calibration

Before continuing with our discussion of tariff shocks, we choose a reference calibration to anchor our analysis. To start, three parameters govern the long-run response (14)–(15): openness α, the import substitution elasticity η, and the export demand elasticity γ.

To calibrate α, we note that the model's steady-state ratio of imports (or exports) to GDP is $\frac{\alpha}{1-\alpha}$. We take the average of the US's 2023 import-to-GDP (13.9%) and export-to-GDP (11.0%) ratios to obtain a target of $\frac{\alpha}{1-\alpha} = 12.5\%$, which implies $\alpha = 1/9 \approx 11.1\%$. For the long-run export elasticity γ, which is the elasticity of substitution between varieties produced by different countries, we take $\gamma = 4$ from Simonovska and Waugh (2014) as the approximate midpoint of an extensive trade literature.[10]

The elasticity η of substitution between imports and domestic value added is in principle distinct from γ. To calibrate it, we use a result from Auclert, Rognlie, Souchier and Straub (2024), who show that a model with substitution between tradables and nontradables, and also substitution between domestic and foreign tradables, is locally equivalent to assuming a particular η. Assuming that preferences over tradables and nontradables are Cobb-Douglas, and that the elasticity between domestic and foreign tradables is also γ, we obtain a long-run estimate of $\eta = 3.07$. Details are provided in appendix A.2.

It is widely understood that trade elasticities are lower in the short run than the long run, since substituting between different goods and suppliers often takes time. Recent work by Boehm et al. (2023) finds a short-run elasticity in response to tariffs that is 3/8 of the central long-run elasticity. Since our analysis primarily deals with the short-run effects of tariffs, we multiply the long-run γ and η above by 3/8 to obtain our primary calibration: $\gamma = 1.5$ and $\eta = 1.15$.

Finally, for dynamics we also need to calibrate the elasticity of intertemporal substitution σ. Here, we view it as crucial to take durable goods into account, since traded goods are disproportionately durable, and durable goods purchases are much more intertemporally substitutable—at least in the short run—than nondurable purchases. In section 4.5, we will show that the effective elasticity of intertemporal substitution in aggregate consumption for one-time shocks to tariffs is $\sigma = (1-\omega)\,\nu + \omega\epsilon_D$, where ν is the elasticity

[10] On the lower end, Boehm, Levchenko and Pandalai-Nayar (2023) find a long-run elasticity of 2, while on the higher end, Eaton and Kortum (2002) find an elasticity of approximately 8.

Table 1: Reference calibration (short run)

	Description	Value
σ	Intertemporal elasticity	1.79
γ	Export elasticity	1.5
η	Import elasticity	1.15
α	Openness	0.11

of intertemporal substitution for nondurable consumption, ϵ_D is the elasticity of durable investment to durable price, and $\omega = \frac{D}{C+D}$ is the share of durables in total consumption. We take $\omega = 11\%$ from the 2023 national accounts, $\epsilon_D = 8.2$ from the main estimates in Baker, Kueng, McGranahan and Melzer (2019), and assume a standard nondurable elasticity of $\nu = 1$, leaving us with $\sigma = 1.79$.

Table 1 summarizes this reference calibration.

3 Tariff shocks

Our main experiment in the next three sections is a one-time unexpected increase in tariffs, $\tau_0 > 0$, $\tau_t = 0$ for $t \geq 1$. We start with a first-order analysis, and write $\tau_0 = d\tau$.

We derive our results in the limit $\beta \nearrow 1$, following Woodford (2022); conceptually, this corresponds to period 0 being arbitrarily short. This limit greatly improves tractability, as any endogenous changes in the net foreign asset position as a result of the shock have a vanishingly small effect on consumption.[11] Since β is typically close to 1, this is a relatively innocuous assumption. We relax this assumption in our simulations in section 6.

We first consider the case of passive monetary policy, and then the case of an output-stabilizing monetary policy.

3.1 When do tariff shocks cause recessions?

With passive monetary policy and a binding downward wage constraint, we have $i_0 = i$, and, by the UIP condition (7), the exchange rate is stable, $\mathcal{E}_0 = \mathcal{E}$. Thus, the import price (8) moves one-for-one with the tariff, $d \log P_0^F = d\tau$. To first order, the CPI (8) increases by $d \log P_0 = \alpha d\tau$.

[11] The more common way to obtain tractability is to assume complete international markets, as in the original Gali and Monacelli (2005). For date-0 outcomes, this is identical to our $\beta \nearrow 1$ limit, but it has different implications for discounted utility, which matter in section 5. We thus avoid complete markets, since we find it unlikely that domestic households fully insure tariff shocks on international markets.

From the first-order condition for labor demand (6) and the assumption that nominal wages are stable, we see that labor demand is

$$d\log N_0 = d\log Y_0 + \eta d\log P_0. \tag{16}$$

This shows that labor demand is influenced by goods demand $d\log Y_0$ and a substitution effect $\eta d\log P_0 = \alpha\eta d\tau$. The latter *import substitution effect* is positive, creating a channel through which the tariff shock can increase GDP.

Goods demand (13) itself is the sum of export demand and domestic consumption,

$$d\log Y_0 = \alpha d\log X_0 + (1-\alpha)\, d\log C_0. \tag{17}$$

Both unambiguously fall in response to the shock, albeit with different elasticities. Exports (10) fall with the export demand elasticity γ,

$$d\log X_0 = -\gamma d\log P_0 = -\gamma\alpha d\tau, \tag{18}$$

as higher import prices hurt the competitiveness of the home economy's exports.

Consumption is determined by the Euler equation,

$$\frac{1}{P_0}C_0^{-1/\sigma} = \beta\,(1+i_0)\,\frac{1}{P_1}C_1^{-1/\sigma}. \tag{19}$$

With a constant interest rate, $1+i_0$ is independent of the shock. C_1 is also independent of the shock in the limit $\beta \nearrow 1$, since it is unaffected by any net foreign asset position accumulated at the end of period 0. For the same reason, P_1 is also unaffected by the shock. Thus, date-0 consumption is given by

$$d\log C_0 = -\sigma d\log P_0 = -\sigma\alpha d\tau.$$

A greater intertemporal elasticity σ leads to lower consumption, as households postpone purchases in light of high current prices.

Taken together, both consumption and exports pull goods demand (17), and thus labor demand (16) down, while import substitution pushes labor demand up:

$$d\log N_0 = -\left(\alpha\gamma + (1-\alpha)\,\sigma\right)\alpha d\tau + \eta\alpha d\tau.$$

Figure 2 illustrates all three channels. Overall, the tariff shock leads to recession when the

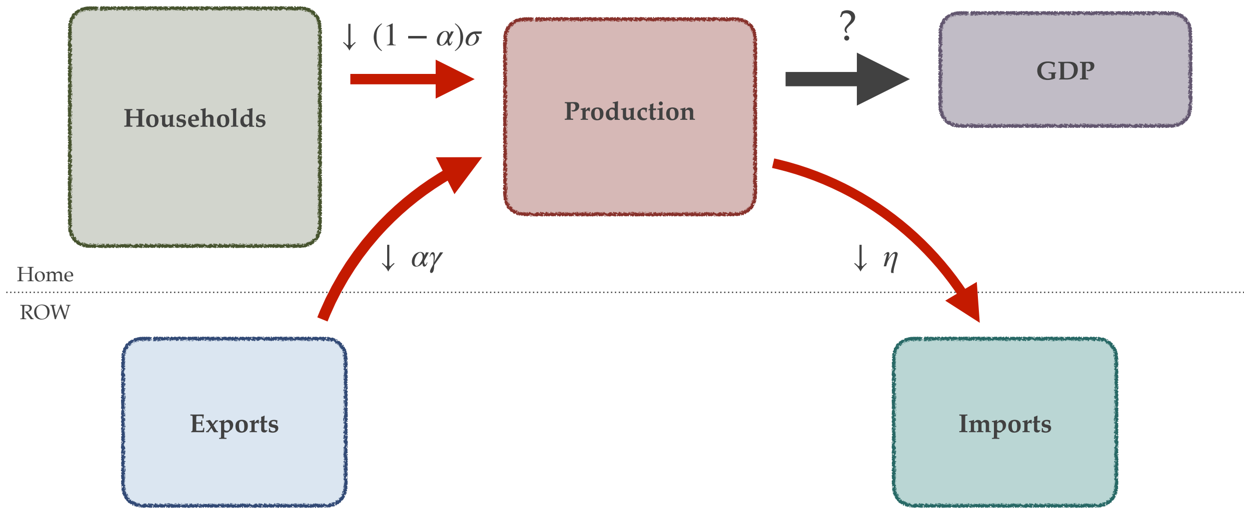


Figure 2: Three transmission channels of the import tariff shock

export demand and intertemporal substitution channels dominate import substitution:

$$(1-\alpha)\,\sigma + \alpha\gamma > \eta. \tag{20}$$

The following proposition summarizes this result and derives implications for other macroeconomic variables.

Proposition 2. *Assume passive monetary policy. The economy is in recession at date 0, $N_0 < \overline{N}$, if and only if (20) holds. In that case, real $GDP_t = N_t$ falls by*

$$d\log GDP_0 = -\alpha\left((1-\alpha)\,\sigma + \alpha\gamma - \eta\right)d\tau, \tag{21}$$

exports and imports fall by

$$d\log X_0 = -\alpha\gamma d\tau \qquad d\log M_0 = -\left((1-\alpha)\,\eta + \alpha\left((1-\alpha)\,\sigma + \alpha\gamma\right)\right)d\tau,$$

the sign of the trade balance response is ambiguous,

$$\frac{dTB_0}{GDP} = \frac{\alpha}{1-\alpha}\left(\alpha + (1-\alpha)\left(\eta + \alpha\left(\sigma - \gamma\right)\right)\right)d\tau, \tag{22}$$

and the CPI rises by $d\log P_0 = \alpha d\tau$.

Proposition 2 shows that, if condition (20) holds, the tariff shock *itself* (without a monetary policy response) is stagflationary. Prices rise at the same time as economic activity slows down: $d\log P_0 = \alpha d\tau > 0$ and $d\log GDP_0 < 0$. Unlike transitory cost-push shocks

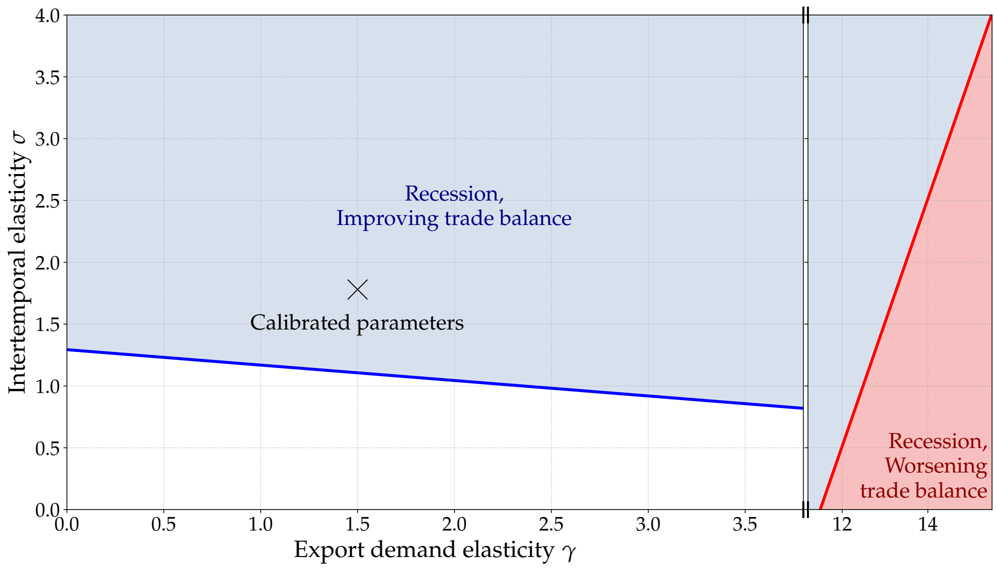


Figure 3: Unilateral tariff shock: Conditions for recession and improving trade balance

in the textbook New Keynesian model, which under passive monetary policy only increase inflation without changing GDP, the import tariff shock not only raises inflation but also simultaneously reduces GDP. This aggravates the trade-off between stabilizing the output gap and CPI inflation. This stagflationary nature of tariff shocks echoes the empirical findings of Furceri, Hannan, Ostry and Rose (2018), as well as the theoretical results in Bergin and Corsetti (2023)—though, in their calibration, tariffs are only stagflationary when there is retaliation.

Proposition 2 also characterizes trade flows and the trade balance. In the likely case where $\alpha(\gamma - 1) < \eta$ (cf section 2.2), exports fall by less than in response to a permanent tariff—since a permanent tariff, unlike here, causes the exchange rate to appreciate. Meanwhile, the effect on the overall trade balance is in principle ambiguous.

In a version of the model without intermediate input trade, equation (20) becomes $\sigma > \eta$, as we show in section 4.4. This is closely related to Guerrieri et al. (2022), who find that, in a two-sector model, temporary supply shocks to a sector reduce employment in the other sector when σ is larger than the elasticity of substitution between sectors. Closer to our context, Monacelli (2025) calibrates his model to $\sigma = 1$ and finds that tariff shocks reduce the natural level of output when $\eta < 1$. Our condition generalizes this result to general σ and to the case with trade in intermediate inputs.

For our model, we illustrate the conditions under which a recession occurs and the trade balance improves in figure 3, which plots the intertemporal elasticity σ on the y-axis and the export demand elasticity γ on the x-axis, holding η fixed at our calibrated $\eta = 1.15$. With sufficiently high σ or γ, the two contractionary channels dominate the expansionary one in (20), placing us in the recession region above the blue line. For high enough γ, is it possible that the trade balance deteriorates—but this requires γ over 12, well beyond a plausible short-run value. We mark the calibration from table 1 with an "X", and see that it puts us in the region with recession but an improving trade balance. Numerically, with this calibration, a 10% tariff shock contracts the economy by 0.66% and improves the trade balance by 1.4% of GDP, or 11.6% of imports.

In sum, the effects of a short-run tariff shock are quite different from the long-run tariff we examined in section 2.2. Here, in response to a short-run tariff, GDP declines, the trade balance improves, and the exchange rate remains unchanged—while for a long-run tariff, GDP and the trade balance remain unchanged, and the exchange rate appreciates.

3.2 Monetary policy response

Next, we study a stabilizing monetary policy that adjusts i_0 to implement full employment $N_0 = \overline{N}$. We call the interest rate i_0 that achieves this the *natural* interest rate, since $N_0 = \overline{N}$ is the natural allocation in this economy—the allocation that would prevail in the absence of wage rigidity.

The interest rate i_0 matters for aggregate demand in several ways. First, a lower interest rate stimulates demand directly via intertemporal substitution in the Euler equation (19) of domestic households. Indeed, linearizing the Euler equation we see that

$$d\log C_0 = -\sigma d\log\left(1+i_0\right) - \sigma d\log P_0. \tag{23}$$

Second, because it depreciates the exchange rate via the UIP condition (7), $d\log\mathcal{E}_0 = -d\log\left(1+i_0\right)$, a lower interest rate increases the price of imports even further,

$$d\log P_0^F = d\tau - d\log\left(1+i_0\right) \qquad \text{and} \qquad d\log P_0 = \alpha d\log P_0^F. \tag{24}$$

This price increase is contractionary assuming condition (20).

Finally, a lower interest rate makes exports more competitive, increasing export demand according to

$$d\log X_0 = -\gamma d\log P_0 - \gamma d\log\left(1+i_0\right). \tag{25}$$

Substituting (23)–(25) into (16) and (17), we derive the following.

Proposition 3. *In response to the tariff shock, the natural interest rate is given by*

$$d\log\left(1+i_0\right) = -\frac{\alpha}{1-\alpha}\frac{\left(1-\alpha\right)\sigma + \alpha\gamma - \eta}{\left(1-\alpha\right)\sigma + \alpha\gamma + \eta\frac{\alpha}{1-\alpha}}d\tau. \tag{26}$$

In particular, the natural rate falls iff the recession condition (20) is satisfied. Under the same condition, the exchange rate $d \log \mathcal{E}_0 = -d \log (1 + i_0)$ depreciates. The trade balance unambiguously improves:

$$\frac{dTB_0}{GDP} = \frac{\alpha}{1-\alpha}\frac{\eta}{1-\alpha}\left(\frac{(1-\alpha)\,\sigma+\alpha}{(1-\alpha)\,\sigma+\alpha\gamma+\eta\frac{\alpha}{1-\alpha}}\right)d\tau. \tag{27}$$

Under the recession condition (20), the natural interest rate falls, depreciating the exchange rate—exactly the opposite of the exchange rate movement from a permanent tariff. This aggravates the tariff shock to some extent, as import prices and the CPI now rise by even more. This leads to a further contraction in imports, and mitigates, to some extent, the decline in exports. The trade balance unambiguously improves.

Given our calibration, the natural interest rate (26) falls by 40 basis points for a 10% tariff shock. The trade balance improves by roughly the same as before, around 1.4% of GDP.

3.3 Comparison with export tax and the failure of Lerner symmetry

Lerner symmetry (Lerner 1936) is the proposition that an import tariff is equivalent to an export tax.[12] In our model, this is indeed true for the permanent case: permanent export and import taxes have identical implications for trade flows.

To investigate the extent to which Lerner symmetry holds for *temporary* import tariffs and export taxes, we now introduce an export tax shock, denoted by τ_t^X. We assume that the import tariff is zero in this subsection, $\tau_t = 0$.

In contrast to (10), the export tax directly reduces export demand:

$$X_t = \alpha Y^* \cdot \left(\left(1+\tau_t^X\right)\frac{P_t}{\mathcal{E}_t}\right)^{-\gamma}.$$

Since the export price at the border is inclusive of the export tax, the tax enters the equation for the trade balance

$$TB_t \equiv \left(1+\tau_t^X\right)\frac{P_t}{\mathcal{E}_t}X_t - M_t,$$

and as with an import tariff, export tax revenue is transferred to households: $T_t = \tau_t^X P_t X_t$.

We study a small export tax at date 0, $\tau_0^X = d\tau$, $\tau_t^X = 0$ for $t > 0$. Assume first that

[12] See Costinot and Werning (2019) and Barbiero, Farhi, Gopinath and Itskhoki (2019) for recent work on Lerner symmetry.

monetary policy is passive. Then the export tax acts by reducing export demand directly,

$$d \log X_0 = -\gamma d\tau,$$

which decreases goods demand and thus demand for labor and imports,

$$d \log N_0 = d \log M_0 = -\alpha\gamma d\tau.$$

An export tax shock thus always causes a short-run recession, irrespective of η and σ.

We summarize this finding in the next proposition, and also derive implications for the case of stabilizing monetary policy.

Proposition 4. *An export tax shock of size $d\tau$ with passive monetary policy causes a recession*

$$d \log GDP_0 = -\alpha\gamma d\tau, \tag{28}$$

and reduces exports and imports, $d \log X_0 = -\gamma d\tau$ and $d \log M_0 = -\alpha\gamma d\tau$. The trade balance worsens for any $\gamma > 1/(1-\alpha)$,

$$\frac{dTB_0}{GDP} = -\left(\left(1-\alpha\right)\gamma - 1\right) d\tau. \tag{29}$$

With stabilizing monetary policy, the natural interest rate unambiguously falls

$$d \log\left(1+i_0\right) = -\frac{\alpha}{1-\alpha}\frac{\gamma}{\sigma\left(1-\alpha\right)+\alpha\gamma+\eta\frac{\alpha}{1-\alpha}} d\tau, \tag{30}$$

leading to an exchange rate depreciation, $d \log \mathcal{E}_0 = -d \log\left(1+i_0\right)$.

Figure 4 highlights the main differences between import and export tax shocks at $t = 0$. An import tariff hits import prices, and leads to substitution away from imports and any goods produced using imports. Whether GDP falls depends on relative elasticities. By contrast, an export tax hits export prices, which leads to lower goods demand and an unambiguous decline in GDP. The trade balance, for reasonable export demand elasticities $\gamma > 1/(1-\alpha)$, worsens rather than improves. Even when monetary policy is stabilizing, import and export tax shocks differ.

Why does Lerner symmetry not apply here? In the long run, trade must balance, so that all exports are ultimately used to pay for imports. This transaction—of exports for imports—is distorted in the same way by import and export taxes, leading to the Lerner symmetry result. In the short-run analysis of proposition 4, by contrast, there is

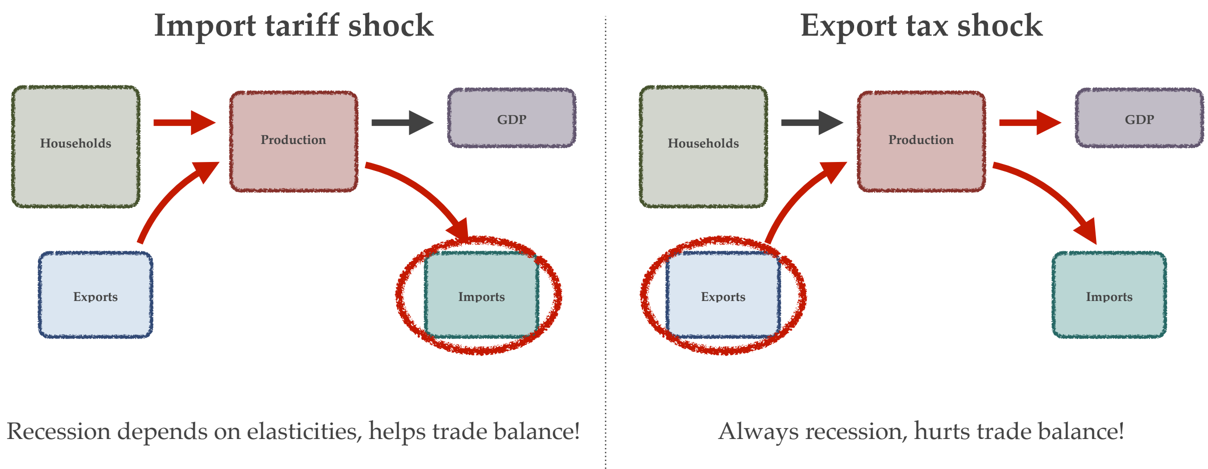


Figure 4: Import tariff vs. export tax

no need for trade to balance, and the home economy is free to adjust exports and imports separately in response to differing taxes.

3.4 Retaliation

So far, we have considered purely unilateral policies. Next, we consider a case in which the rest of the world retaliates and imposes symmetric import tariffs on domestic exports. The world's retaliatory tariff $\tau_t^r = \tau_t$ acts, in many ways, like the export tax in the previous subsection. For example, it reduces export demand according to

$$X_t = \alpha Y^* \cdot \left((1 + \tau_t^r) \frac{P_t}{\mathcal{E}_t} \right)^{-\gamma}$$

There are two differences, however. First, transfers to households are still given by (9), as import tariffs abroad do not contribute to domestic tax revenue. Second, τ_t^* does not enter the trade balance, since the price at the border excludes τ_t^r. TB_t is still given by (12).

Our next proposition characterizes the solution in this case. We focus on the case of passive monetary policy.

Proposition 5. *With retaliation, $\tau_0 = \tau_0^r = d\tau$, and passive monetary policy, domestic GDP declines whenever*

$$(1 - \alpha)\, \sigma + \alpha\gamma + \gamma > \eta, \tag{31}$$

in which case it falls by

$$d \log GDP_0 = -\alpha \left((1 - \alpha)\, \sigma + \alpha\gamma + \gamma - \eta \right) d\tau, \tag{32}$$

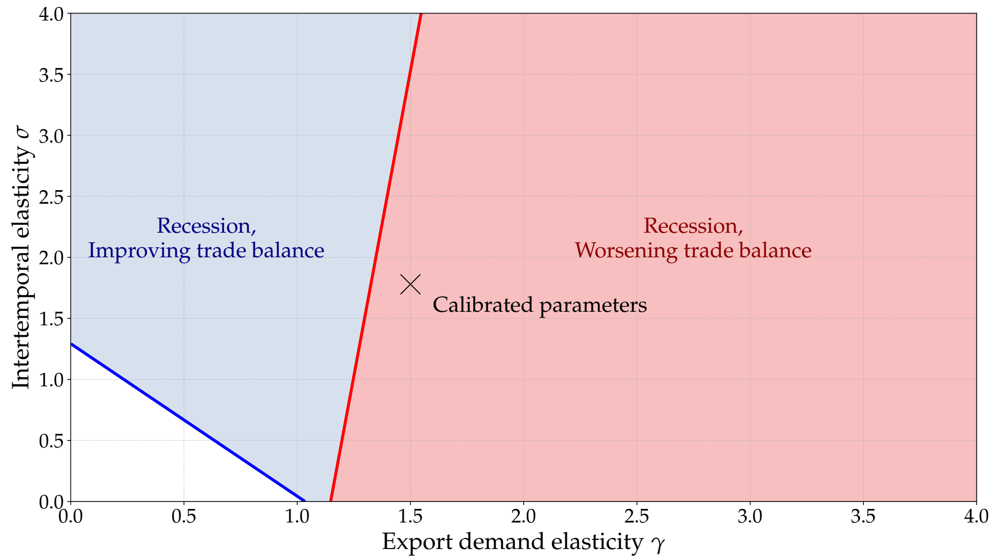


Figure 5: Retaliation: Conditions for recession and improving trade balance

and the trade balance changes by

$$\frac{dTB_0}{GDP} = -\frac{\alpha}{1-\alpha}\left(\left(1-\alpha\right)\left(\gamma-\eta\right)+\alpha\left(1-\alpha\right)\left(\gamma-\sigma\right)-\alpha\right)d\tau. \tag{33}$$

With stabilizing monetary policy, the natural rate falls by more than with unilateral tariffs.

Relative to (20), the recession condition (31) under retaliation adds a γ on the left, reflecting the direct hit to export demand from a retaliatory tariff. This new condition is easily satisfied if, for instance, $\gamma > \eta$. We illustrate this condition as the blue line in figure 5, varying σ and γ as we fix η and α at their calibrated values from table 1. Relative to the unilateral case in figure 3, retaliation rotates this line clockwise, making a recession even more likely.

The trade balance with retaliation, (33), is always strictly worse than without retaliation, by an additional term $\frac{\alpha}{1-\alpha}\gamma d\tau$ that also captures the direct hit to export demand. In fact, for plausible calibrations, this term is sufficiently large to cause the trade balance to deteriorate in response to the shock. In figure 5 these calibrations lie to the bottom right of the red line, a region that includes our reference calibration in table 1. For this calibration, we find that a 10% import tariff with retaliation implies a 2.3% decline in GDP, and a trade deficit of 0.2% of GDP.

One may wonder how it is possible that the home economy sees its trade balance fall, despite seemingly symmetric tariffs at home and in the rest of the world. The reason is that the rest of the world's import tariffs are only applied to imports from the home economy, not from each other. This effectively singles out the home economy and damages its competitiveness on global markets, which for high enough γ leads to a deterioration in the trade balance. In section 4.7, where we consider the case of a "large" home economy relative to the rest of the world, we show that this result hinges on the home economy being smaller than the rest of the world combined.

4 Extensions

Our baseline model in section 2 made several simplifying assumptions, including balanced trade in the initial steady state, fully Ricardian agents, full pass-through of tariffs to prices, a small open economy and more. In this section, we relax these assumptions. For simplicity, we focus mostly on the case of a unilateral import tariff by the home economy and a passive monetary policy.

4.1 Initial trade deficit

In our baseline model, we start from a steady state that features balanced trade: $X = M$. To break this, we now suppose that there is a permanent per-period transfer D in foreign goods from foreign to domestic households.[13] This implies a steady-state home trade deficit $TB = -D$. The following proposition then extends the key results of proposition 2.

Proposition 6. *With unbalanced trade in steady state and passive monetary policy, the home economy enters a recession in response to a unilateral temporary tariff shock if and only if*

$$\left(1 - \alpha^X\right)\sigma + \alpha^X \gamma > \eta$$

where α^X is the ratio of exports to gross output. If there is a recession, GDP falls by

$$d\log GDP_0 = -\alpha^M \left(\left(1 - \alpha^X\right)\sigma + \alpha^X \gamma - \eta\right) d\tau$$

where α^M is the ratio of imports to gross output, and CPI inflation is $d\log P_0 = \alpha^M d\tau$.

Now that the export and import shares no longer equal the same α, proposition 6 shows that they play distinct roles in the transmission of a tariff shock. The export share determines the relative weight on the export elasticity γ in the recession condi-

[13] This D could reflect, for instance, the proceeds from issuing a global reserve currency. If D is instead fixed in home goods, Proposition 6 goes through unchanged.

tion, but the import share—which governs the direct importance of tariffs to domestic costs—determines both the inflation effect and the magnitude of any recession.

4.2 Hand-to-mouth agents

Our baseline results assumed a single domestic representative agent, who can frictionlessly borrow and save over time. We now instead assume that a fraction $\mu \in (0, 1)$ of households are hand-to-mouth: they are unable to hold assets, and must consume exactly their labor income in every period. We assume that the remaining $1-\mu$ of households continue to borrow and save frictionlessly, and for simplicity we assume that per-capita labor income $W_t N_t$ is the same for all households.

Proposition 7. *With a share μ of hand-to-mouth households and passive monetary policy, the home economy enters a recession in response to a temporary tariff shock if and only if*

$$(1-\alpha)(1-\mu)\sigma + (1-\alpha)\mu + \alpha\gamma > \eta \tag{34}$$

If there is a recession, GDP falls by

$$d \log GDP_0 = -\alpha \frac{(1-\alpha)(1-\mu)\sigma + (1-\alpha)\mu + \alpha\gamma - \eta}{1-(1-\alpha)\mu} d\tau, \tag{35}$$

and CPI inflation is still $d \log P_0 = \alpha d\tau$.

Relative to the original condition (20), condition (34) replaces the elasticity of intertemporal substitution σ with $(1-\mu)\sigma + \mu$. This is because hand-to-mouth agents effectively act as if they have σ of 1, cutting their consumption one-for-one with rising prices. If σ is greater than 1, as in our calibration, then this makes a recession less likely. If there is a recession, however, it is amplified by a Keynesian multiplier of $\frac{1}{1-(1-\alpha)\mu}$, which reflects the fact that μ hand-to-mouth agents spend $1-\alpha$ of current income domestically.

4.3 Incomplete pass-through

We now consider a simple model of incomplete pass-through from tariffs to domestic prices. More details are provided in appendix C.3.

Assume that there is a continuum of monopolistically competitive "importers", each of which purchases raw imports on the international market at price $(1+\tau_t)\mathcal{E}_t$ and then costlessly transforms them into a differentiated variety. A CES aggregate of all varieties with price P_t^M enters the domestic production function (4). Importers set prices at an intended markup μ^I over marginal cost; but a fraction $1-\psi_M$ set prices one period ahead, and cannot adjust them in response to shocks. As a result, in response to a surprise tariff shock at $t=0$, the pass-through of tariffs and exchange rates to import prices will be only ψ_M: $d\log P_0^M = \psi_M(d\tau_t + d\log \mathcal{E}_t)$.

We then have the following extension of proposition 2, where we take the limit $\mu^I \to 1$ for simplicity.

Proposition 8. *In the model with importers and incomplete pass-through, all price and quantity effects in response to a temporary tariff shock are equal to those in proposition 2, multiplied by ψ_M. The condition (20) for a recession is unchanged.*

In short, incomplete pass-through of the tariff shock scales down the import price shock and all its downstream effects by the same factor ψ_M. The signs of each effect, however, are unchanged, so that the same condition $(1-\alpha)\sigma + \alpha\gamma > \eta$ still governs whether or not we have a recession.[14]

4.4 Different consumption and export technologies

Our baseline model assumes that the same good is used both for consumption and exports. We now allow for consumption and exports to be different goods, each produced using technologies of the form (4), with potentially different import substitution elasticities η^C and η^X and steady-state import shares θ^C and θ^X. We continue to assume that consumption and exports have steady-state shares α and $1-\alpha$ of combined gross output, and that steady-state trade is balanced, so that $(1-\alpha)\theta^C + \alpha\theta^X = \alpha$.

Proposition 9. *With distinct production technologies for consumption and exports and passive monetary policy, the home economy enters a recession in response to a temporary tariff shock if and only if*

$$(1-\alpha)(1-\theta^C)\theta^C(\sigma-\eta^C) + \alpha(1-\theta^X)\theta^X(\gamma-\eta^X) > 0. \tag{36}$$

If there is a recession, GDP in each sector changes by $d\log GDP_0^C = -\theta^C(\sigma-\eta^C)d\tau$ and $d\log GDP_0^X = -\theta^X(\gamma-\eta^X)d\tau$, and prices change by $d\log P_0^C = \theta^C d\tau$ and $d\log P_0^X = \theta^X d\tau$.

We see that in each sector, if there is an overall recession, the GDP change depends on the gap between the relevant demand elasticity (σ or γ) and import substitution elasticity (η^C or η^X). This is scaled by the share of imports in the production function (θ^C or θ^X), which also governs the price effect.

[14] If there is also incomplete pass-through $\psi_X < 1$ on the export side, then ψ_X will multiply γ in all formulas.

The recession condition (36) then scales the sectoral GDP changes by $(1-\alpha)(1-\theta^C)$ and $\alpha(1-\theta^X)$, which are proportional to each sector's GDP share.[15] When $\theta^C = \theta^X = \alpha$ and $\eta^C = \eta^X \equiv \eta$, it reduces to our original condition (1).

In the original Gali and Monacelli (2005) case where exports are not produced using imported inputs at all, (36) becomes $\sigma > \eta^C \equiv \eta$. This is closely related to the condition in Guerrieri et al. (2022), and is also the condition emphasized for tariff shocks by Monacelli (2025), who further restricts to the special case $\sigma = 1$.

Alternatively, starting from our baseline model with $\theta^C = \theta^X = \alpha$, raising θ^X increases the importance of the export sector in the condition (36). For instance, if we suppose that exports are twice as import-intensive as consumption, while keeping $\alpha = 1/9$ and a single import substitution elasticity η, then $\theta^X = 1/5$ and $\theta^C = 1/10$, and (36) can be written as $0.82\sigma + 0.18\gamma > \eta$, rather than our original $0.89\sigma + 0.11\gamma > \eta$.

4.5 Durables

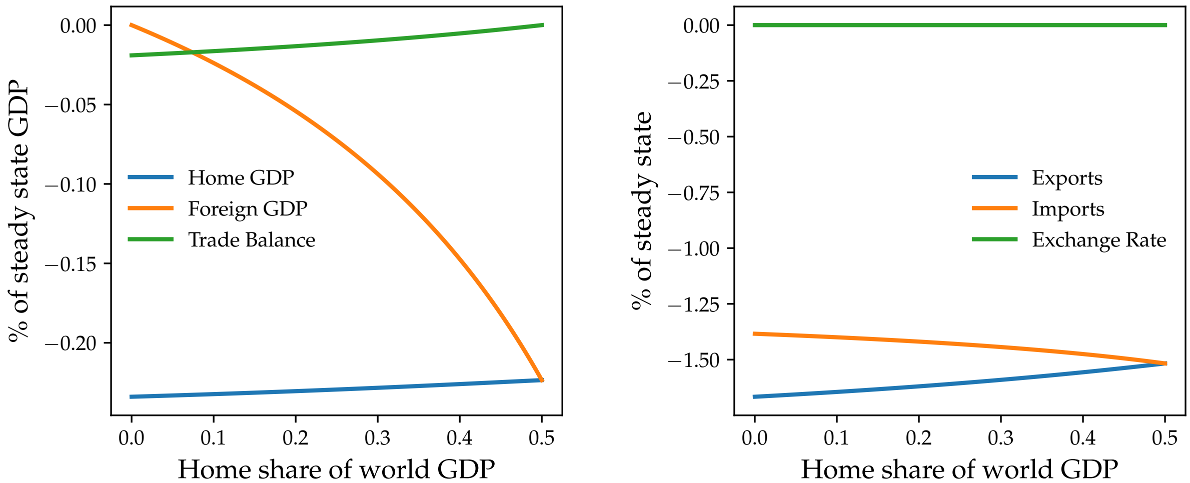
A crucial elasticity in our recession condition (20) is the intertemporal elasticity of substitution σ, which measures the willingness of consumers to postpone purchases in the face of higher prices. A realistic model of σ includes durable goods. We describe the extension of our model to durable goods in more detail in section 6.2, but here we explain why this setup effectively delivers an intertemporal substitution elasticity σ that is much larger than the nondurable intertemporal substitution elasticity, which we denote by ν.

The extension considers a model where households try to smooth both nondurable consumption and the stock of durables over time, with durables subject to quadratic adjustment costs. Durables and nondurables are produced by the same domestic production technology. We denote by ϵ_D the elasticity of durable expenditure to durable Q. Consider then a purely transitory shock to the price of durables $d\log P_0$, with the nominal interest rate unchanged. Durable expenditure is then, by definition,

$$d\log C_0^D = \epsilon_D d\log Q_0.$$

Taking the limit of an arbitrarily short period, we show in appendix E that $d\log Q_0 \simeq -d\log P_0$. Hence, ϵ_D is also the elasticity of durable expenditure to a transitory change in the durable price. Since for nondurable expenditure we have $d\log C_0^{ND} = -\nu d\log P_0$ where ν is nondurable intertemporal substitution, and since aggregate consumer spend-

[15] Interestingly, the condition features a non-monotonicity: the weight on a sector in (36) is low either if its import share θ is close to 0 (because then it is unaffected by tariffs) or if its import share θ is close to 1 (because then it contributes little to GDP).



(a) GDP and trade balance

(b) Trade flows and exchange rate

Figure 6: Large open economy with retaliation

ing is the sum $C_0 = C_0^{ND} + C_0^{D}$, we therefore have that $d \log C_0 \simeq -\sigma d \log P_0$, where

$$\sigma = (1-\omega)\,\nu + \omega\epsilon_D \tag{37}$$

Since estimates of ϵ_D are generally much larger than ν, on the order of 8 to 12 (see, e.g. Baker et al. 2019 and McKay and Wieland 2021), this suggests that the σ in our recession condition (1) should also be thought of as being significantly greater than ν (which is often thought to be around 1).

4.6 Nonlinearities from large tariffs

Our main results use a first-order approximation of the model. In appendix figure 15 we plot a nonlinear solution of the model, varying τ_0 from 0 to 50%, for our baseline calibration. We see some nonlinearities, especially for trade flows. In levels, the sensitivity of imports and exports to tariffs declines with larger tariffs. This is because larger tariffs compress trade volumes, leaving a smaller base for additional tariffs to influence.

4.7 Large open economy

Our baseline model assumes a small open economy. In this section, we extend our analysis to a large open economy. We sketch the main pieces of this extension and relegate the details to the appendix.

We take the world economy to consist of a large open home economy, with a share λ of world GDP, and a mass of small open economies that make up the remaining $1-\lambda$ share of world GDP. Our previous model is the special case where $\lambda \to 0$. We assume that all economies continue to produce using domestic labor and imports according to (4). Imports are a CES bundle of all other countries' products, with weights proportional to their GDP shares, and elasticity of substitution γ. For example, the home economy's imports are given by

$$M_{H0} = \left(\frac{1}{1-\lambda} \int_{\lambda}^{1} m_{Hi0}^{\frac{\gamma-1}{\gamma}} di \right)^{\frac{\gamma}{\gamma-1}}$$

where m_{Hi0} are imports from country i. An individual foreign country i's imports are given by

$$M_{i0} = \left(\lambda m_{iH0}^{\frac{\gamma-1}{\gamma}} + \int_{\lambda}^{1} m_{ij0}^{\frac{\gamma-1}{\gamma}} dj \right)^{\frac{\gamma}{\gamma-1}}$$

where m_{ij0} are imports from country j. Since the home economy is large in the import basket of all other countries, an import tariff shock that reduces home imports from the rest of the world will measurably reduce the rest of the world's exports.

In figure 6 we solve the large open economy model, varying the size of the home economy from 0% (the small open economy limit) to 50% of world GDP. We focus on the case with retaliation here. We see in panel (a) that a larger home economy is itself less affected by a trade war, while the rest of the world is affected more strongly. If the home economy makes up half of the world economy, the GDP decline is symmetric across countries. Panel (b) shows that the trade balance deterioration we found in section 3 is always present, as long as the home economy is less than half of the world economy. For reference, in nominal terms the U.S. accounts for approximately 25% of world GDP.

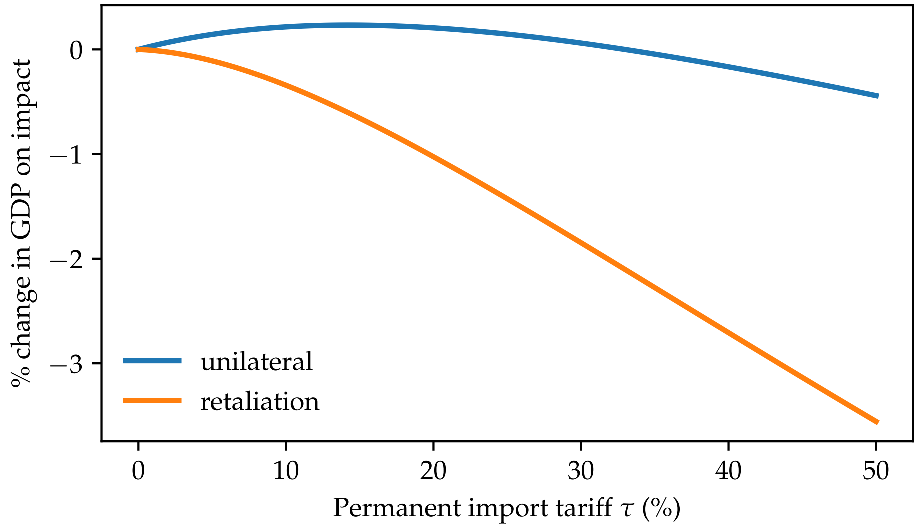
These results suggest that size is power for a temporary trade war: whoever is larger, the home economy or the retaliating rest of the world, takes less damage from a trade war and sees its own trade balance improve.

4.8 Recession from permanent tariffs

So far, we have focused on temporary tariff shocks. In the model described in section 2, permanent tariffs do not cause a recession, as the economy immediately adjusts to its new steady state (proposition 1).

Such a rapid adjustment, however, seems unrealistic, especially in light of the distinction between short-run and long-run elasticities highlighted in section 2.3. We now modify the model to take this distinction into account. In particular, we assume that the

Figure 7: Recessions from sudden permanent tariff surprises



short-run γ and η in period 0 are calibrated as in table 1, but that from period 1 onward these elasticities instead take the higher long-run values $\overline{\gamma}$ and $\overline{\eta}$, where $\gamma = (3/8) \cdot \overline{\gamma}$ and $\eta = (3/8) \cdot \overline{\eta}$ following Boehm et al. (2023), as discussed in section 2.3.

With $\eta < \overline{\eta}$, the nonlinear effect of a large import tariff on domestic prices P_t in (5) is larger in the short run ($t = 0$) than in the long run ($t \geq 1$). This captures the notion that firms may not be able to immediately re-shore their supply chains in the short run, and are only able to substitute toward domestic inputs after some time. With domestic output temporarily more expensive, both domestic consumption and exports suffer.

Meanwhile, the first-order effect of $\eta < \overline{\eta}$ is to reduce import substitution in the short run, which also reduces demand. At the same time, $\gamma < \overline{\gamma}$ means that foreign firms substitute away from domestic goods by less in the short run. This supports short-run GDP.

Figure 7 simulates permanent tariff surprises of different sizes in the two cases of unilateral tariffs and tariffs with symmetric retaliation. We see that the forces supporting GDP in the short run dominate for small unilateral import tariffs.[16] As the tariff gets larger, however, the nonlinear effect described above dominates, and the economy experiences a recession as it adjusts to the permanently higher tariff. Meanwhile, in the retaliation case, a recession occurs for any size of the tariff.

[16] Here, to make figure 7 cleaner, we assume that there is also some nominal rigidity on the upside, so that a slight increase in labor and GDP is possible.

5 Welfare

We now consider the welfare effects of a tariff shock for the home economy.

5.1 First-order welfare effects

We start with a general result for the first-order effect of any tariff shock—possibly persistent or permanent. We will use the notation $PV(x_t) \equiv \sum_{t=0}^{\infty} \beta^t x_t$ to denote the present discounted value of any sequence $\{x_t\}$.

Proposition 10. *Starting from the steady state, let $\{d\tau_t\}_{t=0}^{\infty}$ be a tariff shock, and let $\{d\tau_t^r\}_{t=0}^{\infty}$ be the accompanying retaliation shock. Then the first-order effect on the utility of the domestic household, normalized by $u'(C)C$ to put in units of steady-state consumption, is:*

$$\underbrace{\frac{\alpha}{1-\alpha} \frac{\eta PV(d\tau_t) - (1-\alpha)\gamma PV(d\tau_t^r)}{(1-\alpha)(\gamma-1)+\eta}}_{\text{terms-of-trade effect}} + \underbrace{\left(1 - \alpha \frac{1}{(1-\alpha)(\gamma-1)+\eta}\right) PV(d \log GDP_t)}_{\text{output-gap effect}}. \tag{38}$$

Proof. See appendix D.1. □

In (38), the first-order welfare effect has two components.

First, the traditional *terms-of-trade effect* of tariffs is due to the endogenous change in export prices on international markets—which is only possible because the home economy has market power ($\gamma < \infty$). Holding GDP fixed, an increase in import tariffs $d\tau_t$ causes a decline in import demand proportional to the elasticity η. In partial equilibrium, this improves the trade balance. But since the trade balance must still be zero in the long run, the exchange rate strengthens in general equilibrium—in inverse proportion to the elasticity $(1-\alpha)(\gamma-1)+\eta$ of the trade balance to exchange rates (see also (14)–(15)). Domestic exports then sell at a higher price on international markets, improving the terms of trade and ultimately the home economy's welfare. There is a similar effect, but with the opposite sign, from retaliatory tariffs.

Second, the *output-gap effect* arises from GDP possibly falling below its natural level. If the home economy lacked market power, this would have a one-for-one effect on welfare, but this effect is slightly attenuated by the endogenous strengthening the exchange rate, which also improves the terms of trade.

Discussion and numerical illustration. Typical analyses of optimum tariffs start with the positive terms-of-trade effect of a small tariff, and then determine how high the tariff

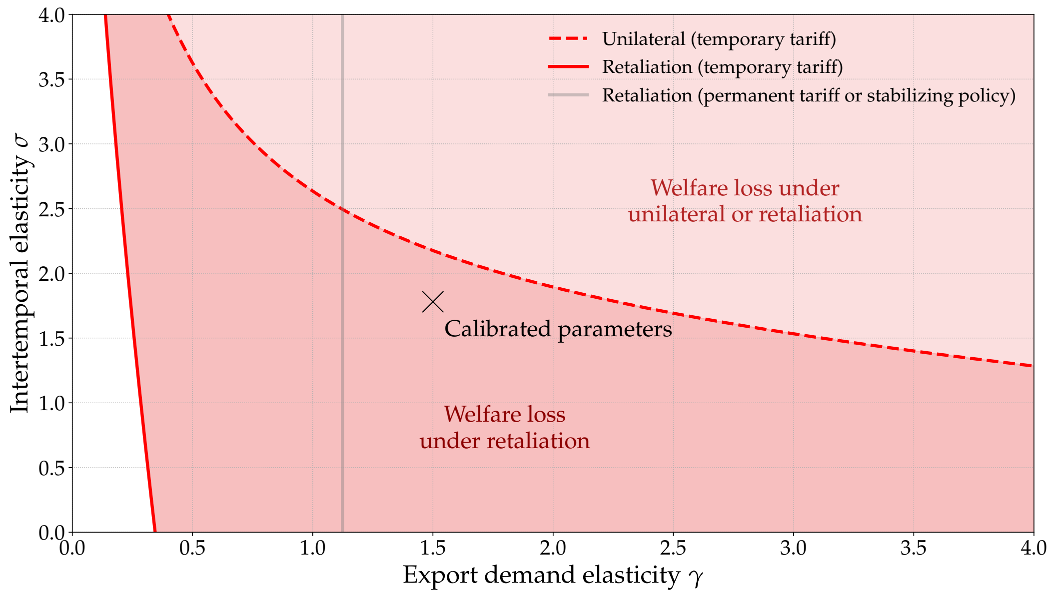


Figure 8: When does a tariff cause a first-order welfare loss?

can be raised until its nonlinear distortionary effects offset this benefit. We will consider these nonlinear effects in the next section. For the first-order effect, here we make two observations.

First, with retaliation, it is quite plausible that the first-order terms-of-trade effect will be negative: this requires only that γ is mildly higher than η, so that $(1-\alpha)\gamma > \eta$. Assuming retaliation, therefore, the welfare effect of a small tariff can be negative for the home country, even in the absence of a recession.

Second, the possibility of a recession, with the output gap contributing negatively to (38), provides another source of first-order welfare losses that is missing in the usual long-run analysis.

We illustrate this numerically by revisiting the case of a temporary shock at date 0, with the $\beta \to 1$ limit and a constant nominal rate as considered in previous sections. Here, the present values in (38) are simply the date-0 shocks: $PV(d\tau_t) = d\tau_0$, $PV(d\tau_t^r) = d\tau_0^r$, and $PV(d\log GDP_t) = d\log GDP_0$.

Figure 8 displays the results as we vary σ and γ, holding α and η fixed as in figures 3 and 5. For sufficiently high γ and σ, there is a first-order welfare loss even with a unilateral tariff, because a negative output-gap effect dominates a positive but smaller terms-of-trade effect. With retaliation $\tau_0^r = \tau_0$, however, a welfare loss is almost inevitable, except when the export elasticity γ is extremely small. This is because a recession is very likely (as in figure 5), so that a negative output-gap effects dominates, and for larger γ this is actually reinforced by a negative terms-of-trade effect.

Alternatively, in the case of either a permanent tariff—where a constant-nominal-rate policy achieves $d \log GDP_t = 0$—or a temporary tariff with stabilizing monetary policy, the output-gap effect in (38) is zero. If $\eta > 0$, the terms-of-trade effect is always positive in the unilateral case, reflecting the standard motivation for an optimal tariff.[17] But if $(1-\alpha)\gamma > \eta$, then with retaliation the terms-of-trade and thus the welfare effect is still negative, even in the absence of a recession. Figure 8 depicts this threshold in light gray.

5.2 Nonlinear welfare effects

The first-order effects in the previous section do not include the economic distortion from tariffs, since any distortionary effects are second-order starting from the steady state with zero tariffs. To study the costs of distortion, and also to investigate the robustness of our first-order analysis, we now look at the nonlinear effects of large tariff shocks. For simplicity, we will continue to focus on the short run: date-0 shocks with the limit $\beta \to 1$.

We define $\mathcal{W}(\tau)$ to be the change in total home utility from setting $\tau_0 = \tau$ vs. $\tau_0 = 0$, assuming passive monetary policy and normalizing by $u'(C)C$ as in proposition 10. We analogously define $\mathcal{W}^{stab}(\tau)$ to be the utility effect of the tariff when there is stabilizing monetary policy, which achieves full employment. Finally, we define $\mathcal{W}^{corr}(\tau)$ to be the utility effect when the Home household receives a transfer $T_t^{corr}(\tau)$ that exactly offsets any change in its foreign-currency export prices resulting from the tariff.[18] This removes any terms-of-trade effects.

We then define the nonlinear decomposition

$$\mathcal{W}(\tau) = \underbrace{\mathcal{W}(\tau) - \mathcal{W}^{stab}(\tau)}_{\text{output-gap effect}} + \underbrace{\mathcal{W}^{stab}(\tau) - \mathcal{W}^{corr}(\tau)}_{\text{terms-of-trade effect}} + \underbrace{\mathcal{W}^{corr}(\tau)}_{\text{distortion effect}} \tag{39}$$

for which we have the following result.[19]

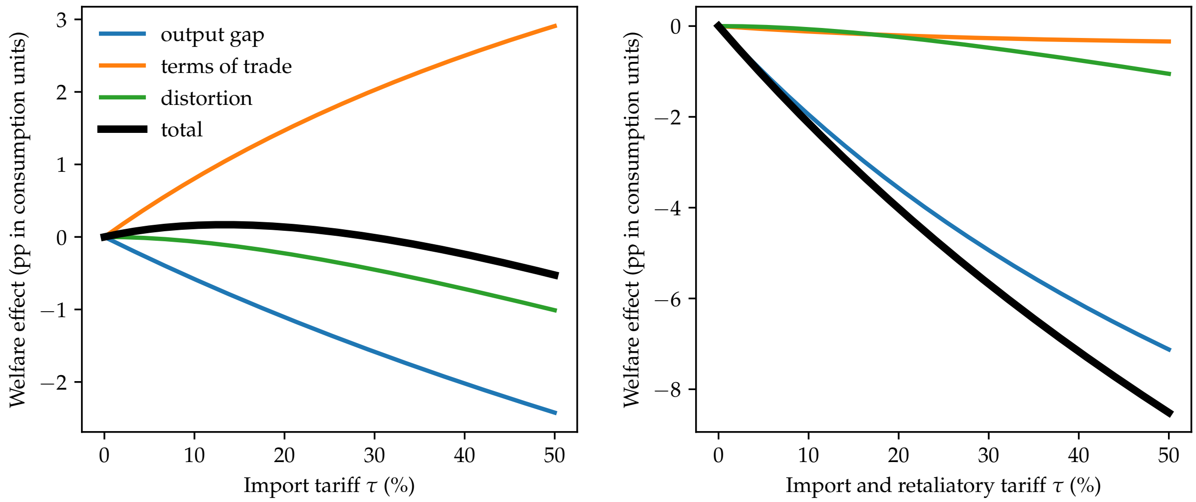
Proposition 11. *To first order in τ, in either the unilateral case ($\tau_0 = \tau$ and $\tau_0^r = 0$) or the retaliation case ($\tau_0 = \tau_0^r = \tau$), the output-gap and terms-of-trade effects in (39) equal those defined in (38).*

[17] Here we assume that $(1-\alpha)(\gamma-1)+\eta > 0$, so that the elasticity of the trade balance to exchange rates has the right sign.

[18] This transfer is defined by the differential equation $(T_t^{corr})'(\tau) = -\frac{d(P_t(\tau)/\mathcal{E}_t(\tau))}{d\tau} \cdot X_t(\tau)$, where $P_t(\tau), \mathcal{E}_t(\tau), X_t(\tau)$ are the price, exchange rate, and exports when the time-0 tariff is τ.

[19] Here, we remove the output gap first, so that the terms-of-trade effect equals the neoclassical effect with full employment.

Figure 9: Decomposition of nonlinear welfare effects from tariff



The distortion effect is zero to first order, and to second order in τ is

$$\mathcal{W}^{corr}(\tau) \simeq -\frac{1}{2}\frac{\alpha}{1-\alpha}\frac{d\log M_0}{d\tau}\tau^2 \tag{40}$$

in either the unilateral or retaliation case.

Proof. See appendix D.2. □

To second order, therefore, the cost of the "distortion effect" in (39) is given by a Harberger triangle, which scales with the responsiveness of date-0 imports to the tariff τ. This is a standard result: at the margin, the distortionary cost of a tariff depends on the interaction between the tariff and the quantity response it induces. In the absence of terms-of-trade effects, this is the typical cost from distorting trade.

How large is the distortion effect characterized in (40) relative to the other two effects? Figure 9 plots the decomposition (39) for our baseline parameters from table 1, given tariff shocks up to $\tau = 0.5$. In the unilateral case, the terms-of-trade effect is slightly larger than the output-gap effect, making a strictly positive tariff optimal, but the distortion effect causes overall welfare to decline above $\tau = 0.15$.[20] In the retaliation case, by contrast, all three effects are negative. The output-gap effect dominates, driving an enormous welfare loss from large tariffs.

[20]The terms-of-trade effect here, which implies that with stabilizing monetary policy the optimal tariff would be over 50%, is arguably too large, driven by the fact that our calibration (intended to reflect short-run responsiveness) has relatively low η and γ, and therefore overstates the exchange rate movement that is needed to achieve long-run trade balance. Appendix D.3 recalculates figure 9 with a long-run calibration of higher η and γ, finding a much smaller terms-of-trade effect and optimal tariff.

Table 2: Calibration for quantitative model

	Description	Value		Description	Value
σ	Intertemporal elasticity	1.79	ϕ_π	Taylor rule coefficient	1.5
γ	Export elasticity	1.5	ρ	Inertia in Taylor rule	0.8
η	Import elasticity	1.15	ε_D	Durable elasticity to q	8.2
ϕ	Frisch elasticity of labor supply	1	ρ_G	Persistence of tariff shock	0.75
α	Import share	0.11	κ	Slope of wage Phillips curve	0.05
β	Discount factor	0.995	ζ	Elasticity of UIP wedge to NFA	0.0001

We conclude that the output-gap effect of tariffs—which is not considered in traditional, long-run trade frameworks—can easily play a major or even dominant role in welfare analysis.

6 Quantitative exploration

We now turn to our quantitative model. We first consider an extension of our model to persistent shocks and then explicitly introduce durable goods and inventories.

6.1 Phillips curve and monetary policy rules

We augment the setup of section 2.1 to include a symmetric wage adjustment rule instead of downward nominal wage rigidity. We follow the standard New Keynesian formulation, in which workers are off their labor supply curves at each time t t, and belong to unions who get Calvo opportunities of resetting their nominal wage W_t on their behalf, as in Erceg, Henderson and Levin (2000). This formulation leads to a linearized Phillips curve for nominal wage inflation

$$w_t - w_{t-1} = \kappa \left(\frac{1}{\sigma} c_t + \frac{1}{\phi} n_t - w_t - p_t \right) + \beta \mathbb{E} \left[w_{t+1} - w_t \right]$$

where ϕ is the Frisch elasticity of labor supply in worker's preferences (ie flow utility is $\frac{C_t^{1-1/\sigma}}{1-1/\sigma} + b \frac{N_t^{1+1/\phi}}{1+1/\phi}$ where b is a constant), and we write $x_t \equiv \log X_t / X$ for the log deviation of variable $X_t \in \{W_t, C_t, N_t, P_t\}$ from steady state.

We consider three types of monetary policy rules: first, our "passive monetary policy" rule is now simply a fixed nominal interest rate $i_t = i$, made determinate by a long-run nominal anchor for the nominal exchange rate; second, we consider a rule that targets zero wage inflation at all dates and therefore implements the flexible-wage allocation (henceforth "natural rate rule"); and finally, we consider a Taylor rule that responds to

CPI inflation with some inertia $i_t = \rho i_{t-1} + (1-\rho)\,\phi_\pi\,(p_t - p_{t-1})$ (henceforth "Taylor rule").

We note from (11) that the net foreign asset position of the country in foreign currency units, $\text{nfa}_t = A_t/\mathcal{E}_t$, satisfies the balance of payments equation

$$\text{nfa}_t - \text{nfa}_{t-1} = TB_t + i^*\text{nfa}_{t-1}$$

Given our representative-agent incomplete-market environment, the model is not stationary, with transitory shocks having permanent effects on the NFA. As is common in the literature (e.g. Schmitt-Grohé and Uribe 2003), we make the model stationary to solve it more easily. We do this by assuming a wedge in the UIP condition, (7), $\mathcal{E}_t = \frac{(1+i^*)\exp\{\zeta\cdot\text{nfa}_t\}}{1+i_t}\mathcal{E}_{t+1}$, where ζ is chosen to be small enough that it does not meaningfully affect short-run dynamics while making sure the NFA returns to its steady-state value in the very long-run. This type of wedge is very common in the literature (e.g. Gabaix and Maggiori 2015, Itskhoki and Mukhin 2021).

We calibrate the economy with the exact same parameters as we have considered so far, $\sigma = 1.78$, $\gamma = 1.5$ and $\eta = 1.15$. We consider a quarterly calibration frequency and set $\kappa = 0.05$ by using the standard Calvo formula with frequency of wage adjustment of 0.2 from Grigsby et al. (2021) and no real rigidity. We set standard values for the Frisch elasticity, $\phi = 1$, the discount factor $\beta = 0.995$ (implying an annual steady state interest rate of 2%), the Taylor rule responsiveness coefficient $\phi_\pi = 1.5$, and inertia in the Taylor rule $\rho = 0.8$. Finally, we solve the model linearly, set the size of the tariff shock at 10% initially, and assume that it takes an AR(1) form with persistence of 0.75 so that it is 1% by the end of year 2 and virtually zero by the end of year 4. Table 2 summarizes our calibration parameters.

Results with passive monetary policy. For the passive monetary policy scenario, figure 10 visualizes the full impulse response to a 10% persistent unilateral tariff shock in this augmented model. The patterns are very similar to those described in the one-period analysis of section 3. At this baseline calibration, GDP, output and domestic consumption all fall, while the trade balance improves because exports fall, but imports fall by more, leading the country to accumulate a net foreign asset position.

Relative to the one-period analysis, wage adjustment brings in somewhat richer dynamics. Tariffs pass through fully to import prices, but the recession causes mild nominal wage deflation initially, mitigating the increase in domestic prices a little. This effect, however, is quantitatively small given the empirically realistic small slope of the wage

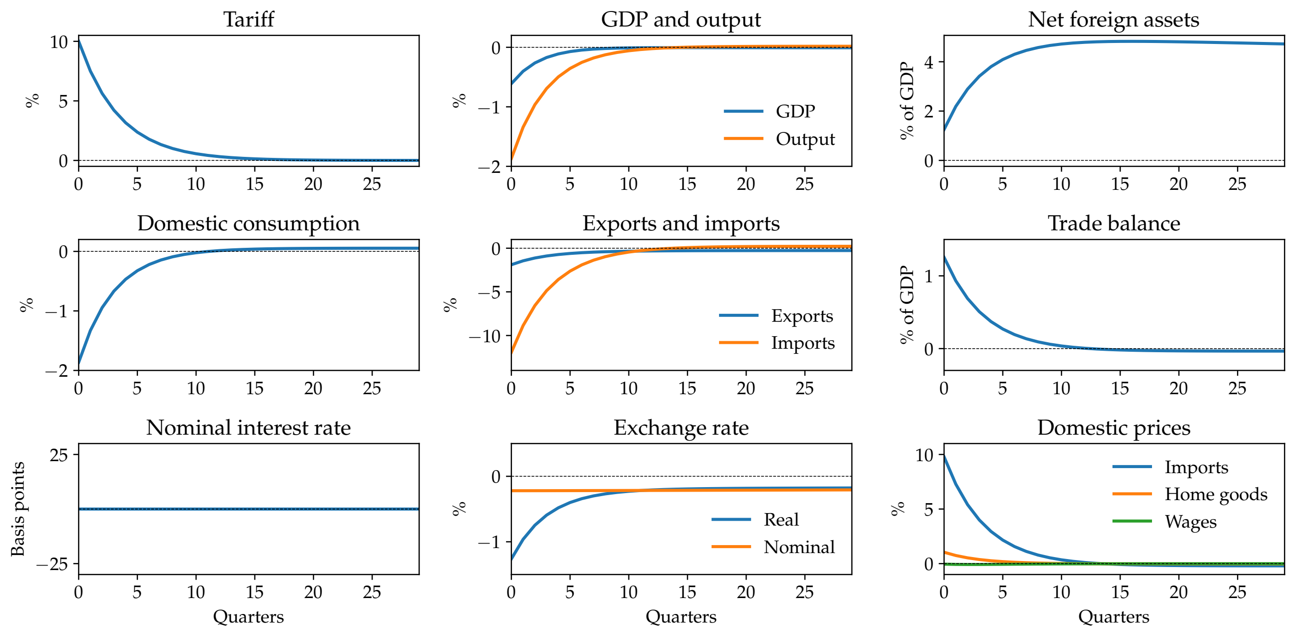


Figure 10: Impulse response to persistent unilateral tariff shock under passive monetary policy

Phillips curve. On the whole, home goods prices do increase and are expected to revert back, leading to a decline in domestic consumption driven by intertemporal substitution and to a decline in exports driven by a decline in foreign competitiveness. Hence, the same mechanisms are at play as described in section 2.1, and quantitatively the formulas from this section still predict the outcomes of the dynamic model really well: for instance, the GDP decline in the quarter of the tariff announcement is -0.61% (equation (21) gives -0.67%) while the trade balance improving by 1.25% of GDP (equation (22) gives 1.29%). In contrast to the static analysis, the expectation of a buildup in the NFA causes a slight appreciation of the nominal exchange rate initially, in spite of the lack of monetary policy response.

Figure 17 in the appendix considers the case of a retaliatory tariff. Again, the same mechanisms are at play as in the analysis of section 3. Now, exports decline not just because of the loss of competitiveness but also because of the retaliation; as a result, the trade balance deteriorates, and GDP falls by more. Here again, the static formulas predict the outcome very well.

Other monetary policy scenarios. We now consider scenarios with alternative monetary policy responses and with retaliation. Appendix E presents the full set of impulse responses for all cases, while Table 3 summarizes the main quantitative results.

Consider first the unilateral tariff scenario. The Taylor rule, even in inertia, responds

Table 3: Impact effects of 10% tariff, alternative scenarios

Scenario	Unilateral			Retaliation		
Outcome	No MP	Taylor rule	Natural rate	No MP	Taylor rule	Natural rate
GDP	-0.61%	-1.10%	-0.25%	-2.05%	-2.45%	-0.87%
Trade balance (of GDP)	1.25%	1.26%	1.29%	-0.19%	-0.18%	-0.20%
Nominal interest rate	0bp	30bp	-6bp	0bp	29bp	-22bp
Nominal exchange rate	-0.22%	-0.47%	0.27%	0.03%	-0.16%	0.87%

to the price inflation created by the tariff shock by tightening, raising nominal interest rates by 30 basis points. This, in turn, worsens the recession and appreciates the currency further. By contrast, the natural rate rule is accommodative since, as in section 3.2, the shock is recessionary and puts downward pressure on the natural rate of interest. With a decline of -6bp in the nominal rate, the recession is mitigated to -0.26% of GDP, and so is the nominal exchange rate appreciation. Under retaliation, with a much more severe recession in the scenario without monetary policy response, the Taylor rule has a similar contractionary effect while the natural rate rule mitigates to a similar extent. These results echo the findings in the New Keynesian literature studying tariff shocks, which find that the optimal monetary policy response to a tariff is to look through the inflation and cut interest rates when the tariffs are recessionary (Bergin and Corsetti 2023, Monacelli 2025).

6.2 Durables

Durable goods such as cars and phones have been at the center of the question of the effects of tariffs. In our baseline model, we have argued that the effective elasticity of intertemporal substitution should be high for this exact reason; here we flesh out the durable model in more detail and consider the dynamics that arise from both the temporary nature of new tariffs and the anticipation of future tariffs.

In the model with durables, households enjoy the stock of a durable good D_t in addition to the consumption of the nondurable good C_t. Their objective function is separable with curvature $1/\nu$ on both consumption C_t and on the stock of durables D_t, namely,

$$\sum_{t=0}^{\infty} \beta^t \left(\frac{\left(C_t^{ND}\right)^{1-1/\nu}}{1-1/\nu} + \varphi \frac{D_t^{1-1/\nu}}{1-1/\nu} \right)$$

where $\varphi > 0$ is a normalization constant. Durables depreciate at rate δ, and they are produced using the same, domestic production technology as nondurable consumption goods. Adjusting durables requires paying a quadratic cost $\frac{1}{2\delta\epsilon_D}\left(\frac{D_t - D_{t-1}}{D_t}\right)^2 D_t$ in units of

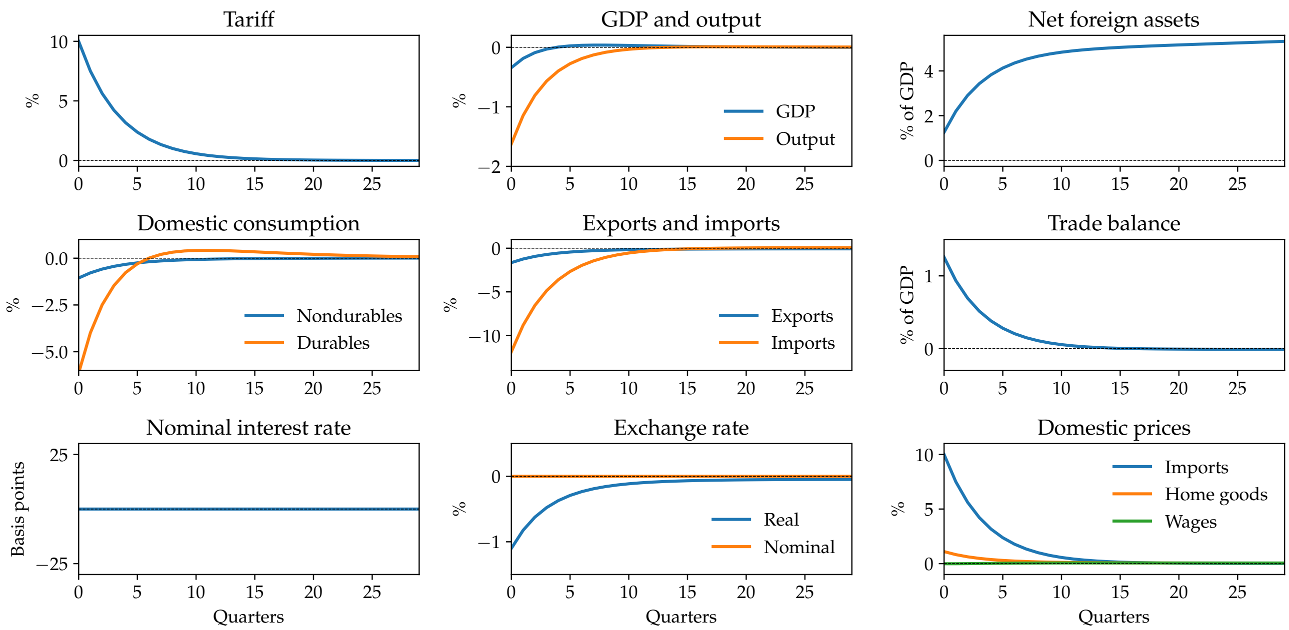


Figure 11: Impulse response with unilateral tariff, passive monetary policy, and durables

home goods. Hence, the household budget constraint is now:

$$P_t C_t^{ND} + P_t C_t^D + P_t \frac{1}{2\delta\epsilon_D}\left(\frac{D_t - D_{t-1}}{D_t}\right)^2 D_t + A_t = W_t N_t + (1 + i_{t-1}) A_{t-1} + T_t$$

where $C_t^D \equiv D_t - (1-\delta) D_{t-1}$ is expenditure on durables.

The Euler equation for non-durables C_t is still (19). The first order condition for durables, however, involves dynamics that can be written using Q-theory type equations, namely:

$$\frac{D_t - D_{t-1}}{D_t} = \delta\epsilon_D (Q_t - 1) \tag{41}$$

$$Q_t = \varphi\left(\frac{D_t}{C_t}\right)^{-1/\nu} - \frac{1}{2\delta\epsilon_D}\left(\frac{D_t - D_{t-1}}{D_t}\right)^2 + \frac{1}{1+r_t}(Q_{t+1} - \delta) \tag{42}$$

The market clearing condition (13) now becomes

$$Y_t = X_t + C_t^{ND} + C_t^D \tag{43}$$

To simulate the model, we set $\nu = 1$, but $\epsilon_D = 8.2$ using the evidence on durable expenditure elasticity to expected changes in sales taxes documented in Baker et al. (2019). We also calibrate $\delta_D = 20\%$ as in McKay and Wieland (2021), and set the share of durable

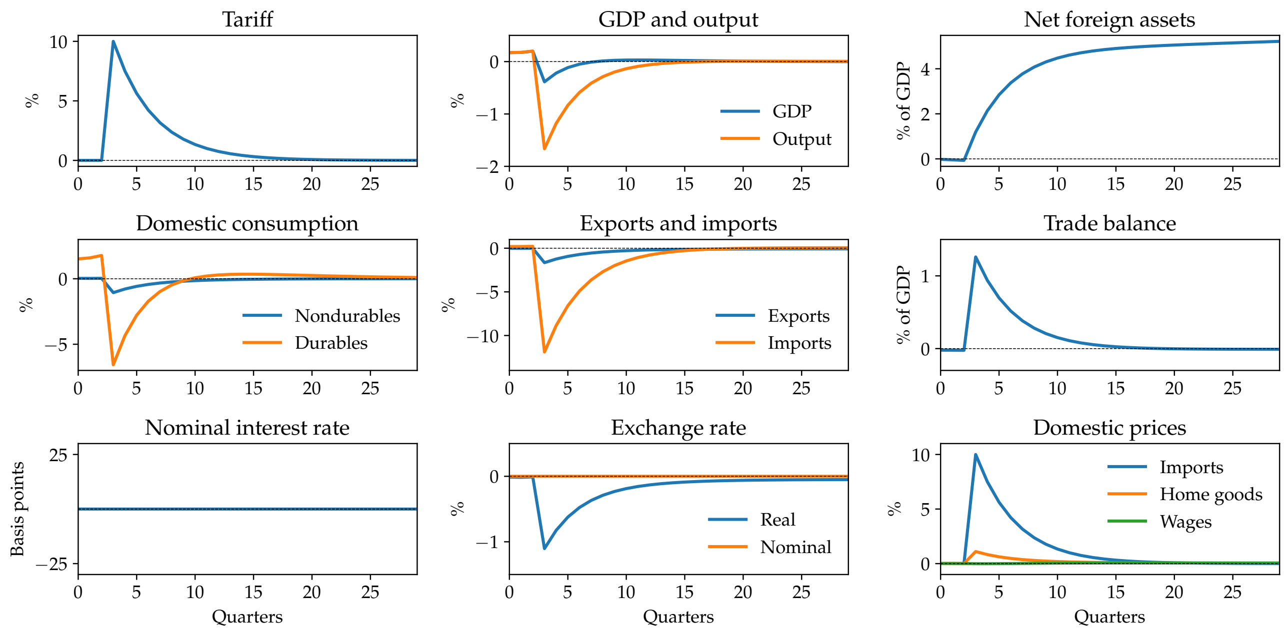


Figure 12: Impulse response with unilateral tariff, passive monetary policy, and durables

to total consumption to 11% as in the 2023 NIPA.

Figure 11 shows the impulse response in the presence of durable goods, for the case of a unilateral tariff and passive monetary policy. The general patterns are similar to those of figure 10, which featured the model without durable goods calibrated with a higher elasticity of intertemporal substitution. Of course, the result of section 4.5 that the models are exactly equivalent after recalibration does not hold directly; but the magnitudes are nevertheless close. For instance, the recession in GDP is -0.34% in this model.

Explicitly modeling durables has additional benefits. First, we see that the demand decline is highly concentrated in durables, with durable expenditures falling 6% on impact of the tariffs compared to only 1% in nondurables. In addition, the decline in durables is partly reverted as the tariffs start to abate, with durable spending above trend by year 2. This durable snap-back effect is responsible for a small boost to GDP at this horizon.

Anticipated tariffs. Another implication of the high degree of intertemporal substitution in durable is for anticipated tariffs. Figure 11 shows the impulse response to the announcement of a tariff in three quarters, reflecting potential implementation delays or, more speculatively, limited short-run pass-through of tariffs to retail prices. This result in a small boom in GDP on impact, driven entirely by durable goods as households rush to buy their durables ahead of the price increases. This result may explain the recent behavior of car and phone sales.

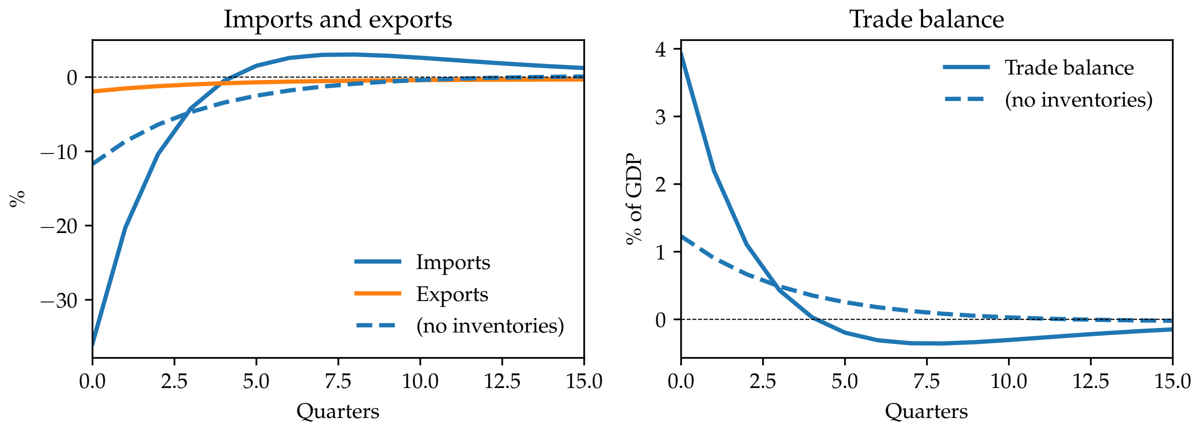


Figure 13: Response of trade balance to unilateral tariff shock: the role of inventories

6.3 Inventories

Because imports are often durables, they are often held in inventory before they are sold in the retail market. Modeling inventory behavior may therefore be important to understand the dynamics of imports in response to tariffs.

We introduce inventories to our model by replacing the production function (4) with

$$Y_t = \left((1-\alpha)^{1/\eta} N_t^{\frac{\eta-1}{\eta}} + \alpha^{1/\eta} G_t^{\frac{\eta-1}{\eta}} \right)^{\frac{\eta}{\eta-1}}$$

where G_t is now a composite import good. This good is produced by import retailers, using goods in their inventory $\tilde{M}_t$ as well as the inventory stock S_t.[21] The production function for G_t is also given by a CES aggregator

$$G_t = \left((1-\chi)^{1/v} \left(\tilde{M}_t\right)^{\frac{v-1}{v}} + \chi^{1/\eta} \left(S_t\right)^{\frac{v-1}{v}} \right)^{\frac{v}{v-1}}$$

Imports M_t increase the stock of inventories, use of inventories in production $\tilde{M}_t$ reduces it. We assume that inventories are kept for a sufficiently short time that they do not depreciate, so that the inventory accumulation equation is

$$S_t = S_{t-1} + M_t - \tilde{M}_t \tag{44}$$

[21] Having the inventory stock in the production function is a simple way to have a well-defined stock of inventories in the steady state. This proxies for the role of inventories in smoothing production and avoiding stockouts modeled more explicitly in the literature, e.g. Ramey and West (1999) and Kryvtsov and Midrigan (2013).

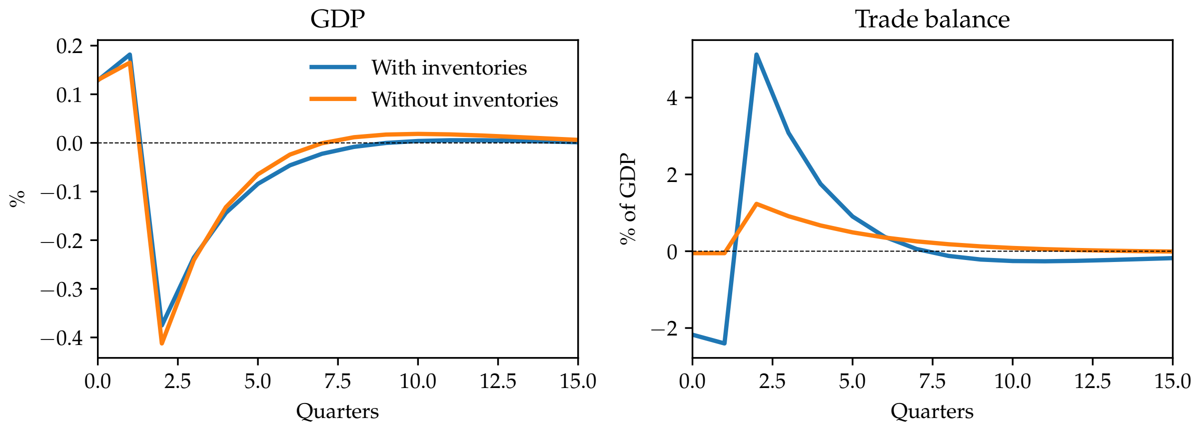


Figure 14: Response to anticipated unilateral tariff shocks: the role of inventories

Further, we assume that import retailers incur costs $\frac{\Psi_S}{2}\left(\frac{S_t - S_{t-1}}{S_t}\right)^2 S_t$ to adjust their inventory stock. Import retailers maximize the present value of profits $\Pi_t \equiv P_t^G G\left(\tilde{M}_t, S_t\right) - P_t^F M_t - P_t^F \frac{\Psi_S}{2}\left(\frac{S_t - S_{t-1}}{S_t}\right)^2 S_t$, subject to (44).

The first-order conditions for the import retailer give $P_t^G G_{\tilde{M}t} = P_t^F$, together with the optimal inventory dynamics

$$\frac{S_t - S_{t-1}}{S_t} = \frac{1}{\Psi_S}\left(Q_t^S - 1\right) \tag{45}$$

$$Q_t^S = \left(\frac{1-\chi}{\chi}\frac{S_t}{\tilde{M}_t}\right)^{-\frac{1}{v}} - \frac{\Psi_S}{2}\left(\frac{S_t - S_{t-1}}{S_t}\right)^2 + \frac{1}{1+r_t^F} Q_{t+1}^S \tag{46}$$

where $1 + r_t^F = (1 + i_t)\frac{P_{Ft}}{P_{Ft+1}}$ is the foreign-price-based real interest rate. Real GDP is now given, to first order, by $dGDP_t = dY_t - dM_t + dS_t - dS_{t-1}$, that is, gross output net of imports and inclusive of inventory accumulation.

We calibrate $v = 1$ so that G_t is a Cobb-Douglas in inventory outflows and inventory stock, and set χ to hit a steady-state ratio of inventories to imports S/M of 0.33 at quarterly frequency (so that inventories are one month of sales).

Figure 11 shows the impulse response of components of the trade balance to to the tariff shock in Figure 11. The full impulse response, presented in appendix E.4, is similar to the one from the model with only durables, but inventories add more interesting dynamics to the trade balance: the introduction of a tariff now generates a collapse in imports as firms substitute them for their inventory stock during the height of the tariff. This generates a very large but short-lived improvement in the trade balance, which gets reversed once firms replete their inventories after about a year.

The macroeconomic effects of anticipated tariff shocks are also very similar whether or not we take inventories into account, but anticipated tariffs generate a large deterioration in the trade balance ex-ante as firms rush to pile up inventories before the tariffs take effect, and then run them down, as figure Figure 14 shows. Anecdotally, this appears to be what firms were in fact doing in the run-up to Liberation Day.

7 Conclusion

When do temporary import tariffs generate recessions? We provide a general analysis of this question in the context of a simple New Keynesian model. Even when the tariffs are unilateral and even when monetary policy does not respond, tariffs are recessionary when $(1-\alpha)\sigma + \alpha\gamma > \eta$, ie when intertemporal substitution and export substitution dominate import substitution. We argue that this condition is likely satisfied in practice, especially since durable goods have much scope for intertemporal substitution and since it is easier for foreigners to substitute between different types of exports than for domestic residents to substitute between home and foreign goods. Retaliation by other countries worsen the recession and typically lead to a deterioration of the trade balance. The optimal tariff is significantly lower once this possibility of recession is taken into account.

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A Appendix to section 2

A.1 Proof of proposition 1

Under a permanent increase in import tariffs, the economy immediately jumps to a new steady state, still with zero NFA. We continue to denote steady state objects without t subscripts. Without loss, we assume the nominal wage is still $W = 1$, which here is simply a choice of numeraire to make nominal exchange rate well defined and comparable to our later analysis.

The nonlinear steady state equations are then given as follows. For households, we find

$$PC = 1 - \alpha + \tau \mathcal{E} M$$

For prices we find

$$P^F = (1+\tau)\,\mathcal{E} \qquad P = \left[1 - \alpha + \alpha \left(P^F\right)^{1-\eta}\right]^{\frac{1}{1-\eta}}$$

For exports we find

$$X = \alpha \cdot \left(\frac{P}{\mathcal{E}}\right)^{-\gamma}$$

and for output

$$C + X = Y = \left((1-\alpha) + \alpha^{1/\eta} M^{\frac{\eta-1}{\eta}}\right)^{\frac{\eta}{\eta-1}}$$

Linearizing these equations, we find for prices

$$d\log P^F = d\tau + d\log \mathcal{E} \qquad d\log P = \alpha d\tau + \alpha d\log \mathcal{E}$$

Consumption then is

$$d\log C = \frac{\alpha}{1-\alpha} \alpha d\log\left(1+\tau\right) - \alpha d\log \mathcal{E}$$

and exports are

$$d\log X = -\gamma\left(\alpha d\tau - (1-\alpha)\, d\log \mathcal{E}\right)$$

After some algebra, output must then be

$$d\log Y = \alpha^2 \left(1-\gamma\right) d\tau + \alpha\left(\gamma - 1\right)\left(1-\alpha\right) d\log \mathcal{E}$$

Since the labor market clears at $N = 1 - \alpha$ as in the original steady state without tariffs, it must be that

$$0 = d \log N = d \log Y + \eta d \log P^F$$

Evaluating the expression pins down the exchange rate,

$$d \log \mathcal{E} = -\frac{\eta - \alpha (\gamma - 1)}{(\gamma - 1)(1 - \alpha) + \eta} d\tau$$

which is exactly (15). With this exchange rate, exports and imports are both given by

$$dX = dM = -\frac{\gamma \eta}{(\gamma - 1)(1 - \alpha) + \eta} d\tau$$

which is exactly (14).

A.2 Calibration of long-run η

Appendix E.2 in Auclert et al. (2024) generalizes the Gali-Monacelli model so that the final consumption good is a CES aggregate with elasticity $\tilde{\zeta}$ between tradable and nontradable goods, where the steady-state tradable share is $\tilde{\phi}$. The tradable good is then a CES bundle of foreign and home-produced tradable goods with elasticity $\tilde{\eta}$, with a steady-state home share $1 - \tilde{\alpha}$ within tradables. (We add tildes to these parameters to distinguish them from our own calibration.)

In equation (A.167), Auclert et al. (2024) show that this implies an effective elasticity η between home and foreign goods of

$$\eta = \frac{(1 - \tilde{\alpha})\tilde{\eta} + (1 - \tilde{\phi})\tilde{\alpha}\tilde{\zeta}}{(1 - \tilde{\alpha}) + (1 - \tilde{\phi})\tilde{\alpha}} \tag{47}$$

This is a weighted average of the elasticity $\tilde{\eta}$ between home and foreign tradables and the elasticity $\tilde{\zeta}$ between nontradable and tradable goods.

We calibrate (47) as follows. We take the steady-state tradable share $\tilde{\phi}$ to be the share of goods in total U.S. personal consumption expenditures in 2024, which was 31.5% in NIPA Table 2.3.5. We then calibrate $\tilde{\alpha} = \alpha / \tilde{\phi} = 12.5\% / 31.5\% \approx 39.7\%$. This implies weights on $\tilde{\eta}$ and $\tilde{\zeta}$ in (47) of 68.9% and 31.1%, respectively.

Taking the elasticity $\tilde{\eta}$ between home and foreign tradables to be the same as our $\gamma = 4$ between-country elasticity, and assuming Cobb-Douglas $\tilde{\zeta} = 1$, this evaluates to $\eta \approx 3.07$.

B Appendix to section 3

B.1 Nonlinear solution of the model for a one-period tariff, and the $\beta \nearrow 1$ limit

Here we describe the solution of the model for a one-period import tariff shock τ_0 of arbitrary size, assuming that import tariffs are back at zero thereafter, $\tau_t = 0$ for $t > 0$. We then take the limit $\beta \nearrow 1$.

Since there is no tariff after date 0, and the NFA is the only backward looking state variable, we can characterize the allocation after date 1 as a function of the NFA entering period 1, A_0. We guess and verify that all equilibrium variables are constant after $t = 0$.

$$\begin{aligned}
C_1 &= 1-\alpha+i^* A_0 \\
Y_1 &= \left(1-\alpha+\alpha^{1/\eta} M_1^{\frac{\eta-1}{\eta}}\right)^{\frac{\eta}{\eta-1}} \\
P_1 &= \left[1-\alpha+\alpha\mathcal{E}_1^{1-\eta}\right]^{\frac{1}{1-\eta}} \\
1 &= Y_1 P_1^{\eta} \\
X_1 &= \alpha\left(\frac{P_1}{\mathcal{E}_1}\right)^{-\gamma} \\
C_1+X_1 &= Y_1
\end{aligned}$$

Since, after date 1, $i_t = i^* = \beta^{-1} - 1$, the households' Euler equation holds for constant consumption, and the UIP condition also holds for a constant interest rate.

In general, this system of equations has a complicated and intractable solution. In the limit $\beta \nearrow 1$, however, we also have $i^* = i \searrow 0$. This implies that the steady state solution solves the system above. Thus, in this limit, the economy returns to the steady state at date 1. This allows us to significantly reduce the complexity of our analysis.

To get at the date 0 behavior nonlinearly, we collect the following model equations, for arbitrary import tariff and monetary policy shocks:

- Euler equation

$$C_0 = P_0^{-\sigma}\left(1+i_0\right)^{-\sigma}$$

- Pricing (5)

$$P_0 = \left[1-\alpha W_0^{1-\eta}+\alpha\left(\mathcal{E}_0\left(1+\tau_0\right)\right)^{1-\eta}\right]^{\frac{1}{1-\eta}}$$

- UIP (7)

$$\mathcal{E}_0 = \frac{1}{1+i_0}$$

- Exports (10)

$$X_0 = \alpha \left(\frac{P_0}{\mathcal{E}_0}\right)^{-\gamma}$$

- Goods demand (13)

$$C_0 + X_0 = Y_0$$

- Labor and imports demand (6)

$$N_0 = (1-\alpha)\, Y_0 \left(\frac{W_0}{P_0}\right)^{-\eta} \qquad M_0 = \alpha Y_0 \left(\frac{P_0^F}{P_0}\right)^{-\eta}$$

- Downward rigidity

$$W_0 = \begin{cases} 1 & \text{if } N_0 < 1-\alpha \\ \geq 1 & \text{if } N_0 = 1-\alpha \end{cases}$$

B.2 Proofs of propositions 2 and 3

B.2.1 General derivations

To prove proposition 2, we first derive the linearized solution of the model for arbitrary import tariff shocks $d\tau$ and and interest rate responses $d \log (1+i_0)$. Then, we take the special case of $d\log(1+i_0) = 0$. This allows us to reuse the equations when proving Proposition 3.

First we derive expressions for the exchange rate and prices. By the UIP condition (7), the exchange rate moves inversely to interest rates,

$$d \log \mathcal{E}_0 = -d \log (1+i_0)$$

The price of foreign goods (8) is then given by

$$d \log P_0^F = d\tau + d\log \mathcal{E}_0 = d\tau - d\log(1+i_0)$$

and the CPI P_0 by

$$d \log P_0 = \alpha \left(d\tau + d \log \mathcal{E}_0\right) = \alpha \left(d\tau - d\log(1+i_0)\right)$$

Linearizing (10) and (19), we find for exports and consumption

$$\begin{aligned} d\log X_0 &= -\gamma d\log\left(P_0/\mathcal{E}_0\right) = -\gamma\left(\alpha d\tau + (1-\alpha)\, d\log\left(1+i_0\right)\right) \\ d\log C_0 &= -\sigma\left(1-\alpha\right) d\log\left(1+i_0\right) - \sigma\alpha d\tau \end{aligned} \tag{48}$$

From the goods market clearing condition (13), we then derive total goods demand as in (17)

$$d\log Y_0 = -\left(1-\alpha\right)\left(\sigma\left(1-\alpha\right)+\alpha\gamma\right) d\log\left(1+i_0\right) - \alpha\left(\left(1-\alpha\right)\sigma+\alpha\gamma\right) d\tau$$

With this, we can evaluate total labor demand linearizing (6)

$$\begin{aligned} d\log N_0 = -\left(\left(1-\alpha\right)\left(\sigma\left(1-\alpha\right)+\alpha\gamma\right)+\eta\alpha\right) d\log\left(1+i_0\right) \\ + \alpha\left(\eta-\left(\left(1-\alpha\right)\sigma+\alpha\gamma\right)\right) d\tau \end{aligned} \tag{49}$$

For imports, we find

$$\begin{aligned} d\log M_0 = -\left(1-\alpha\right)\left(\sigma\left(1-\alpha\right)+\alpha\gamma-\eta\right) d\log\left(1+i_0\right) \\ -\left(\left(1-\alpha\right)\eta+\alpha\left(\left(1-\alpha\right)\sigma+\alpha\gamma\right)\right) d\tau \end{aligned} \tag{50}$$

and for the trade balance we find (after some algebra)

$$\begin{aligned} \frac{dTB_0}{X} = \left(1-\alpha\right)\left(\sigma\left(1-\alpha\right)+\alpha\gamma-\eta+\left(1-\gamma\right)\right) d\log\left(1+i_0\right) \\ +\left(\left(1-\gamma\right)\alpha+\left(1-\alpha\right)\eta+\alpha\left(\left(1-\alpha\right)\sigma+\alpha\gamma\right)\right) d\tau \end{aligned} \tag{51}$$

B.2.2 Proof of proposition 2

For proposition 2, we assume a passive monetary policy, $i_0 = i$. Thus, (49) simply becomes

$$d\log N_0 = \alpha\left(\eta-\left(\left(1-\alpha\right)\sigma+\alpha\gamma\right)\right) d\tau$$

identical to (21). It immediately follows that there is a recession if (20) holds. (48) becomes

$$d\log X_0 = -\gamma\alpha d\tau$$

For imports, from (50), we obtain

$$d\log M_0 = -\left(\left(1-\alpha\right)\eta+\alpha\left(\left(1-\alpha\right)\sigma+\alpha\gamma\right)\right) d\tau$$

and the trade balance, expressed relative to GDP, becomes

$$\frac{dTB_0}{X} = \left(\left(1-\gamma\right)\alpha + \left(1-\alpha\right)\eta + \alpha\left(\left(1-\alpha\right)\sigma + \alpha\gamma\right)\right)d\tau$$

which can be rearranged to (22).

B.2.3 Proof of proposition 3

To obtain the natural interest rate, we back out from (49) the interest rate response $d\log\left(1+i_0\right)$ that leaves labor demand unchanged. After some algebra, we obtain (26). Substituting this interest rate $d\log\left(1+i_0\right)$ into the trade balance equation (51), we obtain (27).

B.3 Proof of proposition 4

The direct effects of the tax, (28) and (29), follow immediately from the calculations preceding proposition 4. We can find the natural interest rate by combining the direct effect of the export tax on GDP,

$$d\log N_0 = -\alpha\gamma d\tau$$

with the effect of monetary policy on GDP from (49),

$$d\log N_0 = -\left(\left(1-\alpha\right)\left(\sigma\left(1-\alpha\right)+\alpha\gamma\right)+\eta\alpha\right)d\log\left(1+i_0\right)$$

Combining those two equations, we find that an interest rate reduction as in (30) is needed to undo the effect of the export tax on GDP.

B.4 Proof of proposition 5

The GDP response to retaliation with passive monetary policy is simply the sum of what happens under unilateral tariffs and what happens with an export tax. The reason for this is that the additional tax revenue is irrelevant for date 0 spending in the limit $\beta \nearrow 1$. Thus, the sum of (21) and (28) gives us (32). For the trade balance, we start from (29). However, with a foreign import tariff, the price at the border changes (while it did not for a domestic export tax). Thus, the direct effect of retaliation is given by

$$\frac{dTB_0}{GDP} = -\left(1-\alpha\right)\gamma d\tau$$

Combining this equation with the effect of a uni-lateral import tariff on the trade balance, (22), we find (33). Finally, since the retaliation itself is contractionary, in necessarily lowers the natural interest rate (on its own). This must mean that the natural rate falls by more in response to import tariffs if they are being retaliation for than if they are not.

C Appendix for section 4

C.1 Initial trade deficit and proof of proposition 6

In the steady state (where we normalize all prices to 1), the household's budget constraint implies that $X + D = M$, so that the trade balance is $TB = -D$.

The derivation of proposition 2 goes through mostly unchanged. The log-linearization in (17) now has $\alpha^E \equiv \frac{X}{Y}$ as the weight on $d\log X_0$, which becomes the weight on γ in the recession condition, but the change in the CPI is $d\log P_0 = \frac{M}{Y} d\log P_0^F + \frac{WN}{Y} d\log W_0 = \alpha^I d\tau$, which then scales $d\log X_0$ and $d\log C_0$, and thus the magnitude of the GDP change, via (18) and (19).

C.2 Hand-to-mouth agents and proof of proposition 7

Since the domestic representative agent in our baseline steady state also consumes its labor income in every period, there is no change to the steady state from replacing a fraction of its mass with hand-to-mouth households.

For dynamics, denote the consumption of the hand-to-mouth and "Ricardian" (unconstrained) households by C_t^{HTM} and C_t^R.

Hand-to-mouth households' date-0 consumption is given by $C_0^{HTM} = \frac{W_0 N_0}{P_0}$. Assuming fixed W_0, $d\log P_0 = \alpha d\tau$ is unchanged, and to first order this implies $d\log C_0^{HTM} = d\log N_0 - d\log P_0 = d\log N_0 - \alpha d\tau$. Meanwhile, Ricardian households behave just as before, with $d\log C_0^R = -\sigma\alpha d\tau$. Replacing the $-\sigma d\tau$ in our previous derivation with $-\alpha\left((1-\mu)\sigma + 1\right)d\tau + \mu d\log N_0$, the equation for change in GDP ($d\log GDP_0 = d\log N_0$) becomes

$$d\log GDP_0 = -\alpha\left((1-\alpha)\left((1-\mu)\sigma + 1\right) + \alpha\gamma - \eta\right) + \mu(1-\alpha) d\log GDP_0$$

which solves out to give the desired formula (35). This is consistent with a decline in GDP if the inner expression $(1-\alpha)\left((1-\mu)\sigma + 1\right) + \alpha\gamma - \eta$ is positive, consistent with condition (34).

C.3 Incomplete pass-through and proof of proposition 8

To model incomplete pass-through, we assume that imported goods are purchased at price $\mathcal{E}_t(1+\tau_t)$ abroad, and sold domestically by a mass 1 of monopolistically competitive importers, labelled by k. Goods imported by importer k are denoted by m_{kt} and enter a CES aggregate

$$M_t = \left(\int_0^1 m_{kt}^{\frac{\xi-1}{\xi}} dk\right)^{\frac{\xi}{\xi-1}}$$

Importers optimally set their price equal to a constant markup over marginal cost,

$$p_{kt}^M = \frac{\xi}{\xi-1}\mathcal{E}_t(1+\tau_t)$$

We assume that a fraction $1-\psi_M$ of importers are required to set their prices one period in advance. Thus, in period 0, we have

$$P_0^M = \frac{\xi}{\xi-1}\left(\psi_M\left(\mathcal{E}_0(1+\tau_0)\right)^{1-\xi} + 1 - \psi_M\right)^{\frac{1}{1-\xi}}$$

Since we are not interested in the importer monopoly distortion, we focus on the limit $\xi \to \infty$. In that limit, to first order, we have

$$d\log P_0^M = \psi_M(d\tau_t + d\log\mathcal{E}_t)$$

From this, it immediately follows that, absent a monetary policy response, any import tariff shock of size $d\tau_t$ is effectively now smaller by a factor ψ_M. Proposition 8 follows directly from this argument.

C.4 Multiple production technologies and proof of proposition 9

We generalize (4) by writing a consumption-specific technology

$$C_t = \left((1-\theta^C)^{1/\eta^C}(N_t^C)^{\frac{\eta^C-1}{\eta^C}} + (\theta^C)^{1/\eta^C}(M_t^C)^{\frac{\eta^C-1}{\eta^C}}\right)^{\frac{\eta^C}{\eta^C-1}}$$

and an analogous technology for exports. We continue to normalize all steady-state prices to 1, so that steady-state import shares for consumption and exports are θ^C and θ^X. Given a date-0 tariff shock $d\tau$ and passive monetary policy, if there is a recession it follows immediately from constant wages and exchange rates that $d\log P_0^C = \theta^C d\tau$ and

$d\log P_0^X = \theta^X d\tau$, reflecting the direct effect of tariffs on costs.

We then observe that (using $GDP_t^C = N_t^C$, $GDP_t^X = N_t^X$)

$$\begin{aligned} d\log GDP_0^C &= \frac{d\log C_0 - \theta^C d\log M_0^C}{1-\theta^C} = d\log C_0 + \frac{\theta^C}{1-\theta^C}\eta^C(d\tau - d\log P_0^C) \\ &= d\log C_0 + \frac{\theta^C}{1-\theta^C}\eta^C(1-\theta^C)d\tau = d\log C_0 + \theta^C\eta^C d\tau \end{aligned}$$

and similarly $d\log GDP_0^X = d\log X_0 + \theta^X\eta^X d\tau$. Like before, with constant rates we have $d\log C_0 = -\sigma d\log P_0^C = -\theta^C\sigma d\tau$ and $d\log X_0 = -\theta^X\gamma d\tau$, so overall we have $d\log GDP_0^C = -\theta^C(\sigma-\eta^C)d\tau$ and $d\log GDP_0^X = -\theta^X(\gamma-\eta^X)d\tau$.

Finally, noting that steady-state GDP weights on C and X are proportional to $(1-\alpha)(1-\theta^C)$ and $\alpha(1-\theta^X)$, the condition (36) for a decline in GDP follows from aggregating $d\log GDP_0^C$ and $d\log GDP_0^X$.

C.5 Durable goods and the relation between σ, ν and ϵ_D

Loglinearizing the equations in (41)–(42) around the steady state, using small letters to denote log deviations from steady state, we obtain:

$$\begin{aligned} d_t - d_{t-1} &= \delta\epsilon_D q_t & (52) \\ q_t &= -\frac{r+\delta}{1+r}\cdot\frac{1}{\nu}\left(d_t - c_t^{ND}\right) + \frac{1}{1+r}q_{t+1} - \frac{1-\delta}{1+r}\left(i_t - p_{t+1} + p_t\right) & (53) \end{aligned}$$

while loglinearizing $C_t = C_t^{ND} + C_t^D = C_t^{ND} + D_t - (1-\delta)D_{t-1}$ gives

$$c_t = (1-\omega)c_t^{ND} + \omega\left(\frac{1}{\delta}d_t - \left(\frac{1}{\delta}-1\right)d_{t-1}\right) \tag{54}$$

where $\omega = \frac{C^D}{C}$ is the steady state share of durables in consumption. Note that if we take the limit of infinitely short periods, $r \to 0$ and $\delta \to 0$, the dynamics of q are just given by

$$q_t = q_{t+1} - (i_t - p_{t+1} + p_t)$$

Consider a one-time tariff shock at time 0, with no monetary reaction $i_t = 0$ for all t. At $t = 1$ we reach the steady state with $p_t = q_t = 0$ for all $t \geq 1$. Hence, we have $q_0 = -p_0$.

Moreover, since $d_{-1} = 0$, combining (52) and (54) we obtain

$$\begin{aligned} c_0 &= (1-\omega)\, c_0^{ND} + \omega \epsilon_D q_0 \\ &= (1-\omega)\,(-\nu p_0) + \omega \epsilon_D\,(-p_0) \\ &= -\sigma p_0 \end{aligned}$$

where $\sigma \equiv (1-\omega)\,\nu + \omega \epsilon_D$.

C.6 Nonlinearities from large tariffs

Figure 15 shows the effect on trade flows, the exchange rate and GDP, under passive monetary policy and in the natural allocation, and under unilaterall tariffs and retaliation, from large tariffs of up to 50%. The first-order approximations given in the main text hold up well for tariffs of up to 10%, but the effects from large tariffs tend to be smaller.

D Appendix to section 5

D.1 Proof of proposition 10

We can write the optimization problem for the Home representative agent as

$$\max \sum_{t=0}^{\infty} \beta^t u(C_t)$$

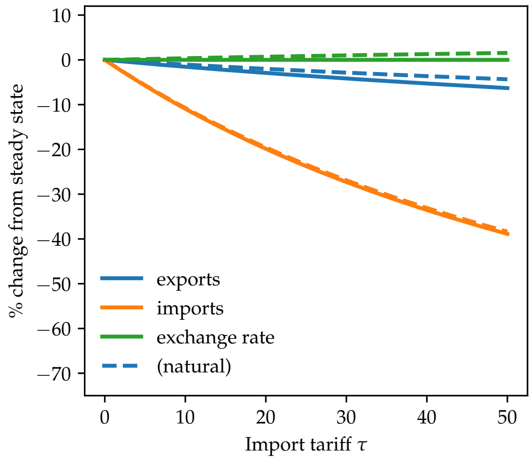
$$\frac{P_t C_t - W_t N_t}{\mathcal{E}_t} = (1+i^*)\tilde{A}_{t-1} - \tilde{A}_t + \frac{T_t}{\mathcal{E}_t} \tag{55}$$

where we have divided by $\mathcal{E}_t$ to rewrite the budget constraint (3) in terms of foreign currency, defining $\tilde{A}_t \equiv A_t/\mathcal{E}_t$. The current-value Lagrange multiplier on the constraint is $\lambda_t = u'(C_t)\frac{\mathcal{E}_t}{P_t}$, and it follows from the envelope theorem that given first-order changes $\{dP_t, dW_t, dN_t, d\mathcal{E}_t, dT_t\}$, the first-order effect on the objective is the discounted sum of

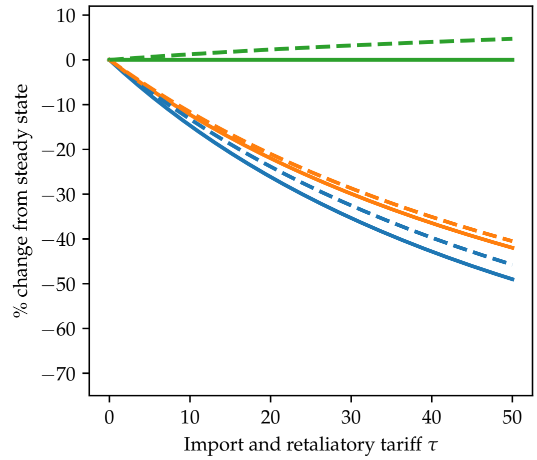
$$\frac{P_t C_t}{\mathcal{E}_t} d\log P_t - \frac{W_t N_t}{\mathcal{E}_t}(d\log W_t + d\log N_t) - \frac{dT_t}{\mathcal{E}_t} - \frac{P_t C_t - W_t N_t - T_t}{\mathcal{E}_t} d\log \mathcal{E}_t \tag{56}$$

times $-\lambda_t$.

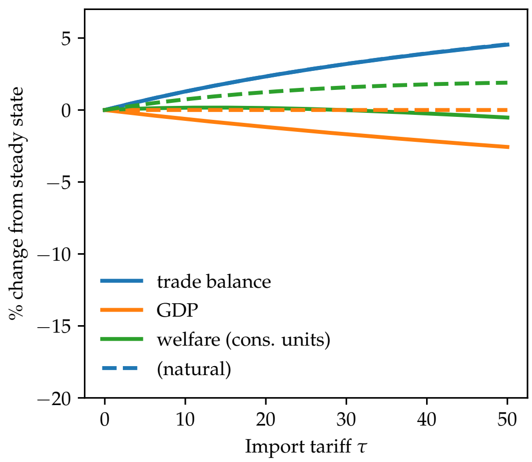
First-order effect starting from steady state. Starting from the steady state, we can remove the t subscripts on $P_t C_t/\mathcal{E}_t$, etc., in (56). Multiplying by $-\lambda = u'(C)\frac{\mathcal{E}}{P}$, but dividing



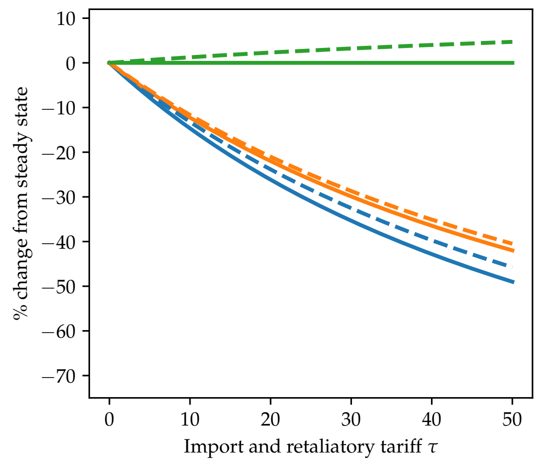
(a) Unilateral tariff: Trade



(b) Retaliation: Trade



(c) Unilateral tariff: GDP, welfare



(d) Retaliation: GDP, welfare

Figure 15: Large tariff shocks

Note. Reference calibration from table 1. y axis in % from initial steady state values, except trade balance which is in pp. of steady state GDP.

by $u'(C)C$ to put in units of steady-state consumption, (56) becomes

$$-d\log P_t + d\log N_t + \frac{dT_t}{PC} \tag{57}$$

where we use that in steady state, $PC = WN$ and $T = 0$, and also use $d\log W_t = 0$. We then have $d\log P_t = \alpha(d\log \mathcal{E}_t + d\tau_t)$ and $\frac{dT_t}{PC} = \frac{\alpha}{1-\alpha}d\tau_t$, so that (57) becomes just

$$d\log N_t - \alpha d\log \mathcal{E}_t + \frac{\alpha^2}{1-\alpha}d\tau \tag{58}$$

where $d\log N_t$ is the direct effect of any change in labor, and the other two terms correspond to changes in the terms of trade.

Exchange rate effects and first-order welfare. Next, we characterize the endogenous $-\alpha d\log \mathcal{E}_t$ term in (58), allowing for the possibility of retaliatory tariffs. First, note that

$$\begin{aligned} P_tC_t - W_tN_t - T_t &= P_tY_t - W_tN_t - P_tX_t - T_t \\ &= (1+\tau_t)\mathcal{E}_tM_t - P_tX_t - \tau_t\mathcal{E}_tM_t = \mathcal{E}_tM_t - P_tX_t. \end{aligned}$$

Noting that $1 + i^* = \beta^{-1}$, it follows that we can combine (55) into the single present-value budget constraint

$$\sum_{t=0}^{\infty} \beta^t \left(\frac{P_tX_t}{\mathcal{E}_t} - M_t \right) = 0.$$

Log-linearizing around the steady-state with balanced trade, this implies

$$\sum_{t=0}^{\infty} \beta^t \left(d\log P_t - d\log \mathcal{E}_t + d\log X_t - d\log M_t \right) = 0. \tag{59}$$

We also have $d\log X_t = -\gamma(d\log P_t + d\tau_t^r - d\log \mathcal{E}_t)$ and $d\log M_t = d\log Y_t - \eta(d\log \mathcal{E}_t - d\log P_t) = (1-\alpha)d\log N_t + \alpha d\log M_t - \eta(d\log \mathcal{E}_t - d\log P_t)$, which can be simplified to $d\log M_t = d\log N_t - (1-\alpha)^{-1}\eta(d\log \mathcal{E}_t + d\tau_t - d\log P_t)$. Plugging these into (59), we get

$$\sum_{t=0}^{\infty} \beta^t \Big((1 - \gamma - (1-\alpha)^{-1}\eta)(d\log P_t - d\log \mathcal{E}_t) + (1-\alpha)^{-1}\eta d\tau_t - \gamma d\tau_t^r - d\log N_t \Big) = 0$$

We further observe that $d\log P_t - d\log \mathcal{E}_t = -(1-\alpha)d\log \mathcal{E}_t + \alpha d\tau_t$. Using PV notation to denote discounted sums (i.e. $PV(Z_t) \equiv \sum_{t=0}^{\infty} \beta^t Z_t$ for any $\{Z_t\}$), this becomes

$$((1-\alpha)(\gamma-1)+\eta)\left(PV(d\log \mathcal{E}_t) + \frac{\alpha}{1-\alpha}PV(d\tau_t)\right) = -(1-\alpha)^{-1}\eta PV(d\tau_t) + \gamma PV(d\tau_t^r) + PV(d\log N_t)$$

and we can solve to obtain

$$PV(d\log \mathcal{E}_t) + \frac{\alpha}{1-\alpha}PV(d\tau_t) = \frac{-(1-\alpha)^{-1}\eta PV(d\tau_t) + \gamma PV(d\tau_t^r) + PV(d\log N_t)}{(1-\alpha)(\gamma-1)+\eta} \quad (60)$$

The overall first-order welfare effect is the present value of (58). Substituting (60) into this, and using $GDP_t = N_t$, we have a first-order welfare effect of

$$\frac{\alpha}{1-\alpha}\frac{\eta PV(d\tau_t) - (1-\alpha)\gamma PV(d\tau_t^r)}{(1-\alpha)(\gamma-1)+\eta} + \left(1 - \alpha\frac{1}{(1-\alpha)(\gamma-1)+\eta}\right)PV(d\log GDP_t)$$

which is exactly the first-order result (38) in proposition 10.

D.2 Proof of proposition 11

The first-order equivalence of the output-gap effect in (39) with (38) follows immediately, since full-employment monetary policy in response to a tariff sets $d\log GDP_t = 0$ and thus the output gap to zero in (38), while leaving the other term unchanged.

We now turn to the other two terms.

Starting from any point, the terms-of-trade correction adds $dT_t^{corr} = d\left(\frac{P_t}{\mathcal{E}_t}\right)X_t = \frac{P_t X_t}{\mathcal{E}_t}(d\log P_t - d\log \mathcal{E}_t)$ to (56). Given monetary policy, such that $d\log N_t = 0$, and also $d\log W_t$, (56) becomes

$$\frac{P_t C_t}{\mathcal{E}_t}d\log P_t - \frac{dT_t}{\mathcal{E}_t} - \frac{P_t C_t - W_t N_t - T_t}{\mathcal{E}_t}d\log \mathcal{E}_t + \frac{P_t X_t}{\mathcal{E}_t}(d\log P_t - d\log \mathcal{E}_t).$$

Noting that $P_t X_t + P_t C_t = P_t Y_t$ and also that $P_t Y_t - W_t N_t - T_t = P_t^F M_t - T_t = \mathcal{E}_t M_t$, we can add $\frac{P_t X_t}{\mathcal{E}_t}d\log P_t$ from the last term to the first term, and similarly $-\frac{P_t X_t}{\mathcal{E}_t}d\log \mathcal{E}_t$ from the rightmost term to the third term, and obtain the simplification

$$\frac{P_t Y_t}{\mathcal{E}_t}d\log P_t - \frac{dT_t}{\mathcal{E}_t} - M_t d\log \mathcal{E}_t. \quad (61)$$

Next, we observe that $d\log P_t = \frac{(1+\tau_t)\mathcal{E}_t M_t}{P_t Y_t}d\log \mathcal{E}_t + \frac{\mathcal{E}_t M_t}{P_t Y_t}d\tau_t$, so that the first term above simplifies to $(1+\tau_t)M_t d\log\mathcal{E}_t + M_t d\tau_t$. Finally, $\frac{dT_t}{\mathcal{E}_t} = M_t d\tau_t + \tau_t dM_t + \tau_t M_t d\log\mathcal{E}_t$. All terms in (61) then cancel except $-\tau_t dM_t$.

Multiplying by $-\lambda_t = -u'(C_t)\frac{\mathcal{E}_t}{P_t}$, this becomes

$$\frac{u'(C_t)}{P_t}\cdot(\tau_t\mathcal{E}_t dM_t) \tag{62}$$

i.e. the revenue effect of changing imports at the current tariff, converted into current consumption units.

Starting from the steady state with zero tariffs, (62) is zero, so that $\mathcal{W}^{corr}(\tau)$ is zero to first order in τ. It follows that $\mathcal{W}^{fe}(\tau) - \mathcal{W}^{corr}(\tau)$ must be, to first order, the remaining term in (38), namely the terms-of-trade effect.

Second-order characterization of distortion effect. If the only tariff change is $\tau_0 = \tau$ at date 0, (62) implies that $(\mathcal{W}^{corr})'(\tau) = \frac{1}{u'(C)C}\frac{u'(C_0)}{P_0}\cdot(\tau\mathcal{E}_0 M_0'(\tau))$.

We have already observed that this is zero when $\tau = 0$. Expanding $\mathcal{W}^{corr}(\tau)$ to *second order* around $\tau = 0$, the only surviving term is therefore

$$\frac{1}{2}\frac{1}{u'(C)C}\frac{u'(C)}{P}\tau\mathcal{E}\frac{dM_0}{d\tau}\tau = \frac{1}{2}\frac{1}{PC}\mathcal{E}\frac{dM_0}{d\tau}\tau^2.$$

Finally, if we write $\frac{1}{PC}\mathcal{E}dM_0 = \frac{\mathcal{E}M}{PC}d\log M_0 = \frac{\alpha}{1-\alpha}d\log M_0$, this simplifies to just

$$\frac{1}{2}\frac{\alpha}{1-\alpha}\frac{d\log M_0}{d\tau}\tau^2. \tag{63}$$

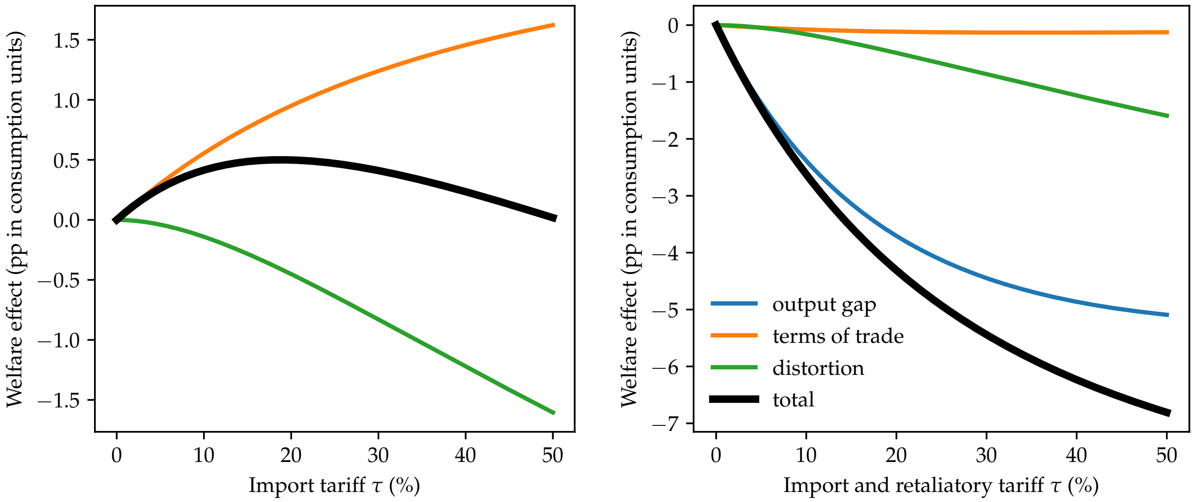
which is our final second-order expression in (40).

D.3 Analysis with long-run elasticities

Figure 16 redoes figure 9, replacing our calibrated values of $\eta = 1.15$ and $\gamma = 1.5$ with long-run values of $\eta = 3.07$ and $\gamma = 4$. (As discussed in section 2.3, the latter are more plausible long-run values, which we convert to short-run values by multiplying by 3/8, in line with Boehm et al. (2023).)

We see that in the unilateral case, there is no output-gap effect, since our recession condition (20) no longer holds with these elasticities. The first-order terms-of-trade effect initially dominates the distortion effect, but the latter grows quickly enough to imply an optimal tariff below 20%.

Figure 16: Decomposition of nonlinear welfare effects from tariff



In the retaliation case, all three effects are still negative (although the terms-of-trade effect is small), implying large costs from tariffs.

E Appendix to section 6

E.1 Retaliation with passive monetary policy

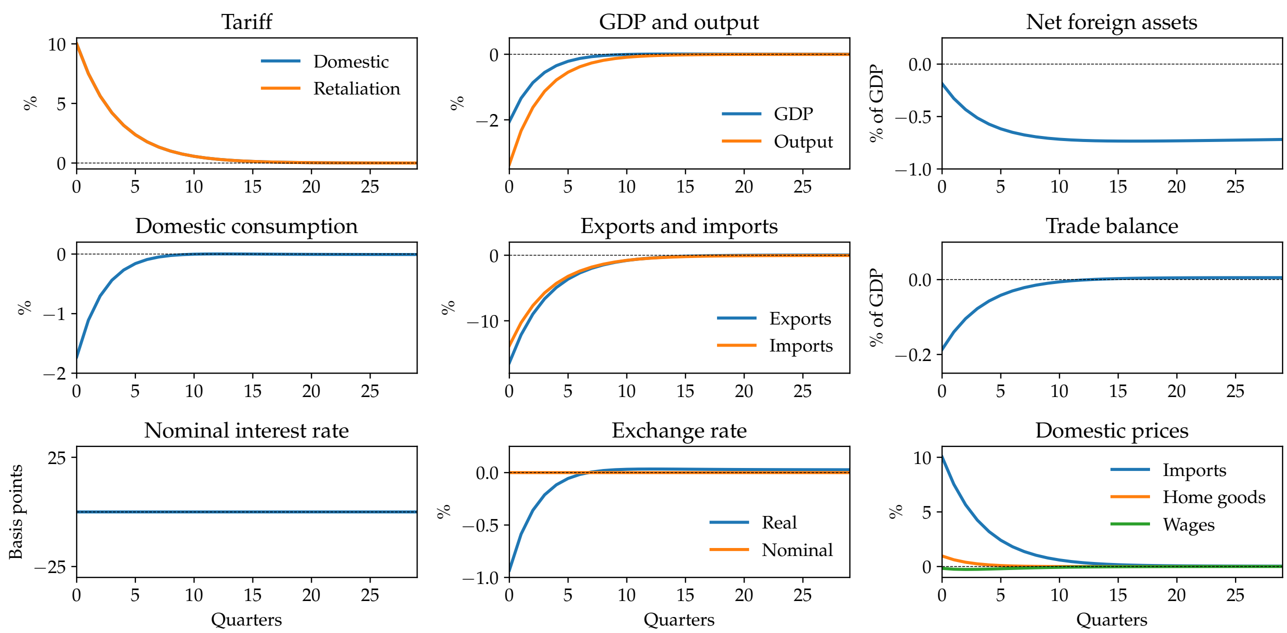


Figure 17: Persistent tariff shock with retaliation and passive monetary policy

E.2 Natural allocation

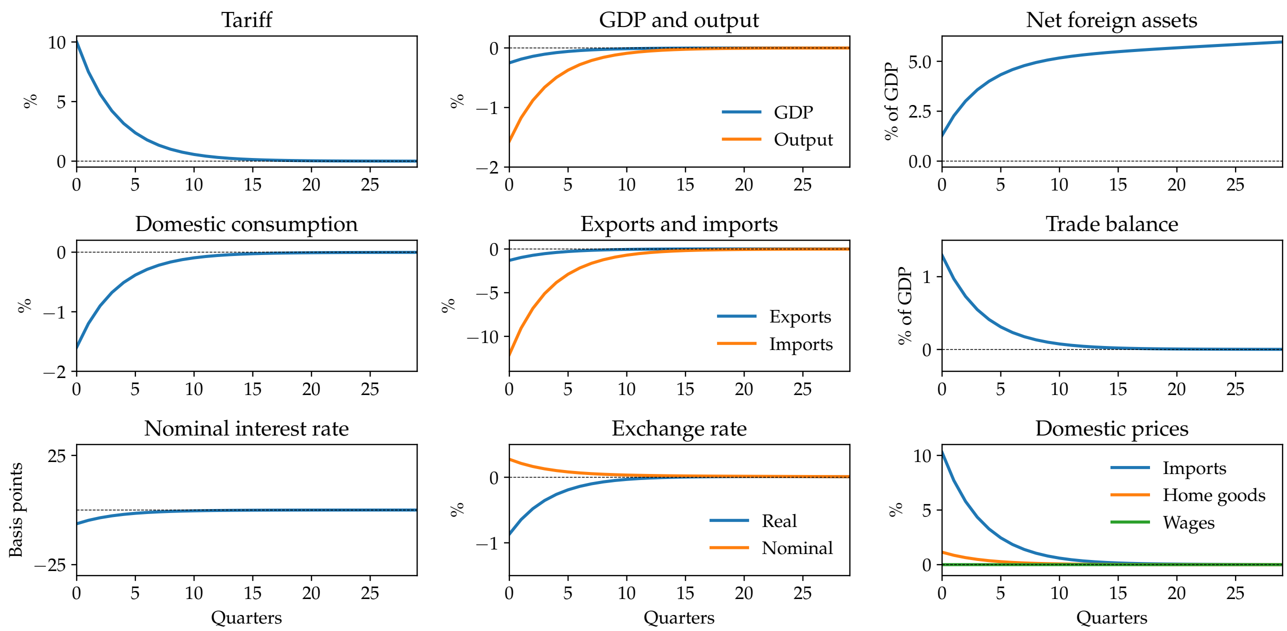


Figure 18: Persistent unilateral tariff shock: response with natural rate

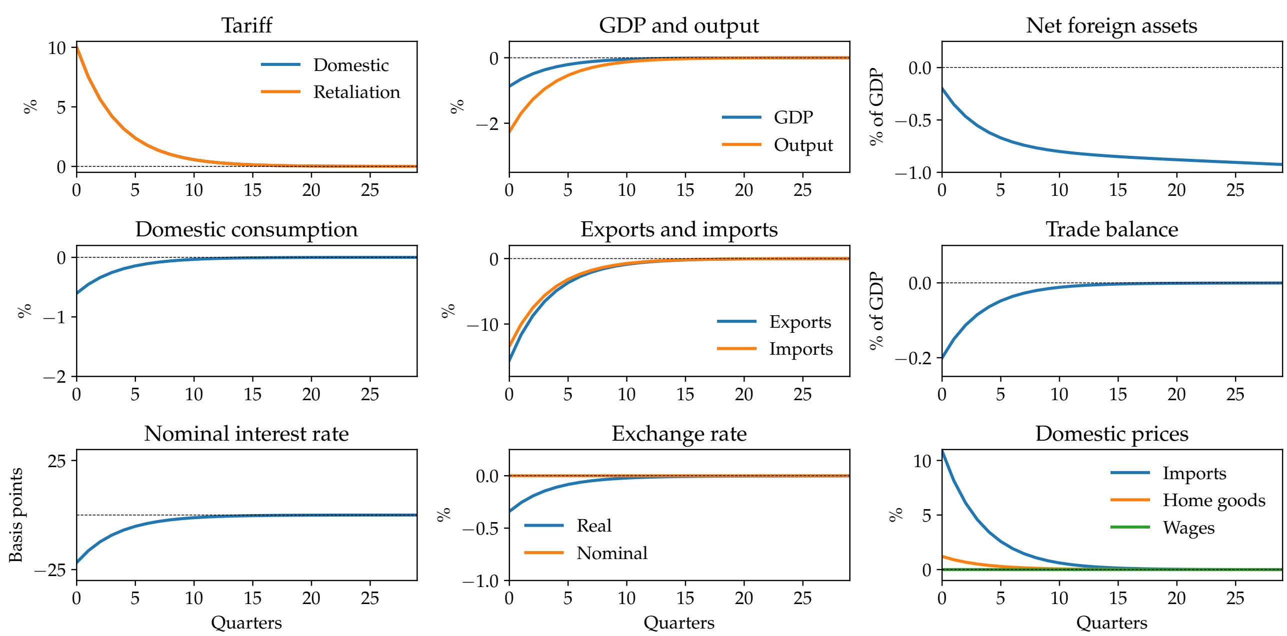


Figure 19: Persistent tariff shock with retaliation: response with natural rate

E.3 Taylor rule

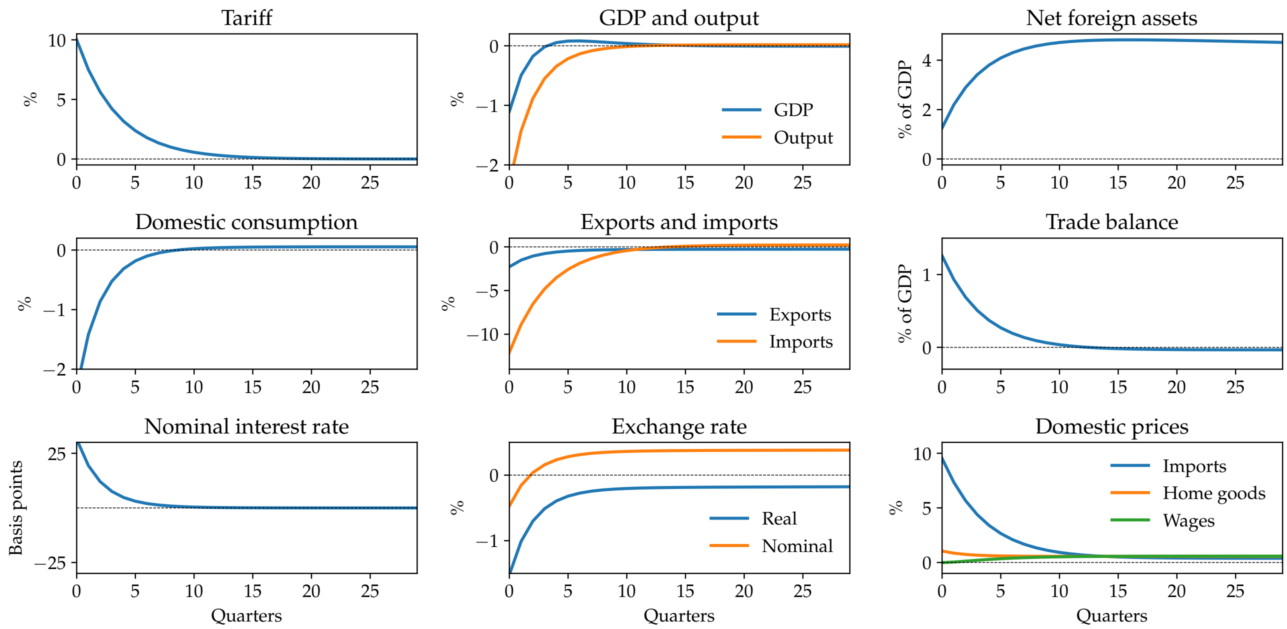


Figure 20: Impulse response to persistent unilateral tariff shock under intertial Taylor rule

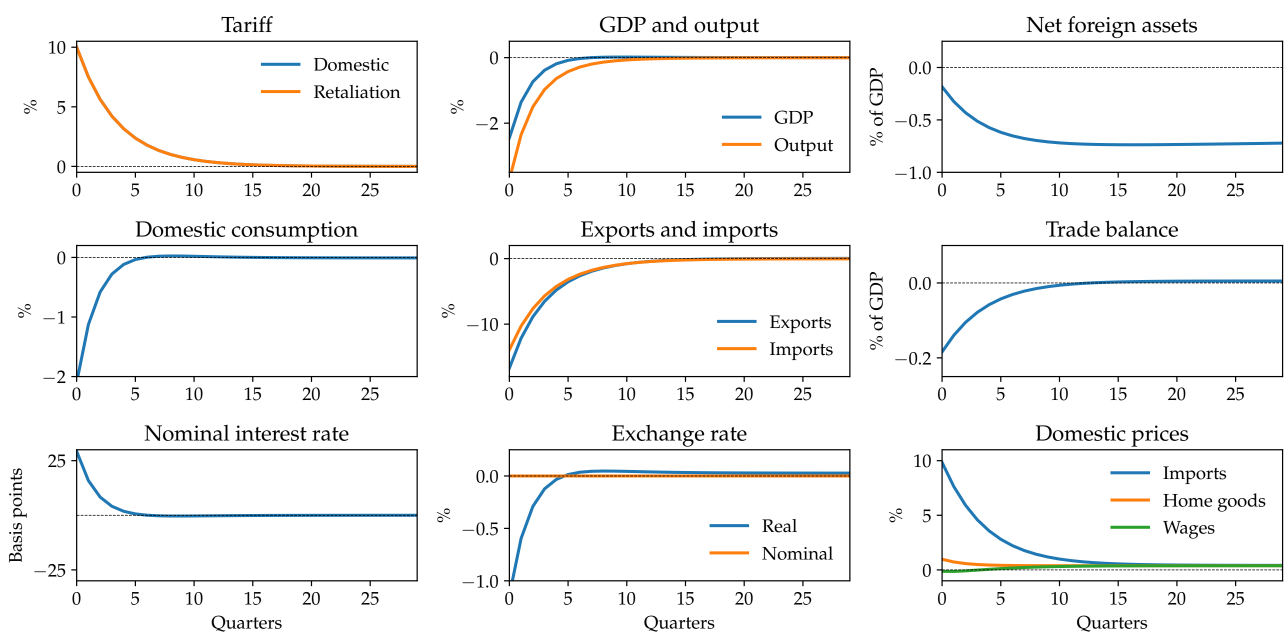


Figure 21: Persistent tariff shock with retaliation and intertial Taylor rule

E.4 Inventories

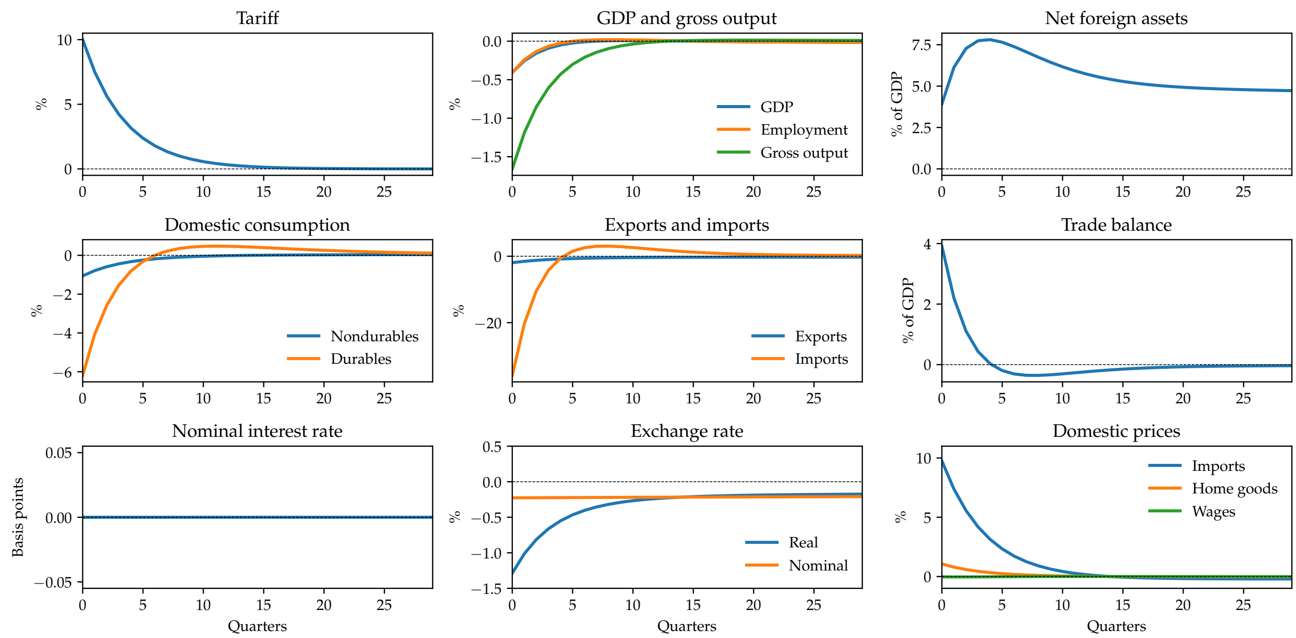


Figure 22: Persistent unilateral tariff shock: durables and inventories

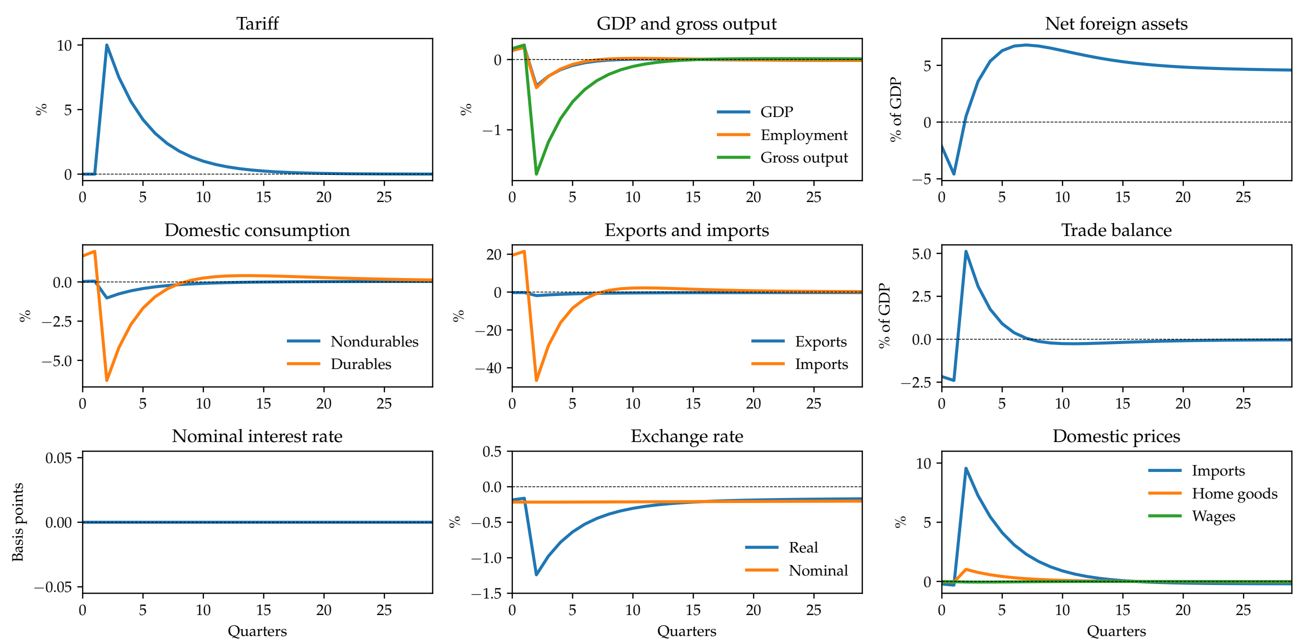


Figure 23: Anticipated unilateral tariff shock with durables and inventories