Trade Wars and the Optimal Design of Monetary Rules

Stéphane Auray[b,1], Michael B. Devereux[1], Aurélien Eyquem[c]

[a]*CREST-Ensai and Rennes School of Business. ENSAI, Campus de Ker-Lann, Rue Blaise Pascal, BP 37203, 35172 BRUZ Cedex, France.* `stephane.auray@ensai.fr`.

[b]*Vancouver School of Economics, University of British Columbia 6000, Iona Drive, Vancouver B.C. Canada V6T 1L4, CEPR and NBER.* `michael.devereux@ubc.ca`.

[c]*Department of Economics, University of Lausanne, Internef, CH-1015 Lausanne, Switzerland. Email:* `aurelien.eyquem@unil.ch`.

Abstract

Countries have an incentive to use tariffs to gain advantage over trade partners, but an optimal tariff must weigh the benefits of an improved terms of trade against the costs that the tariff imposes on the domestic economy. In the presence of monopoly distortions and nominal rigidities, the stance of monetary policy may have a large effect on the evaluation of these costs. In a global economy where all countries set tariffs unilaterally in a 'trade war', the final outcome can differ dramatically depending on different monetary policy rules. We set out a model of a trade war in a New Keynesian open-economy model. For any one country, a tariff improves the terms of trade but is costly due to its deflationary effect on the domestic economy. A monetary rule which targets the CPI or stabilizes the nominal exchange rate exacerbates these latter costs, and leads to lower equilibrium tariff rates in a trade war. Furthermore, an optimally delegated monetary rule can in fact completely eliminate a trade war.

Keywords: Protectionism, Trade Wars, Inflation Targeting.

JEL classification: F30, F40, F41.

[1]Devereux thanks SSHRC for research funding. Auray and Eyquem acknowledge financial support from the French National Research Agency (ANR-20-CE26-0018-02).

1. Introduction

The world has recently experienced a breakdown in the effectiveness of trade agreements. Countries have begun to pursue unilateral protectionist policies in the form of tariffs or other trade restrictions. The incentive to levy tariffs is well understood. Given the policies of other countries, any one country can benefit by levying a tariff. But a tariff may also impose costs on the domestic economy. In the presence of pre-existing distortions and nominal rigidities, these costs may be substantially affected by the stance of monetary policy. Following this logic, our paper explores the impact of alternative monetary policy rules on the optimal tariff choices in open economies, and the implications of alternative monetary policy rules for the outcome of generalized tariff competition, or trade wars.

A key motive for non-cooperative trade policies is to exploit the so-called terms-of-trade externality (see Corsetti and Pesenti [15], Benigno and Benigno [5] or Ferrero [24] and references therein for a recent survey). In Johnson [32]'s classic paper, each country faces a unilateral incentive to improve its terms of trade and induce welfare gains, given the actions of other countries. A trade war is then an equilibrium in which all countries set tariffs to improve their terms-of-trade, leaving the global economy with reduced trade volume and lower welfare compared to a world with free trade.

In a monetary economy, any movement in the terms of trade has to have an effect on exchange rates or price levels. In a standard New Keynesian economy where monetary policy follows an interest rate rule, by reducing consumption of imports and raising domestic goods consumption, a tariff is likely to be deflationary. But when output is inefficiently low due to markup distortions, a deflation has negative welfare consequences. If an optimal tariff balances the benefits of terms of trade improvement against the welfare costs from deflation, then the stance of monetary policy can have important effects on the final outcome.

In the New Keynesian open economy with producer currency pricing, it is well known from Clarida et al. [14] and Engel [19] among others that an optimal monetary policy should target the inflation rate of the domestic goods (or the producer price index or PPI). We show that this result no longer applies in the context of a trade war. Our first result shows that consumer price index (CPI) inflation targeting strictly welfare dominates PPI targeting because it leads to lower tariffs as the outcome of a trade war. The logic follows the intuition described above. While CPI targeting stabilizes the response of the overall CPI to any shocks, it leads to a greater response of the PPI. In the context of endogenous trade policy, this will reduce the desired optimal tariff.

We illustrate these results in a simple analytical version of our model in Section 3. In the presence of monopoly pricing distortions, an optimal tariff has to balance the welfare gains from improving the terms of trade against the welfare costs from the worsening of the monopoly distortions. CPI targeting leads the tariff authority to place more weight on these welfare costs, thus leading to a lower desired tariff. In a fully symmetric global economy, each country's tariffs offset the other's, and therefore welfare is higher under CPI targeting, because average tariffs are lower.

But in fact, one can do better than that. We go on to show that neither exact rule (PPI or CPI targeting) is optimal from the perspective of a cooperative authority that could design a rule which internalizes the motive behind national trade policies and the subsequent impact of the monetary rules on tariff choices. We think of this as a situation where the monetary rule is delegated to independent central banks, but the form of the rule is designed *ex ante*, taking into account the nature of trade policy and the implementation of monetary policy. In this case, we show that an optimal cooperatively designed rule will place a high weight on stabilizing a function of the tariff-adjusted terms of trade. This rule acts so as to fully offset the incentive to impose tariffs, and so in fact eliminates the trade war completely. The optimal rule actually leads to small *negative* tariffs, which have the effect of undoing part of the pre-existing monopoly distortions in production. Hence, remarkably, in the presence of endogenous tariff setting, a particular monetary policy rule can not only end the trade war, but also partly alleviate the underlying production distortion in each economy, and in so doing actually *dominates* a free trade outcome in welfare terms.

We then show that the optimal cooperatively designed monetary policy is very close to a non-cooperative outcome where each individual country designs its monetary rule and delegates it to its own central bank. First, if a rule must be transparent in the sense that it targets an official price index, then we find that CPI rather than PPI targeting will be unilaterally optimal for each country. But if the rule allows for more flexibility, we show that in this case also, the optimal rule leads to an endogenous elimination of the trade war, and a partial offsetting of the monopoly distortion. Hence, we may conclude that a purely self-oriented policy of optimal monetary design and delegation can achieve major welfare gains in an environment of endogenous non-cooperative trade policy and monopoly distortions in production.

In a final section, we use the model in an empirical application to the US-China trade war. Using an estimated version of the model based on macro data from China and the US, under plausible assumptions about the settings of monetary policy in each country, we look at the impact of a trade war assuming that both countries switched from the existing tariff structure to a Nash equilibrium of a trade war beginning in 2018. The model produces estimates of equilibrium tariffs very close to those observed in the data. Then we look at counterfactual monetary policy rules based on our previous theoretical results. We find that these alternative rules can lead to lower tariffs and higher welfare, as in our theoretical model, although the quantitative estimates are modest, due to the relative low degree of trade openness in each country.

Besides the presence of markup distortions and sticky prices, two other features of the model are important for our results. First, we assume that the motive for setting tariffs is to improve a country's terms of trade. While the trade literature has covered many other motivations behind protectionist trade policy, Bagwell and Staiger [3] argue that terms of trade improvement is the most important and empirically relevant driver of tariffs.[2] A second assumption is that trade policy is made without commitment. This may be interpreted as reflecting the increasing breakdown in rules based trade policy mentioned above, which would lead to a shift towards discretionary protectionism.[3]

The rest of the paper is organized as follows. Section 2 reviews some related literature. Section 3 develops the main intuition of our results within an example model of a small open economy. Section 4 develops the full model, and our main numerical results are presented in Section 5. Following this, we explore the welfare-maximizing delegation rule for monetary policy in Section 6. Section 7 looks at the consequences of asymmetric monetary rules for trade wars. Section 8 applies the model to an analysis of the US-China trade war. Some conclusions follow.

2. Literature

This paper builds on a long tradition of macroeconomic models dealing with monetary policy in open economies. Using a two-country model with monopolistic competition, Corsetti and Pesenti [15] show how national welfare may depend on a terms-of-trade externality. There are many subsequent papers analyzing optimal monetary policy in different open-economy frameworks, among them Benigno and Benigno [5], Galì and Monacelli [26], Faia and Monacelli [21], de Paoli [17], Bhattarai and Egorov [8], Groll and Monacelli [27], Fujiwara and Wang [25], or more recently Egorov and Mukhin [18]. Most if not all of the above contributions highlight the importance of the terms-of-trade externality for the design and effects of monetary policy in open economies.

[2] Supporting this view, in an empirical study, Broda et al. [10] et al find that tariffs are systematically higher on imported goods with more inelastic supply schedules.

[3] Our definition of discretionary trade policy is identical to that in Staiger and Tabellini [38] . If tariff setters could commit to a sequence of future tariffs the interaction between monetary policy and trade policy would be lessened, as we discuss below.

There is also a growing literature analyzing the interplay between trade, nominal rigidities and monetary policy. Based on a trade framework, a series of recent papers investigates how the relationship between trade flows, nominal wage rigidities and employment dynamics shapes the effects of trade or labor-market shocks. Rodríguez-Clare et al. [35] explore the welfare effects of the China shock on the US economy. Fadinger et al. [20] show that the German labor-market reform crowded-out employment in the manufacturing sector because of the interaction between downward wage rigidities and the currency union setting. Gurkova et al. [28] find that the welfare gains from a trade liberalization driven by the decline in the CPI overwhelm the losses from wage cuts, job destruction, and capital losses, hence highlighting the key importance of price adjustment and potential monetary policy responses to changes in trade conditions.

Based on a more macro set-up, Bergin and Corsetti [6] consider tariffs as policy instruments in addition to monetary policy, but their focus is rather on the implications of monetary policy on the building of comparative advantages. Jeanne [31] investigates the interaction between 'currency wars' and 'trade wars' in an analytical framework of a continuum of small open economies with downward nominal wage rigidity and, in some cases, a global liquidity trap, and explores the benefits of international cooperation. Bergin and Corsetti [7] develop a multi-country DSGE model with trade in intermediate goods and firms entry. They look at the optimal response of monetary policy to exogenous tariff shocks, which they find to be expansionary given the deflationary effects of tariff hikes. Barattieri et al. [4] show both empirically and theoretically that tariff shocks have a contractionary effect on the economy. In a previous paper Auray et al. [2], we analyzed the interaction between monetary policy and trade policy, focusing on the difference between rules and discretion in monetary policy. That paper highlighted an important distinction between rules and discretion in the presence of endogenous trade policy and a trade war between countries. That paper took a standard Taylor rule for monetary policy (based on PPI targeting) as a benchmark, comparing that to a purely discretionary monetary policy, showing that both tariffs and inflation rates would be higher in the latter case. However, that paper did not compare alternative monetary policy rules, nor did we explore how an optimal monetary rule would be determined in a non-cooperative trade policy environment.

The specific characteristic our paper is its focus on the design of monetary policy in an environment with non-cooperative trade policy. From this we illustrate the welfare benefits of CPI inflation targeting. Under free trade, when prices are sticky in domestic currencies – a case known as producer currency pricing – Clarida et al. [14] and Engel [19] among others have shown that an optimal monetary policy should target the inflation rate of the domestic goods. We show that this result does not hold when there is a breakdown in cooperative trade policies. The reason is that central banks can curb the incentive to apply tariffs by targeting an inflation rate that incorporates changes in terms-of-trade, thereby partly offsetting attempts at terms-of-trade manipulation.

Another related literature concerns the design and delegation of monetary policy rules. Rogoff's seminal paper ([36]) first highlighted the implications for optimal monetary policy when policy is made in the presence of other distortions aside from price stickiness. Rogoff shows that a second-best optimal policy should place an excessive weight on inflation deviations from target relative to the socially optimal weight. A large follow-up literature explored issues related to the design of optimal monetary policy rules. [40] and [39] placed the question of monetary policy design in the form of principal agent relationships between society and a central bank, and compared alternative forms of rules that took into account the incentives of the central bank in implementing policy. Our paper differs somewhat in that we show how an optimal monetary rule may need to take account of the incentive structure of trade policymakers.[4]

Our paper finally relates to a literature showing the potential benefits of targeting

[4] In this, the context is similar to [16] who show how an optimal monetary rule should be guided by the presence of other policymakers with different instruments and objectives.

a different price index than the PPI, and of incorporating changes in the real exchange rate. This has been show to be relevant for certain values of the trade elasticity (de Paoli [17]), for certain configurations of global value chains (Huang and Liu [29], Wei and Xie [41]) or when exchange rate pass-through is incomplete (Monacelli [34], Engel [19]), . However, in comparison to the above contributions, the motive for choosing a different inflation target is original and stems from the commitment of the central bank to offset terms-of-trade manipulations from tariff setters *in the steady state*, implying lower tariffs and thus large steady-state welfare gains.

3. An Example Model

The complete model is described in Section 4. For now, we describe a simplified small open economy version of the model. This helps to build intuition regarding the link between monetary policy rules and the optimal tariff choice. The details of this model are set out fully in Appendix A.[5] In the small economy, trade is balanced every period, and there is an exogenous Foreign demand curve for the Home export good. The Home country government sets a tariff to maximize Home utility. Trade policy is made under discretion. Monetary policy follows a 'Taylor-type' rule, but allows for different inflation target indices. The key focus is the comparison of optimal tariffs across the different forms of the monetary rule.

3.1. Equilibrium Conditions

Households. Preferences over consumption and hours are given by:

$$\mathbb{E}_t \sum_{j=0}^{\infty} \beta^j \left\{ u\left(C_{ht}, C_{ft}\right) - \ell\left(H_t\right) \right\}, \tag{1}$$

where, $\beta < 1$, C_{ht} ($C_{f,t}$) represents consumption of the Home (Foreign) good, u satisfies the usual conditions of differentiability and quasi concavity, $\ell(.)$ is a function of hours

[5] The model is developed more fully in Auray et al. [2], to which we refer readers.

worked, and satisfies $\ell'(.) > 0$, and $\ell''(.) > 0$.

The Home country budget constraint is:

$$B_t + P_{ht}C_{ht} + (1+\tau_t) S_t P^*_{ft} C_{ft} = R_{t-1}B_{t-1} + W_t H_t + \Pi_t + TR_t. \tag{2}$$

Here P_{ht} (P^*_{ft}) represents the Home (Foreign) goods price in Home (Foreign) currency, and S_t is the nominal exchange rate. B_t represents holdings of Home nominal bonds and R_t is the gross nominal interest rate paid on bonds.[6] Variable W_t and Π_t are the Home nominal wage and the profit from Home firms, respectively, while τ_t is an import tariff. Finally, TR_t is a lump-sum transfer from the Home government.

Firms. A continuum of Home firms produce differentiated goods. The aggregate good is a composite of these differentiated goods, where the elasticity of substitution between goods $\epsilon > 1$. Output of firm i is: $Y_t(i) = AH_t(i)$ where A is a measure of aggregate productivity. Firm i chooses a price to maximize the present value of its expected profits subject to the demand function for individual goods $Y_t(i) = (P_{ht}(i)/P_{ht})^{-\epsilon} Y_t$ and to Rotemberg adjustment costs $\phi \geq 0$. Assuming symmetry among individual good producers, profit maximization produces the following Phillips curve:

$$\mathbb{E}_t \{\Omega_{t,t+1}\} = \mathcal{W}_t A_t^{-1} = \mathbb{E}_t \left\{ \theta + \phi\epsilon^{-1} \left(\pi_{ht} (\pi_{ht} - 1) - \beta \pi_{ht+1} (\pi_{ht+1} - 1) \right) \right\}, \tag{3}$$

where $\mathcal{W}_t = W_t / P_{ht}$ is the real wage and $\theta = (1+s)(\epsilon - 1)/\epsilon \leq 1$ is a subsidy-adjusted measure of monopolistic distortions – the inverse of the subsidy-adjusted markup, where s is a revenue subsidy.[7] If an optimal subsidy $s = 1/(\epsilon - 1)$ is in place, then $\theta = 1$ and the markup is zero. If current and future inflation is zero and the optimal subsidy is in

[6] We introduce nominal bonds to rationalize an interest rate rule for monetary policy. In the simple model, all bonds are issued by home government and held only by domestic agents, so that the economy satisfies balanced trade.

[7] Here we simplify by assuming the firm's discount factor for the expected future inflation cost is constant at β. This makes no difference to the example model.

place, then $\mathbb{E}_t\{\Omega_{t,t+1}\} = 1$ and $\mathcal{W}_t = A_t$. $\mathbb{E}_t\{\Omega_{t,t+1}\}$ measures the overall distortion bearing on the real wage. As we see below, the presence of a distorted steady state is critical in linking the stance of monetary policy to the choice of optimal tariffs.

There are two aspects associated with (3) that are critical for our results. First, we assume that $\theta < 1$, so that even in the absence of price rigidities ($\phi = 0$), there remains an existing monopoly distortion. The presence of a monopoly distortion leads the level of output to fall below its efficient level. We note that a large empirical literature has persuasively established the fact of markups in almost all countries.[8] As shown below, when $\theta < 1$, trade policy must balance the efficiency costs of higher tariffs against the benefits of improved terms of trade. The second and separate key feature of our results is the presence of sticky prices. In order for the monetary rule to affect the choice of an optimal tariff, it must be the case that prices are sticky, or $\phi > 0$. Clearly, with fully flexible prices monetary policy would have no implications for tariff choice.

Government and Foreign sector. The Home government earns revenue from tariffs, rebates this in the form of transfers TR_t to households, and issues bonds to households. The government budget constraint is written as:

$$B_t + TR_t = R_{t-1}B_t + \tau_t S_t P^*_{ft} C_{ft}, \tag{4}$$

Without loss of generality, in equilibrium, we will assume that bonds are in zero net supply.

We make the simple assumption that the small open economy faces the following

[8] See **?**] for an empirical characterization of markups in the U.S., and **?**] for a global perspective. More generally, we might argue that political constraints make it impossible for the fiscal authority to subsidize monopolistic firms, or alternatively that informational asymmetries between firms and the government (not modeled here) prevent the use of targeted subsidies for firms with market power.

Foreign demand for its exported goods:

$$C^*_{ht} = \Lambda \mathcal{S}_t^{\eta}, \tag{5}$$

where $\mathcal{S}_t = S_t P^*_{ft}/P_{ht}$ denotes the terms of trade (the relative price of the Foreign good), Λ is a constant and η is the elasticity of Foreign demand.

Monetary policy. We assume that monetary policy follows a simple Taylor-type rule, although the target price index may differ across rules:

$$R_t = \beta^{-1} \left\{\pi_t^{tar}\right\}^{\mu_\pi}. \tag{6}$$

For this example, let the target inflation vary between a producer price inflation index, in which case $\pi_t^{\text{tar}} = \pi_{h,t} = \frac{P_{h,t}}{P_{h,t-1}}$, and a consumer price inflation index, written as $\pi_t^{\text{tar}} = \pi_{\text{cpi},t} = \frac{P_t}{P_{t-1}}$, where $P_t = P(P_{ht}, (1+\tau_t)S_t P^*_{ft})$ is the Home consumer price index. Note that since the CPI is homogeneous of degree one we may write:

$$\pi_{\text{cpi},t} = \pi_{h,t} \frac{\mathcal{P}((1+\tau_t)\mathcal{S}_t)}{\mathcal{P}((1+\tau_{t-1})\mathcal{S}_{t-1})} \tag{7}$$

where $\mathcal{P}((1+\tau_t)\mathcal{S}_t) \equiv P(1, (1+\tau_t)\mathcal{S}_t)$. Therefore, the goal of CPI stabilization can be thought of as amalgam of PPI stabilization, and the stabilization of a function of the change in the tariff-adjusted terms of trade.

The main goal of the paper is to show how different rules lead to substantially different outcomes for a trade war between countries. It is well known from the results of Clarida et al. [14] and Engel [19] among others that in the basic New Keynesian model, when prices are sticky in domestic currency, an optimal monetary policy should target the inflation rate of the Home good (or the PPI). In this paper, we show that in a trade war, due to the interaction between trade policy and monetary policy, it may be preferable to employ a rule targeting the overall CPI. In either case, the stance of monetary policy is measured by the reaction coefficient of the Taylor rule μ_π. We take μ_π as given, and show below how the choice of an inflation target affects the equilibrium degree of protection when the Home tariff is chosen optimally by the Home authority under discretion.

Equilibrium. Conditional on the following goods market clearing condition:

$$A_t H_t \Phi_t = C_{ht} + C^*_{ht},$$

where $\Phi_t = 1 - \frac{\phi}{2}(\pi_{ht} - 1)^2$, and assuming balanced trade every period, the full equilibrium reduces to:

$$\begin{aligned}
\text{Balanced trade} &: \quad \Lambda \mathcal{S}_t^{\eta} = \mathcal{S}_t C_{ft}, && (8)\\
\text{Market clearing} &: \quad A_t H_t \Phi_t = C_{ht} + \Lambda \mathcal{S}_t^{\eta}, && (9)\\
\text{Labor market} &: \quad \ell'(H_t) = A_t u_{c_{ht}} \mathbb{E}_t \{\Omega_{t,t+1}\}, && (10)\\
\text{Optimal spending} &: \quad u_{c_{ht}} (1+\tau_t) \mathcal{S}_t = u_{c_{ft}}, && (11)\\
\text{Inflation: PPI target} &: \quad \mathbb{E}_t \left\{ \frac{\pi_{ht}^{\mu_\pi}}{\pi_{ht+1}} \frac{u_{c_{ht+1}}}{u_{c_{ht}}} \right\} = 1, && (12)\\
\text{Inflation: CPI target} &: \quad \mathbb{E}_t \left\{ \frac{\pi_{ht}^{\mu_\pi}}{\pi_{ht+1}} \left(\frac{\mathcal{P}(1,(1+\tau_t)\mathcal{S}_t)}{\mathcal{P}(1,(1+\tau_{t-1})\mathcal{S}_{t-1})} \right)^{\mu_\pi} \frac{u_{c_{ht+1}}}{u_{c_{ht}}} \right\} = 1. && (13)
\end{aligned}$$

The last two equations stem from combining the Euler equation with the monetary policy rule. We assume that the Home government chooses tariffs to maximize the current-period argument of Equation (1) subject to Equations (8), (9), (10) and either (12) for PPI inflation targeting or (13) for CPI inflation targeting. Equation (11) is ignored since it determines the tariff rate given the equilibrium of the real economy. We assume that trade policy is made under discretion, whereby the government takes its successor's decisions as given. While the economy features balanced trade, the trade authority must still take account of its choice of tariffs on the next period's problem given the future period terms in (12) or (13). We note also that the tariff-adjusted terms-of-trade expressions in condition (13) can be replaced using (11) since:

$$(1+\tau_t)\mathcal{S}_t = \frac{u_{ch,t}}{u_{cf,t}} \tag{14}$$

Appendix A gives the details and proofs of the following results that focus on steady-state outcomes.

But before exploring the implications of alternative monetary rules for equilibrium tariff rates, we note conditional on a given tariff, both PPI and CPI targeting achieve the same steady-state outcomes.[9] This follows because under either monetary rule, to be consistent with a constant steady state terms of trade, both the PPI inflation and CPI inflation should be zero. Hence, there is no welfare case for either targeting rule above the other under *for given tariff rates*.[10] More generally, as we noted above, the literature on New Keynesian open macro models has shown that in general PPI targeting dominates CPI targeting under producer currency pricing, since it acts to stabilize the price in which there are costs of adjustment and allows for efficient relative price change through nominal exchange rate adjustment.

A second feature of the example model is useful to understand the results that follow. Holding constant all period $t+1$ variables, a rise in the current tariff rate will reduce the current PPI inflation rate, and the fall in PPI inflation is greater when the monetary rule (13) is followed than in the case of the monetary rule (12). To see this, note first from (12) that a rise in $C_{h,t}$ that is induced by a one time increase in the tariff rate, holding constant future consumption and future inflation, must reduce current PPI inflation π_{ht},

[9] We are assuming the monetary rule satisfies the conditions for uniqueness of equilibrium.

[10] Note that $\frac{P_t}{P_{t-1}} = \pi_{h,t}\left(\frac{\mathcal{P}_t}{\mathcal{P}_{t-1}}\right)$, so given that the second term on the right-hand side is constant and equal to one in a steady state, PPI and CPI targeting lead to the same real and welfare outcomes with zero inflation. An extended analysis of optimal monetary and trade policy in a dynamic environment is beyond the scope of this paper, but in any case would still embed the result that optimal discretionary tariffs would be affected by the monetary policy rule.

since it reduces the marginal utility of home consumption u_{cht} (or equivalently, reduces the natural real interest rate in terms of home goods). Then, turning to the case of the monetary rule (13) we see that when the CPI is the inflation target, there is an additional channel through which a rise in the current tariff is deflationary, since a rise in the tariff must raise the term $(1+\tau_t)\mathcal{S}_t$, which is in equilibrium equal to the marginal rate of substitution between home and foreign goods, from (14). Therefore a rise in the current tariff, holding future variables constant, must be more deflationary for the PPI in the case of CPI inflation targeting, relative to PPI targeting.[11]

3.2. *Results*

3.2.1. *Optimal Tariff under PPI Inflation Targeting*

We first derive the optimal tariff when the monetary authority follows a PPI inflation targeting monetary rule so that $\pi^{target} = \pi_{h,t}$. Hence, the optimal tariff choice must take account of (12). Since tariff policy is chosen without commitment, the policymaker chooses an optimal tariff taking as given all future variables. Then, from the monetary rule (12), tariff policy will take account of its effect on current home goods consumption and current inflation, given future consumption and inflation. But with sticky prices, this has implications for employment and output through the labor market equilibrium condition (10). We show the following result.

Result 1. *Under a PPI inflation targeting rule, ($\phi > 0$, $\pi^{target} = \pi_{h,t}$) the steady-state equilibrium inflation rate is zero, $\pi_h = 1$, and the optimal tariff is given by:*

$$1 + \tau^{ppi} = \frac{\eta}{\eta - 1}\frac{1-\theta\Delta_1}{1-\Delta_1} \leq \frac{\eta}{\eta-1}, \tag{15}$$

where $\Delta_1 = \frac{A^2 u_{c_{hh}}}{\ell''(H)}\left(\theta + \frac{\phi}{\mu_\pi \epsilon}\right) < 0$.

a) When $\theta = 1$ (no monopoly distortions), the tariff rate equals $\frac{1}{\eta-1}$, the monopoly tariff formula.

[11] Note that an important assumption is that tariffs are chosen under policy discretion. With tariff commitment, the policymaker would have to take account of tariffs chosen for the future on consumption in period $t+1$ which would tend to offset the direct effect on the marginal utility of consumption in period t.

b) When $\theta < 1$ (monopoly distortions), the tariff rate is lower than $\frac{1}{\eta-1}$, and is decreasing (increasing) in ϕ (μ_π).[12]

Proof 1. *See Appendix B.*

We can explain Result 1 as follows. First, when $\theta = 1$, Result 1 indicates that $\tau = \frac{1}{\eta-1}$ implying that the tariff is set according to the classic monopoly tariff formula, and is focused solely on exploiting the market power of Home firms over Foreign demand. But when $\theta < 1$ Home output is inefficiently low due to the monopoly distortion, and a tariff would exacerbate this distortion by increasing the consumption of the Home good and reducing output, due to the income effect on labor supply. Hence, the policymaker chooses to set a lower tariff than the pure monopoly rate.

When $\theta = 1$, the tariff is also independent of the degree of price stickiness. But in the general case where $\theta < 1$, Result 1 indicates that the optimal tariff rate depends on the degree of price stickiness. The purely flexible price case can be obtained from Result 1 when $\phi = 0$. But as ϕ rises, the optimal tariff falls below the flexible price case.

Why are tariffs lower with sticky prices? As before, the tariff raises the consumption of Home goods relative to Foreign imports. As described above, a rise in C_{ht}, given C_{ht+1}, would reduce the natural interest rate $u_{c_{ht}}/u_{c_{ht+1}}$. This will in turn would reduce the PPI inflation rate which is determined through the policy rule (12). When prices are sticky, a fall in inflation would reduce current output through the Phillips curve (3). Since output is already inefficiently low given $\theta < 1$, this further raises the welfare cost of the tariff and leads the policymaker to set an equilibrium tariff below the flexible price tariff. Since under discretion, the policymaker in each period behaves in the same way, taking future policy as given, it follows that with the monetary rule (12), the tariff rate under sticky prices must always fall below that with price flexibility.[13]

[12] This result combines Result 1 and Result 2 from Auray et al. [2].

[13] While the model implies that a temporary rise in a tariff will reduce PPI inflation, this does not necessarily imply an empirical prediction of a negative association between tariffs and inflation. First,

We also see from Result 1 that the optimal tariff is increasing in the strength of the monetary policy rule μ_π. A tighter monetary policy rule would reduce the (negative) impact of the tariff on inflation, and thus reduces the policymaker's perceived distortionary impacts of a tariff on output. In the limit, as μ_π rises arbitrarily high, the price level is fully stabilized and the tariff approaches its flexible price level.

3.2.2. Optimal Tariff under CPI Inflation Targeting

We now contrast the above results with those arising when monetary policy targets the CPI rate of inflation, $\pi_t^{\text{target}} = \pi_t$. Appendix B shows that the optimal tariff under CPI targeting is given by:

$$1+\tau^{\text{cpi}} = \frac{\eta}{\eta-1}\frac{1-\theta\Delta_2}{1-\Delta_2}(1+\Delta_3) \leq 1+\tau^{\text{ppi}} \leq \frac{\eta}{\eta-1}, \tag{16}$$

where $\Delta_2 = \frac{A^2 u_{c_{hh}}}{\ell''(H)}\left(\theta + \frac{\phi}{\mu_\pi \epsilon}(1+\mu_\pi\alpha(1-\beta))\right) < 0$, $\Delta_3 = \frac{\phi A^2 u_{c_h}}{\mathcal{S}\epsilon\ell''(H)}\alpha\frac{u_{c_{ff}}}{u_{c_f}}(1-\beta)\frac{(1-\theta)}{(1-\theta\Delta_1)} < 0$, and α is the share of Foreign goods in consumer spending.

Result 2. *The optimal tariff under CPI targeting is less than that under PPI targeting.*

Proof 2. *Appendix B outlines the full proof. We see from (16) that if $\theta = 1$, the tariff rate is again equal to the full monopoly tariff. But for $\theta < 1$ the tariff falls below the monopoly tariff rate and also below the tariff under PPI inflation targeting (with sticky prices).*

Why does CPI inflation targeting produce a lower optimal tariff rate? Following the discussion above, the intuition can be seen from the policy adjusted Euler equation (13). When the optimal tariff is determined under discretion, the policymaker takes account of a change in the tariff on both the current PPI inflation and the tariff-adjusted terms

---

we note that while the negative channel through which tariff choice affects the PPI inflation rate is taken account of in the tariff choice by the policy-maker, in equilibrium inflation is at the target rate of zero, while tariffs are positive. Secondly, although an exogenous temporary spike in the tariff will reduce PPI inflation, it can still increase CPI inflation through the term $(1+\tau)\mathcal{S}$. This is in line with the empirical evidence linking tariff shocks to CPI inflation. (e.g. Barattieri et al. [4]). Finally, while Result 1 describes a steady state tariff rate given PPI targeting, macro shocks which affect the optimal tariff choice are likely to produce a positive association between tariffs and inflation. In particular, a negative temporary productivity shock will lead to a rise in the optimal tariff rate and a rise in PPI inflation.

of trade. An increase in the tariff will tend to raise the policy-adjusted terms of trade $(1+\tau_t)\mathcal{S}_t$. Given that (13) is always binding, in order to target the CPI, the policymaker must allow a greater fall in the PPI inflation rate, relative to PPI targeting. This fall in the PPI inflation rate $\pi_{h,t}$ further exacerbates the domestic output distortion. This leads the tariff setter to reduce the size of the optimal tariff further than in the case with only PPI targeting.

This illustrative example covers only the case of a small economy, taking Foreign demand (and any Foreign tariff) as given. In this scenario without retaliation an optimal tariff will clearly raise the country's welfare, relative to free trade with a zero tariff. But in the extended model below, we show that when both countries choose optimal tariffs, then a policy of CPI targeting in both countries can reduce the depth of a trade war and increase welfare in all countries.

4. The Full Model

The extended model follows closely Auray et al. [2] and is described in detail in the Appendix Appendix C. There are two countries denoted Home and Foreign. Households supply labor, consume goods from both countries with an elasticity of substitution λ, and trade non-contingent bonds. The world is populated with a unit mass of agents and Home has share n of these, with Foreign share $1-n$. We assume that firms supply imperfectly substitutable varieties of local goods, set prices in the currency of producers (PCP), and adjust prices constrained by Rotemberg price adjustment costs.

The model can be reduced to a system of two Phillips Curves (Equations (Appendix C.40) and (Appendix C.41) in Appendix C), two good market clearing conditions (Equations (Appendix C.42) and (Appendix C.43)), two Euler equations (Equations (Appendix C.45)-(Appendix C.46)), and Equations (Appendix C.44), (Appendix C.47) and (Appendix C.48) that describe the external equilibrium – the terms of trade (Equation (Appendix C.47)) and two net foreign asset positions (Equation (Appendix C.44 and

Equation (Appendix C.48)). Conditional on a given set of tariffs $\{\tau_t, \tau_t^*\}$ and monetary policies $\{R_t, R_t^*\}$, these equations determine $\left\{\pi_{ht}, \pi_{ft}^*, C_t, C_t^*, Y_t, Y_t^*, b_t, b_t^*, \mathcal{S}_t\right\}$.

4.1. Economic Policy

There are two separate levers of policy in the model. Trade policy may be used to levy tariffs on imports, and monetary policy can be used to stabilize inflation with a flexible exchange rate between the two countries, or to stabilize inflation in one country and the nominal exchange rate in the other country, *i.e.* a fixed exchange rate regime. As argued above, given the ubiquity of markups in the real economy, we leave aside a third possible policy lever and disregard any potential subsidy aimed at correcting markup distortions. As shown above, this has important implications for optimal tariffs set in interaction with monetary policy, as optimal country-level tariffs balance the utility gains from improved terms of trade (achieved with higher tariffs) and the costs from lower output while output is already inefficiently low due to markup distortions.

4.1.1. Monetary Policy

With a flexible exchange rate, the model is closed by the two following monetary policy rules:

$$R_t = \beta^{-1} \left(\pi_t^{tar}\right)^{\mu_\pi}, \tag{17}$$

$$R_t^* = \beta^{-1} \left(\pi_t^{*tar}\right)^{\mu_\pi^*}, \tag{18}$$

where π_t^{tar} and π_t^{*tar} can be either the PPI inflation rate or the CPI inflation rate.

If the Foreign country has a nominal exchange rate target, it cedes control over its domestic inflation rate, leaving the Home country to run an independent monetary policy. In this case, the Foreign monetary policy rule is replaced by the following condition:

$$\pi_{ht} = \pi_{ft}^* \frac{\mathcal{S}_{t-1}}{\mathcal{S}_t}. \tag{19}$$

Because the nominal exchange rate is fixed, the terms of trade can change only due to changes in nominal price levels, implying that the terms of trade follows the dynamics of relative inflation rates.

4.1.2. *Trade Policy*

With a flexible exchange rate, a discretionary Nash equilibrium of trade policy implies that the Home government solves:

$$\max_{\{C_t,C_t^*,Y_t,Y_t^*,b_t,b_t^*,\mathcal{S}_t,\pi_{ht},\pi_{ft}^*,\tau_t\}} V(b_{t-1}) = U(C_t,H_t) + \beta\mathbb{E}_t\left\{V(b_t)\right\}, \tag{20}$$

subject to Equations (Appendix C.40)-(Appendix C.48) and monetary policy rules (17)-(18), while the Foreign government solves:

$$\max_{\{C_t,C_t^*,Y_t,Y_t^*,b_t,b_t^*,\mathcal{S}_t,\pi_{ht},\pi_{ft}^*,\tau_t^*\}} V^*(b_{t-1}^*) = U(C_t^*,H_t^*) + \beta\mathbb{E}_t\left\{V^*(b_t^*)\right\}, \tag{21}$$

subject to the same constraints. The resulting first-order conditions determine optimal discretionary Nash tariffs and select the equilibrium.

With a fixed exchange rate, the rule (19) adds an additional state variable to the model – in addition to net foreign assets – in the form of the lagged terms of trade. Since the nominal exchange rate is pegged, the terms of trade can adjust *only* via differences in inflation rates. Under a fixed exchange rate regime, the problem can be stated as:

$$\max_{\{C_t,C_t^*,Y_t,Y_t^*,b_t,b_t^*,\mathcal{S}_t,\pi_{ht},\pi_{ft}^*,\tau_t\}} V(\mathcal{S}_{t-1},b_{t-1}) = U(C_t,H_t) + \beta\mathbb{E}_t\left\{V(\mathcal{S}_t,b_t)\right\}, \tag{22}$$

subject to (Appendix C.40)-(Appendix C.48) and monetary policy rules (17)-(19) for the Home policymaker and similarly:

$$\max_{\{C_t,C_t^*,Y_t,Y_t^*,b_t,b_t^*,\mathcal{S}_t,\pi_{ht},\pi_{ft}^*,\tau_t^*\}} V^*(\mathcal{S}_{t-1},b_{t-1}) = U(C_t^*,H_t^*) + \beta\mathbb{E}_t\left\{V^*(\mathcal{S}_t,b_t)\right\}, \tag{23}$$

for the Foreign. Assuming $\mathcal{S}_{-1} = 1$ on top of $b_{-1} = 0$ selects only symmetric equilibria in the Nash tariff game.

5. Trade Wars under Alternative Monetary Policy Regimes

5.1. Calibration

To provide a quantitative evaluation of the extended model we need to pin down parameter values. Section 8 describes how a number of key parameters are estimated on quarterly data for China and the U.S. Table .2 in Section 8 sets out the values of all parameter values measured at a quarterly frequency. For this section, we calibrate to annual frequency, but being informed by the estimates of Section 8. The discount factor of households is $\beta = 0.96$, consistent with a real interest rate of 4% *per annum*. Both countries are of equal size in the baseline calibration so that $n = 0.5$. Further, we assume a home bias parameter $x = 0.4$ which implies $\gamma = \gamma_x = (1-\gamma^*) = (1-\gamma_x^*) = 0.7$. Under free trade (zero tariffs), this number is associated with a 60% total trade openness ratio. We consider a baseline value of $\sigma = 1$, implying a log utility for consumption. The Frisch elasticity is $\psi^{-1} = 0.4$ following **?**] and we normalize $\chi = 1$. The elasticity of substitution between varieties is $\epsilon = 6$, consistent with a 20% steady-state price-cost markup.[14] The (annual) Rotemberg parameter is $\phi = 25$ in line with the empirical evidence found in section 8, and the baseline monetary policy rule inflation parameter is $\mu_\pi = 1.5$, in line with empirical estimates. In line with Bergin and Corsetti [7], we set the share of intermediate goods in production to be $\alpha = 0.4$. Last, the trade elasticity is set at $\lambda = 5$ This is intermediate between the estimates of **?**], and the higher estimates of **?**] and in a frictionless model would imply an optimal tariff equal to 25%. The bond adjustment cost parameter suggested by **?**] is 0.0025 in a quarterly set-up which, in

[14] **?**] provides a discussion of the challenges in measuring aggregate markups. **?**] and **?**] estimate markups for the US economy close to the 20% range. Our qualitative results are not sensitive to alternative values of the markup.

our annual set-up, implies $\nu = 0.01$. Finally, the baseline results are derived under the assumption that trade is balanced in the steady state, *i.e.* $b = b^* = 0$.

5.2. *Markup distortions*

Most parameter values above are standard and, if they affect the results quantitatively they do not change the qualitative results. As we have noted above, an important maintained hypothesis is that the there are monopoly markups in each country, and markup distortions are not offset by an appropriate subsidy to firms' sales. As shown in the example model above, in the absence of markup distortions, monetary policy has no effects on the optimal tariffs resulting from the Nash game, which are simply equal to the classic monopoly formula in this case, *i.e.* $1 + \tau = \frac{\lambda}{\lambda - 1}$. With pre-existing markups, optimal tariffs under flexible prices are lower, because policymakers do not want to lower output too much since output is already low because of markup distortions. What we show below is that sticky prices make tariffs lower than under flexible prices, but with a different magnitude depending on the type of monetary policy conducted by central banks.

5.3. *Baseline Results*

Figure .1 reports the steady-state levels of tariffs, consumption and labor resulting from a trade war equilibrium as a function of the Rotemberg parameter ϕ for the three monetary policy set-ups described in the model section. It also reports the associated welfare losses with respect to the free-trade equilibrium.

– Insert Figure .1 –

First, Figure .1 confirms that when prices are flexible, monetary policy does not interact with the choice of optimal tariffs since the three monetary policy regimes deliver similar outcomes. Optimal tariffs are 22.5 percent, slightly below the classic monopoly tariff implied by the value of the trade elasticity (25 percent).

Second, the Figure confirms the result of Auray et al. [2] according to which tariffs – and welfare losses – fall with price stickiness, but generalizes it to CPI inflation targeting. Further, it shows that the equilibrium with a fixed exchange rate yields lower tariffs than PPI inflation targeting for any given value of price stickiness. In this case, changes in the nominal exchange rate are perfectly offset by the commitment of the Foreign central bank, which is internalized by tariff setters and results in lower tariffs. Tariffs can be as low as 16 percent with a fixed exchange rate when prices are very sticky.

Third, Figure .1 shows that CPI inflation targeting produces an even lower level of optimal tariffs. The reason is that the CPI inflation rate incorporates changes in the real exchange rate – or equivalently, changes in terms of trade. Hence, when tariff setters seek to manipulate the terms of trade, they internalize the fact that the monetary rule will largely offset these movements, which reduces the incentive to raise tariffs. As a result, tariffs are much lower than under the two alternative monetary policies for any value of price stickiness, and can be as low as 7.5 percent with very sticky prices.

As one would guess, with tariffs ranging from 22.5 to 7.5 percent, the welfare losses with respect to the free-trade equilibrium vary massively: from 3.4 percent (flexible prices) to 3 percent (with very sticky prices) under PPI inflation targeting, 2.3 percent with a fixed exchange rate regime, and less than 1 percent under CPI inflation targeting. For the baseline calibrated value of $\phi = 25$, CPI inflation targeting reduces the intensity of the trade war so as to imply welfare losses that are less than half of those arising under PPI inflation targeting.

6. Welfare-maximizing Inflation Target under Trade Wars

We have shown that adopting inflation targeting rules that incorporate changes in tariff-adjusted terms of trade can attenuate the severity and welfare losses of trade wars. But can central banks completely eliminate the incentive for tariff setters to improve terms of trade in a trade war? To answer this question, we now consider general monetary policy rules of the form:

$$R_t = \beta^{-1}\left(\pi_{ht}\left(\frac{\mathcal{P}_t}{\mathcal{P}_{t-1}}\right)^{d_r}\right)^{\mu_\pi}, \tag{24}$$

$$R_t^* = \beta^{-1}\left(\pi_{ft}^*\left(\frac{\mathcal{P}_t^*}{\mathcal{P}_{t-1}^*}\right)^{d_r}\right)^{\mu_\pi}. \tag{25}$$

These general rules are symmetric in that both countries target the same inflation rate, and imbed two of the three previous cases: $d_r = 0$ implies PPI inflation targeting while $d_r = 1$ implies CPI inflation targeting.[15] But the rules are more general in the sense that they allow central banks to place a larger weight on changes in $\mathcal{P}_t$, the relative price of consumption goods in terms of the domestic goods. Looking at the definition of $\mathcal{P}_t$ shows that it embeds two important determinants: the domestic tariff rate and the terms of trade. A credible commitment to stabilize changes in $\mathcal{P}_t$ thus amounts to a credible commitment in stabilizing changes in tariffs and terms of trade.

How should we interpret this type of monetary rule? We may think of this as a case of a cooperative monetary policy design, where *ex ante*, the designer chooses a weighting scheme on a monetary rule to be applied by the monetary authority, and then delegates the rule to each separate central bank, taking into account the manner in which trade policy is determined, and also how trade policy is affected by the form of the monetary rule being applied. The cooperative monetary policy design then chooses the form of the rule to maximize global *ex ante* welfare.

Can the stabilization of changes in terms of trade be large enough to fully avoid trade wars? Figure .2 below reports the welfare maximizing value of d_r for a range of price stickiness parameters ϕ and the corresponding equilibrium outcomes in terms of tariffs,

[15] Indeed, assuming $dr = 1$ and replacing the definition of $\mathcal{P}_t = \frac{P_t}{P_{ht}}$ in the Home rule yields $R_t = \beta^{-1}(\pi_t)^{\mu_\pi}$, where $\pi_t = \frac{P_t}{P_{t-1}}$ is the CPI inflation rate. Similar manipulations yield an equivalent outcome for the Foreign rule.

consumption, labor and the welfare losses compared to the free trade equilibrium.

– Insert Figure .2 –

Figure .2 reports a stark result: inflation targeting monetary policies with an adequately chosen parameter d_r can fully prevent trade wars. As a matter of fact, they completely eliminate incentives for tariff setters to manipulate the terms of trade. This leaves them with the only possible motive when setting tariffs: eliminate the (purely local) monopoly distortions.

Indeed, the implied level of tariffs is negative and corresponds to a subsidy, *i.e.* $\tau = \tau^* = -0.054$. This value in fact exactly matches the welfare-maximizing level of tariffs that tariff setters would choose cooperatively to offset monopoly distortions when sales subsidies are absent. With an optimally designed monetary rule, tariffs are thus used exclusively to offset monopoly distortions.

As such, welfare-maximizing inflation targeting rules can, in the context of non-cooperative trade policies, raise welfare by fully eliminating the terms-of-trade externality. Remarkably, as we show below, this delivers a welfare level greater than that under free trade with zero tariffs.[16] To achieve this outcome, the weight placed on changes in the relative price of traded goods must be above the weight implied by CPI inflation targeting, and be larger (smaller) when prices are more flexible (sticky).

7. Asymmetric Inflation Targeting

Given the above results, a natural question arises regarding asymmetry in the inflation target: what happens when central banks target different inflation rates? What are the aggregate and national welfare implications and thus the national incentives to

[16]Note however, that this does not attain the first-best outcome that would hold in the absence of markups and zero tariffs. This is because the tariff chosen in this case must distort the composition of consumption between Home and Foreign goods.

choose the inflation target? Last, what do asymmetries imply for the outcome of trade wars?

7.1. Home Targets CPI inflation and Foreign PPI inflation

We start our analysis by looking at the case where the Home central bank targets the CPI inflation rate while the Foreign central bank targets the PPI inflation rate. Figure .3 illustrates this case.

– Insert Figure .3 –

Figure .3 shows that in this asymmetric case, where Foreign targets the PPI, targeting the CPI inflation rate in the Home country generates smaller tariffs for *both* Home and Foreign economies compared to symmetric PPI inflation targeting. Aggregate welfare losses are thus lower, but since CPI inflation targeting directly curbs incentives to set tariffs only in the Home economy, tariffs are much lower in the Home than the Foreign economy. However, this alleviates trade tensions for both countries, leading to lower overall tariffs and higher welfare than in the case of uniform PPI inflation targeting. This asymmetry in inflation targets and resulting tariffs also leads to an asymmetry in welfare losses: losses fall more for the Foreign economy – which sets a higher tariff than the Home economy, thus gaining a terms-of-trade advantage – and less for the Home economy. Nevertheless, *given* that the Foreign country follows a PPI inflation target, targeting the CPI rate of inflation is welfare improving for the Home economy.

The comparison of Figure .3 to Figure .1 suggests an even stronger result, given our current calibration, confirmed by Figure .4 below. If the Home country follows a CPI targeting rule, then given an *ex ante* choice, the Foreign country would be better off choosing a CPI targeting rule also, since the welfare loss from a symmetric CPI outcome is in fact less than the loss attained by the Foreign country in the asymmetric case where it follows a PPI rule and the Home country follows a CPI rule. We could envisage a two-stage game where each policy authority chooses *ex ante* the form of the monetary policy rule, restricted to be either a CPI or a PPI rule, and then delegates this to the monetary authority. Then, given this comparison, we would conclude the CPI targeting is a Nash equilibrium of this game. In the next section, we go beyond this comparison to allow for the unrestricted choice of monetary policy rules.

– Insert Figure .4 –

7.2. *Optimal Non-cooperative Inflation Target under Trade War*

The result of the the previous section described the differential tariffs and welfare outcomes for each country when countries follow different inflation targeting strategies, but they do not directly inform us of the optimal choice of inflation target in a situation of non-cooperative strategic interaction. We now focus on this question. We ask how a country would choose an inflation target of the type described in equation (25) in a non-cooperative setting.

In Section 6, we considered symmetric rules and inflation targets. The implicit assumption was that authorities were cooperating in choosing their optimal inflation target. However, cooperation may be difficult to implement in practice. Hence, we would like to characterize Nash equilibria. In this policy game, both central banks commit to Taylor-type rules and choose their optimal inflation target (determined by d_r or d_r^*) given the optimal inflation target chosen by the other central bank. Note that the monetary policy set-up will be internalized by tariff setters, and that central bankers take this into account. We thus compute the reaction functions of the Home and Foreign central banks in this set-up and report them for different degrees of price stickiness in Figure .5 below.

– Insert Figure .5 –

First, Figure .5 shows that the intuition derived from the last subsection continues to apply. Imagine the Foreign central bank targets PPI ($d_r^* = 0$). In this case we have already seen that, if the Home central bank targets the CPI, both countries are better off. So from the perspective of the Home country it is always optimal to adopt a target that stabilizes tariff-adjusted terms of trade, even if the Foreign households gain more from it. Figure .5 illustrates this and shows that the optimal weight d^r is large when the Foreign central bank adopts a low d_r^*. When the Foreign central bank increases its weight placed on $\mathcal{P}^*$ enough, the Home central bank does not need to target anything else than the PPI, and thus adopts $d_r = 0$. Hence, the Nash equilibrium stems from both countries adopting an inflation target featuring a moderate – but in any case larger-than-one – weight on tariff-adjusted terms of trade.

Second, Figure .5 shows that the optimal Nash weights are decreasing in price stickiness ϕ, which aligns perfectly with the results about the welfare-maximizing weight. When prices are more flexible, a larger weight should be placed on relative prices to stabilize changes in the tariff-adjusted relative price of traded goods.

Third, Figure .5 shows that the optimal Nash weights are always below the welfare-maximizing weights discussed in Section 6. Hence, we expect Nash equilibria to produce lower levels of welfare than cooperative equilibria. To confirm that, Table .1 reports the optimized inflation targets (characterized by d_r and d_r^*) and the steady-state allocations resulting from the Nash equilibrium for different degrees of price stickiness, and compares them to all the equilibria discussed so far, including the welfare-maximizing rules discussed in Section 6.

– Insert Table .1 –

The first column of Table .1 reports the first-best equilibrium in which the monopoly distortion is offset by a subsidy and tariffs are zero. The second column considers the free-trade equilibrium with monopoly distortions, and shows that these generate lower output, consumption and a 2.66 percent welfare loss. Columns 3-5 report the results already seen in the previous sections: a fixed exchange rate and CPI inflation targeting produce milder trade wars in comparison to PPI inflation targeting, and alleviate the corresponding welfare losses. CPI inflation targeting results in tariffs that are more than half those arising under PPI inflation targeting and cut welfare losses by 1.5-2 percentage points.

Column 6 and 7 of Table .1 compare equilibria resulting from Nash-optimal weights to equilibria resulting from the cooperative choice of (welfare-maximizing) weights. We see that Nash-optimal weights stabilize tariff-adjusted terms of trade enough to bring non-cooperative tariffs below zero. They do not completely eliminate the terms of trade externality as in the case of welfare-maximizing cooperative weights, but do so sufficiently for the tariff setters to focus more on correcting the monopoly distortions and less on improving their terms of trade. As a result, the allocations are quite close to the cooperative equilibrium, and generate small welfare losses from non-cooperation. It is noteworthy that Nash equilibria in this design-delegation game produce slightly negative tariffs and improve allocations compared to the free-trade equilibrium with monopoly distortions. Finally, the distance between Nash and cooperative equilibria and the welfare losses from non-cooperation shrink as prices become stickier. Intuitively, stickier prices make monetary policy a more powerful stabilization tool to eliminate the terms-of-trade incentive in tariff choice.

From these results we conclude that, even without international cooperation, when the design and delegation of monetary rules is chosen independently by policy-makers, they may act to fully eliminate trade wars, and in fact welfare dominate a free trade equilibrium.

8. A Quantitative Exploration of the US-China Trade War

We now propose a quantitative exploration of the US-China trade war based on our model. First, we estimate our model on US and Chinese data from 1997 to 2019 (pre-Covid) to evaluate key parameters affecting price stickiness and monetary policies in both countries. Second, we use the model parameters and compare the equilibrium with low tariffs – as observed before 2018 – to the trade-war equilibrium to quantify the effects of the US-China trade war. Finally, we look at counterfactual monetary policy arrangements and track the resulting changes in tariffs and in the welfare losses from the trade war.

Model set-up and assumptions. We estimate a version of our model where the Home country is the US and the Foreign country China. In the baseline extended model above, international bonds are denominated in the Foreign currency. As shown in Auray et al. [2], the denomination of bonds may have important implications for tariffs in trade wars. We thus modify the extended model as explained in detail in Appendix D, so that bonds are denominated in dollars for the US-China trade war experiment. Another key aspect of the estimated model is the modelling of monetary policies followed by the US and China. For the US, we consider that the central bank follows a flexible interest rate rule:

$$R_t = \beta^{-1} \left(\pi_{ht} \left(\mathcal{P}_t / \mathcal{P}_{t-1} \right)^{d_r} \right)^{\mu_\pi} \tag{26}$$

where the CPI weight d_r and the sensitivity to inflation μ_π will be estimated. The question of monetary policy is more tricky for China, since monetary policy has been shown (see Chang et al. [13]) to be characterized by a mix of interest rate policy – to address domestic inflation developments – and reserve policies – to manage an intermediate exchange rate regime. Further, both policy instruments interact with capital controls. We thus assume that the monetary policy implemented by the Chinese central bank is a weighted average of a fixed exchange rate regime and a flexible interest rate rule:

$$\varpi \left[\pi^*_{ft} \mathcal{S}_{t-1} / \mathcal{S}_t - \pi_{ht} \right] + (1 - \varpi) \left[R^*_t - \beta^{-1} \left(\pi^*_{ft} \left(\mathcal{P}^*_t / \mathcal{P}^*_{t-1} \right)^{d^*_r} \right)^{\mu^*_\pi} \right] = 0 \tag{27}$$

where the weight placed on the fixed exchange rate regime ϖ will be estimated along with the nominal interest rule parameters d^*_r and μ^*_π.

Estimation method and data. We estimate our model on US and Chinese data using Bayesian methods, adopting the standard approach of An and Schorfheide [1]. This implies obtaining the posterior distribution of our estimated parameters based on the linear approximation of the model's solution around the steady state using the Kalman filter. We exploit quarterly data for both the US and China between 1997Q3 and 2019Q4. Our observed variables are the following: quarterly real output growth ($\log(Y_t/Y_{t-1})$ and $\log(Y_t^*/Y_{t-1}^*)$ in our model), quarter-on-quarter growth rate of the GDP deflator (π_{ht} and π_{ft}^*), the nominal interest rate (R_t and R_t^*) and the quarterly growth rate of a model-consistent measure of the terms of trade ($\log(\mathcal{S}_t/\mathcal{S}_{t-1})$). Output and GDP deflator data for the US are taken from the FRED database.[17] For the US nominal interest rate, we use the shadow rate estimate of Wu and Xia [42] to circumvent the long period of zero lower bound.[18] The annualized US nominal rate is converted to quarterly levels. Output and GDP deflator data for China are taken from the database of Chang et al. [12].[19] and treat Chinese data similarly to US data. For the Chinese nominal interest rate, we use the 90-days interbank interest rate provided by the FRED database and convert the annualized rate to quarterly levels.[20] Finally, we obtain a model-consistent measure of terms of trade by multiplying the nominal exchange rate (expressed in dollars per Renminbi) by the Chinese GDP deflator and dividing by the US GDP deflator. We normalize this measure by its value in 1997Q2, and consider its quarterly growth rate. Output growth rates are one-sided HP-filtered with a large smoothing parameter (10 000) to remove low-frequency changes observed both in US and China over the sample and other time series are simply demeaned. As a result, all our time series are stationary and reported

[17] GDP: (GDPC1) Real Gross Domestic Product, Billions of Chained 2017 Dollars, Quarterly, Seasonally Adjusted Annual Rate. GDP deflator: (GDPDEFPCH) Gross Domestic Product: Implicit Price Deflator, Percent Change, Quarterly, Seasonally Adjusted.

[18] The shadow rate series can be found at: https://sites.google.com/view/jingcynthiawu/shadow-rates

[19] The Chinese dataset can be found at: https://www.atlantafed.org/cqer/research/china-macroeconomy.aspx. We use the latest update (July 2024).

[20] Chinese nominal interest rate: (IR3TIB01CNM156N) Interest Rates: 3-Month or 90-Day Rates and Yields: Interbank Rates: Total for China, Percent, Quarterly.

in Appendix E.

Shocks and calibrated parameters. With seven quarterly time series, identification requires at least seven shocks. We consider that both countries are hit by persistent productivity, discount factor and nominal interest rate shocks. We also add a shock to the UIP condition – sometimes also labeled a financial shock in the literature – since these shocks have recently been argued to play a key role in the dynamics of open-economy models (see Itskhoki and Mukhin [30]). Last, we introduce a shock on the weight of the fixed exchange rate regime ϖ, which we label an exchange rate regime shock. This shock is intended to capture shocks on international reserves.[21]

Some of our model parameters are set relying on data or previous literature, as in Section 4. Country size n is set to match the relative population of US vs. China. Based on World Bank population data, this implies $n = 0.186$. The estimated model is quarterly, so we set the discount factor to $\beta = 0.99$ in both countries. We assume $\sigma = 1$ (log-utility), the Frisch elasticity is $\psi^{-1} = 0.4$ following **?**], and we normalize $\chi = 1$. Further, the elasticity of substitution between varieties is $\epsilon = 6$, consistent with a 20% steady-state price-cost markup. As in the baseline calibration we follow Bergin and Corsetti [7] and consider the share of intermediate goods in production to be $\alpha = 0.4$, and the trade elasticity is $\lambda = 5$. Relative productivity levels in the steady state are set to match the observed ratio of GDP per capita between 1997 and 2019. According to World Bank data its average was $Y^*/Y = 0.16$ which implies $A^*/A = 1/3$.[22] Finally, we set home bias parameters to match the bilateral trade openness ratios for the US and China. On average between 1997 and 2019, the total trade openness was 26.4% for the US and 45.8% for China, which assuming that 15% of total trade is bilateral, gives $\gamma = \gamma_x = 1 - 0.264 \times 0.15/2 = 0.9802$ for the US and $\gamma^* = \gamma_x^* = 1 - 0.458 \times 0.15/2 = 0.9657$

[21] With eight shocks and seven time series our model is over-identified.

[22] Let Y^*/Y be the ratio of GDP per capita. Suppose countries supply the same amount of labor per capita. Then our model implies $A^*/A = (Y^*/Y)^{1-\alpha}$ where α is the (common) share of intermediate goods in production.

for China. Last, according to **?**], the average US tariff applied to Chinese exports before the trade war – as of January 2018 – was around $\tau = 3\%$ and the Chinese tariffs on US exports was $\tau^* = 8\%$ The set of calibrated parameters is reported in Table .2 below.

– Insert Table .2 and .3 –

Estimated parameters. The remaining parameters of the model are estimated and our prior distributions are as follows. The portfolio adjustment cost parameter is an Inverse Gamma with prior mean 0.01 and standard deviation 0.01. The Rotemberg parameters on prices ϕ and ϕ^* are Inverse Gammas with prior means 120 and standard deviations 10. The responses of central banks to inflation μ_π and μ_π^* are Inverse Gammas with prior means 1.25 and standard deviations 0.1. The CPI weights in inflation targets d_r and d_r^* are Inverse Gammas with prior means 1 and standard deviations 0.25. Last, the weight on fixed exchange rates in the Chinese monetary policy ϖ is a Beta with prior mean 0.5 and standard deviation 0.15. All persistence parameters are Betas with prior means 0.8 and standard deviations 0.15, and the standard deviations of innovations are Inverse Gammas with prior means 0.01 and infinite standard deviations. Table .3 summarizes the prior distributions of estimated parameters, along with the posterior means and 90% confidence intervals based on 500 000 replications of the MH algorithm where the first 20% were discarded and where the scale parameter was adjusted to obtain a 1/3 acceptance rate. Prior and posterior distributions are reported in Appendix E.

Table .3 shows that most parameters are well estimated.[23] The portfolio adjustment cost is a bit larger ($\nu = 0.0091$) than usually found in the literature – between 0.0007 and 0.006, see Schmitt-Grohe and Uribe [37] or Bouakez and Eyquem [9]) – which aligns well with the view that capital controls are an important feature of the Chinese economy and partly restrict the integration of Chinese financial markets.[24] Rotemberg parameters

[23] Appendix E reports the prior and posterior distributions for the estimated parameters.

[24] The face value of the adjustment cost parameter must be taken with caution since the posterior lands on the prior for this parameter.

are in the ballpark of their usual estimated value, and prices are slightly more sticky in in the US ($\phi = 101.67$) than in China ($\phi^* = 94.715$). Taylor rule parameters suggest a stronger response to inflation in the US ($\mu_\pi = 2.0414$) than in China ($\mu_\pi^* = 1.1635$). According to our estimates, the US monetary policy targets an inflation rate that is closer to CPI than PPI as $0 < d_r = 0.6673 < 1$ in the US, while China seems to target the CPI $d_r^* = 0.9762 \approx 1$, although for this parameter the posterior distribution almost lands on its prior, so that estimation is not very informative. Finally, our estimation is consistent with a Chinese monetary policy putting a relatively low weight on the pursuit of a fixed exchange rate regime ($\varpi = 0.3041$), and a larger weight on the flexible interest rate rule.[25] This result aligns well with Kamber and Mohanty [33], who show that the Chinese monetary policy has become increasingly similar to that in advanced economies. The persistence of shocks and the standard deviations of innovations align overall with existing empirical evidence and suggest much more volatility in China due to much more volatile productivity and monetary policy shocks.

Trade war experiment. Armed with our parameter estimates, we now display the tariff rates, consumption and labor levels and welfare losses resulting from a trade war starting in 2018, as in the data. More specifically, we consider that the economy is on a low-tariff path before 2018 and switches to a non-cooperative equilibrium from 2018 to 2020. We highlight the resulting rise in tariffs and compare it to the observed rise in tariffs. We also compare the estimated trade-war equilibrium to alternative equilibria that would have ensued had central banks targeted the PPI ($d_r = d_r^* = 0$), the CPI ($d_r = d_r^* = 1$) or an inflation target with a very large weight ($d_r = d_r^* = 50$ on tariff-adjusted terms of trade instead of their estimated inflation targets ($d_r = 0.6673$ and $d_r^* = 0.9762$). The results are reported in Table .4.

[25] Based on the standard deviation of exchange rate regime shocks, the time-varying weight on fixed exchange rate varies between 0.31.5 and 0.295 according to our estimates and exhibits a decreasing profile over time.

– Insert Table .4 –

First, comparing the first and second columns of Table .4 shows that the welfare losses from not correcting steady-state markups with a subsidy are similar to what they were in the calibrated model of the previous sections, around 2.65% of permanent consumption in both countries. Second, comparing the second and third columns of Table .4 shows that the situation before the trade war was favorable to China in comparison of a free-trade equilibrium. China was applying an 8% tariff while the US tariff was 3%, and improved its terms of trade, enjoying a 0.024% welfare *gain* while the US was experiencing a 0.106% welfare loss against the free-trade equilibrium.

Third, the trade-war equilibrium given by our model (fourth column of Table .4) predicts tariff levels ($\tau = 0.1506$ and $\tau^* = 0.1787$) that line up very well with the data (0.1930 on average for the US and 0.2110 for China). In particular, the model replicates the fact that the Chinese tariff exceeds the US tariff, which is driven (*i*) by the larger relative size of China compared to the US,[26] and (*ii*) by the fact that prices are relatively less sticky (implying higher tariffs) in China. The specific welfare losses from the trade war are relatively small – compared to the calibrated model discussed before, which is driven by the very low observed trade to GDP ratios. The US welfare loss is 0.087% of permanent consumption, close to existing quantifications (see Fajgelbaum et al. [22] as well as Fajgelbaum and Khandelwal [23] and references therein). The Chinese welfare loss is 0.25%, a bit larger than quantified by Caliendo and Parro [11] (0.09%). The numbers reported are thus consistent with the data on observed tariffs and with existing quantifications of the welfare losses from this specific trade war.

Last, comparing the fourth column of Table .4 to columns 5-7 informs about the effect of alternative monetary policy rules on the intensity of the trade war. In line with our previous results, PPI inflation targeting results in larger tariffs and larger welfare

[26] See Auray et al. [2] for discussion of how size affects the incentive to apply tariffs.

losses for both countries while CPI inflation targeting in lower tariffs and lower welfare losses for both countries. Quantitatively speaking, the effects on tariffs and welfare losses remain small due to low trade openness parameters. The case of a large weight placed on terms of trade (column 7) reduces tariffs by a much more significant amount (from 0.15 to 0.07 for the US, from 0.179 to 0.118 for China) and reduce the welfare losses from a trade war by 2/3 for both countries (from 0.086% to 0.0295% for the US, from 0.25% to 0.084% for China). Overall, the mechanisms highlighted in the previous sections are at work but their strength is dampened by the small observed trade to GDP ratios. According to our model, had the US and China been more opened to trade or had bilateral trade been more important quantitatively, the welfare losses from the trade war would have been much larger, just as the effect of monetary policies on its intensity.

9. Conclusions

This paper has explored the consequences of alternative monetary policy rules for non-cooperative trade policy. A principle objective of protectionist trade policy is to manipulate the terms of trade in a country's favour. In a second best environment however, an optimal tariff must take account of the distortionary effects of an increase in the tariff rate, and weigh this against the benefits of an improved terms of trade. By targeting alternative price indices, the monetary authority can alter the incentives of the tariff setter. This may lead to a higher weight placed on the distortionary costs of the tariff, and hence deliver lower equilibrium tariff rates. In a global setting, CPI targeting therefore may enhance all countries welfare by leading to lower tariffs and higher trade volumes. Extending the argument further, it is shown that a particularly chosen monetary rule can actually do better than free trade, because it leads to equilibrium tariffs targeted on the monopoly distortions themselves. An application to the U.S. China trade war of 2018 suggests that the model is quantitatively relevant.

A general message of the paper is that in the environment of multiple policymakers acting non-cooperatively, the interaction between decision makers may lead to non-standard implications for optimal policy. Hence, as noted by [16], any recommendation for monetary policy should be informed of the wider context in which different policy-makers operate.

References

[1] An, S., Schorfheide, F., 2007. Bayesian Analysis of DSGE Models. Econometric Reviews 26, 113–172.

[2] Auray, S., Devereux, M.B., Eyquem, A., 2024. Trade wars, nominal rigidities and monetary policy. Review of Economic Studies Accepted.

[3] Bagwell, K., Staiger, R.W., 2010. The world trade organization: Theory and practice. Annual Review of Economics 2, 223–256.

[4] Barattieri, A., Cacciatore, M., Ghironi, F., 2021. Protectionism and the Business Cycle. Journal of International Economics 129, 103417.

[5] Benigno, G., Benigno, P., 2003. Price Stability in Open Economies. The Review of Economic Studies 70, 743–764.

[6] Bergin, P.R., Corsetti, G., 2020. Beyond Competitive Devaluations: The Monetary Dimensions of Comparative Advantage. American Economic Journal: Macroeconomics 12, 246–286.

[7] Bergin, P.R., Corsetti, G., 2023. The Macroeconomic Stabilization of Tariff Shocks: What is the Optimal Monetary Response? Journal of International Economics , 103758.

[8] Bhattarai, S., Egorov, K., 2016. Optimal Monetary and Fiscal Policy at the Zero Lower Bound in a Small Open Economy. Globalization and Monetary Policy Institute Working Paper 260.

[9] Bouakez, H., Eyquem, A., 2015. Government Spending, Monetary Policy, and the Real Exchange Rate. Journal of International Money and Finance 56, 178–201.

[10] Broda, C., Limao, N., Weinstein, D.E., 2008. Optimal Tariffs and Market Power: The Evidence. American Economic Review 98, 2032–2065.

[11] Caliendo, L., Parro, F., 2021. Trade Policy. NBER Working Paper 29051.

[12] Chang, C., Chen, K., Waggoner, D.F., Zha, T., 2016. Trends and Cycles in China's Macroeconomy. NBER Macroeconomics Annual 30, 1–84.

[13] Chang, C., Liu, Z., Spiegel, M.M., 2015. Capital Controls and Optimal Chinese Monetary Policy. Journal of Monetary Economics 74, 1–15.

[14] Clarida, R., Gali, J., Gertler, M., 2002. A Simple Framework for International Monetary Policy Analysis. Journal of Monetary Economics 49, 879–904.

[15] Corsetti, G., Pesenti, P., 2001. Welfare and macroeconomic interdependence. The Quarterly Journal of Economics 116, 421–445.

[16] Davig, T., Gürkaynak, R., 2015. Is Optimal Monetary Policy Always Optimal? International Journal of Central Banking 11, 353–382.

[17] de Paoli, B., 2009. Monetary Policy and Welfare in a Small Open Economy. Journal of International Economics 77, 11–22.

[18] Egorov, K., Mukhin, D., 2023. Optimal Monetary Policy under Dollar Pricing. American Economic Review Forthcoming.

[19] Engel, C., 2011. Currency Alignments and Optimal Monetary Policy. American Economic Review 101, 2796–2822.

[20] Fadinger, H., Herkenhoff, P., Schymik, J., 2024. Quantifying the germany shock: Structural labor-market reforms and spillovers in a currency union. Journal of International Economics 150, 103905.

[21] Faia, E., Monacelli, T., 2008. Optimal monetary policy in a small open economy with home bias. Journal of Money, Credit and Banking 40, 721–750.

[22] Fajgelbaum, P.D., Goldberg, P.K., Kennedy, P.J., Khandelwal, A.K., 2019. The Return to Protectionism. The Quarterly Journal of Economics 135, 1–55.

[23] Fajgelbaum, P.D., Khandelwal, A.K., 2022. The economic impacts of the us–china trade war. Annual Review of Economics 14, 205–228.

[24] Ferrero, A., 2020. Fiscal and monetary policy in open economy, Oxford University Press.

[25] Fujiwara, I., Wang, J., 2017. Optimal Monetary Policy in Open Economies Revisited. Journal of International Economics 108, 300–314.

[26] Galì, J., Monacelli, T., 2005. Monetary Policy and Exchange Rate Volatility in a Small Open Economy. The Review of Economic Studies 72, 707–734.

[27] Groll, D., Monacelli, T., 2020. The Inherent Benefit of Monetary Unions. Journal of Monetary Economics 111, 63–79.

[28] Gurkova, E., Helpman, E., Itskhoki, O., 2024. Trade Liberalization, Wage Rigidity, and Labor Market Dynamics with Heterogeneous Firms Manuscript.

[29] Huang, K.X., Liu, Z., 2005. Inflation targeting: What inflation rate to target? Journal of Monetary Economics 52, 1435–1462.

[30] Itskhoki, O., Mukhin, D., 2021. Exchange Rate Disconnect in General Equilibrium. Journal of Political Economy 129, 2183–2232.

[31] Jeanne, O., 2021. Currency Wars, Trade Wars, and Global Demand. NBER Working Paper 29603.

[32] Johnson, H.G., 1953. Optimum tariffs and retaliation. Review of Economic Studies 21, 142–153.

[33] Kamber, G., Mohanty, M., 2018. Do Interest Rates Play a Major Role in Monetary Policy Transmission in China? BIS Working Paper 714.

[34] Monacelli, T., 2005. Monetary policy in a low pass-through environment. Journal of Money, Credit and Banking 37, 1047–1066.

[35] Rodríguez-Clare, A., Ulate, M., Vásquez, J.P., 2020. Trade with Nominal Rigidities: Understanding the Unemployment and Welfare Effects of the China Shock. NBER Working Paper 27905. National Bureau of Economic Research.

[36] Rogoff, K., 1985. The Optimal Degree of Commitment to an Intermediate Monetary Target. Quarterly Journal of Economics 100, 1169–1189.

[37] Schmitt-Grohe, S., Uribe, M., 2003. Closing Small Open Economy Models. Journal of International Economics 61, 163–185.

[38] Staiger, R.W., Tabellini, G., 1989. Rules and Discretion in Trade Policy. European Economic Review 33, 1265–1277.

[39] Svensson, L.E., 1997. Optimal Inflation Targets, 'Conservative' Central Banks, and Linear Inflation Contracts. American Economic Review 87, 98–114.

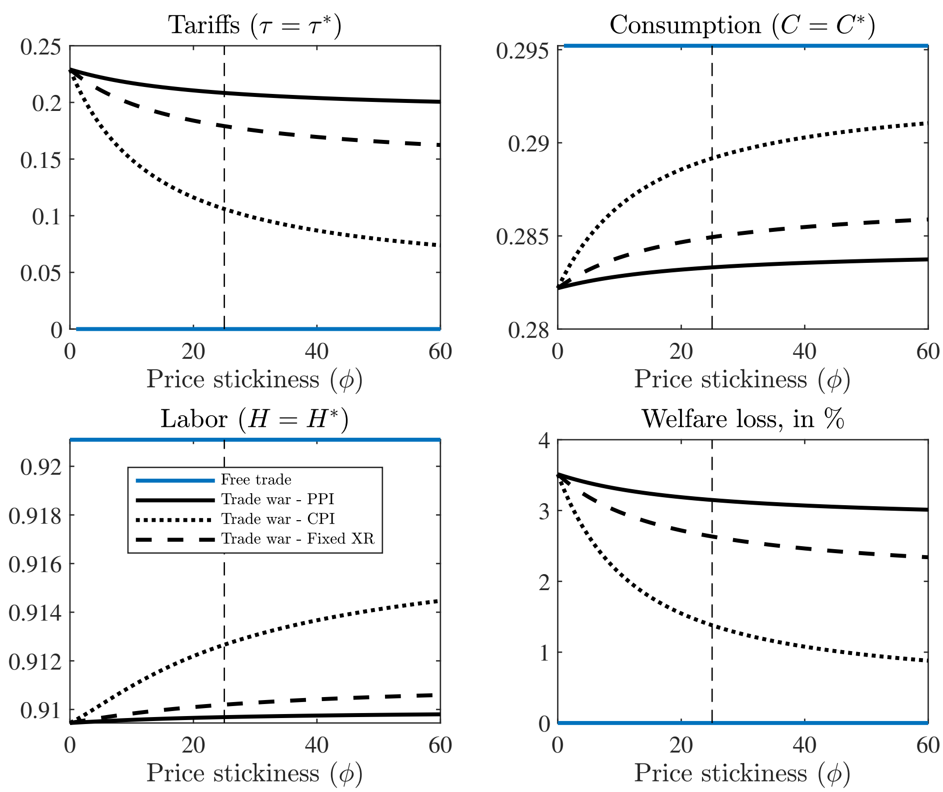
[40] Walsh, C.E., 1995. Optimal Contracts for Central Bankers. American Economic Review 85, 150–167.

[41] Wei, S.J., Xie, Y., 2020. Monetary policy in an era of global supply chains. Journal of International Economics 124, 103299. NBER International Seminar on Macroeconomics 2019.

[42] Wu, J.C., Xia, F.D., 2016. Measuring the Macroeconomic Impact of Monetary Policy at the Zero Lower Bound. Journal of Money, Credit and Banking 48, 253–291.

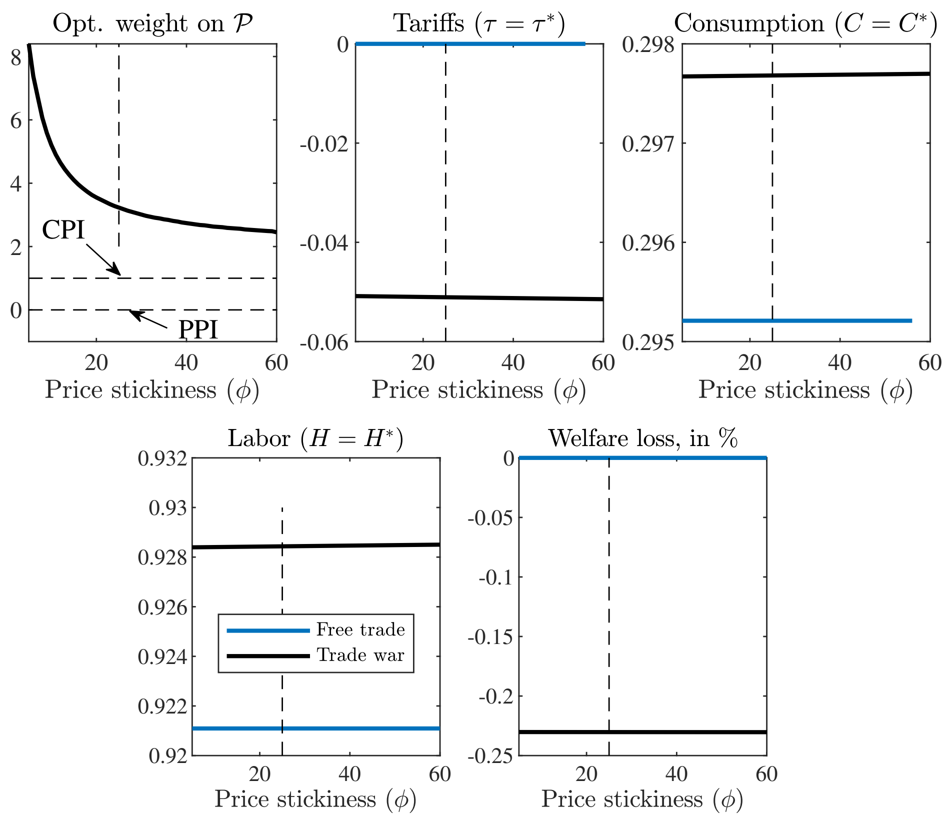
Figures and Tables

Figure .1: Trade Wars under Alternative Monetary Policies.



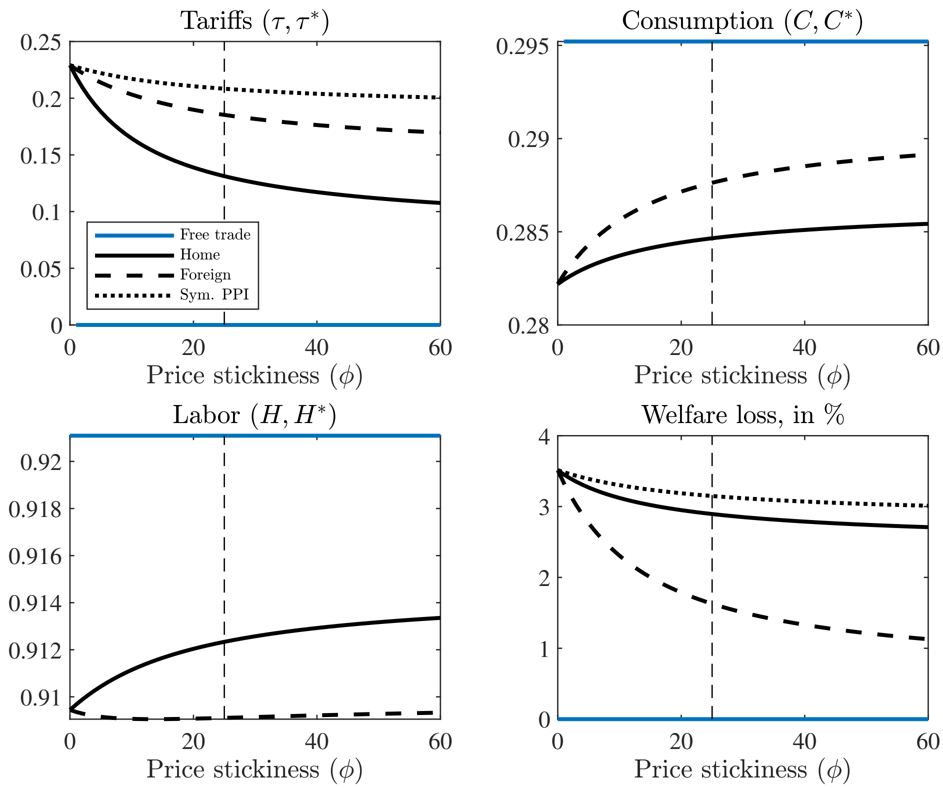
Note: Welfare losses denote the Hicksian consumption equivalent loss compared to the free trade equilibrium. The vertical line indicates the baseline value of $\phi = 25$.

Figure .2: Non-cooperative trade policies under welfare-maximizing inflation targeting rules.



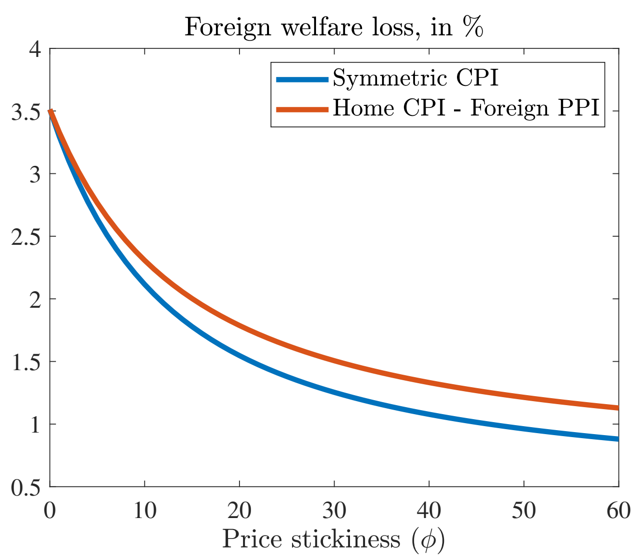
Note: Welfare losses denote the Hicksian consumption equivalent loss compared to the free trade equilibrium. Negative losses indicate welfare *gains*. The vertical line indicates the baseline value of $\phi = 25$. Horizontal lines in the top left panel represent the values of d_r implying CPI ($d_r = 1$) and PPI ($d_r = 0$) inflation targeting.

Figure .3: Trade wars with asymmetric inflation targeting.



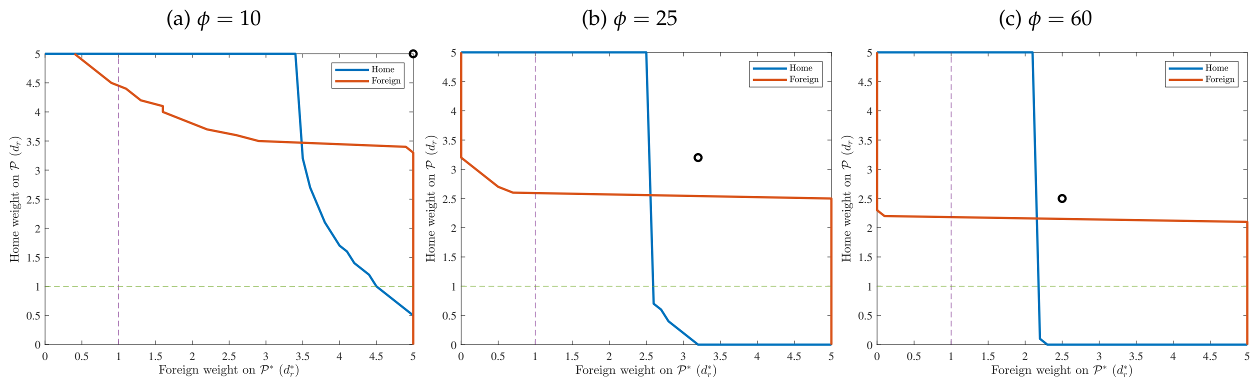
Note: Home targets the CPI inflation rate and Foreign the PPI inflation rate. Welfare losses denote the Hicksian consumption equivalent loss compared to the free trade equilibrium. The vertical line indicates the baseline value of $\phi = 25$.

Figure .4: Foreign welfare loss - Asymmetric targeting vs. symmetric CPI targeting.



Note: In the asymmetric case, Home targets the CPI inflation rate and Foreign the PPI inflation rate. In the symmetric CPI case both countries target the CPI inflation rate. Welfare losses denote the Hicksian consumption equivalent loss compared to the free trade equilibrium.

Figure .5: Central Banks Reaction Functions.



Note: For a given d_r^* (d_r), reaction functions report the welfare-maximizing d_r (d_r^*) chosen by the Home (Foreign) central bank. The black dots represent the 'cooperative' welfare-maximizing inflation target (weight $d_r = d_r^*$) discussed in Section 6.

Table .1: Monetary Policy Design under Trade Wars.

	FB	FT	PPI	FXR	CPI	Coop.	Nash
				$\phi = 10$			
$d_r = d_r^*$	–	–	0.000	–	1.000	5.000	3.483
$\tau = \tau^*$	0.000	0.000	0.217	0.199	0.150	−0.046	0.018
$C = C^*$	0.326	0.295	0.283	0.284	0.287	0.297	0.294
$L = L^*$	1.000	0.921	0.910	0.910	0.911	0.928	0.919
Utility	−1.407	−1.434	−1.468	−1.465	−1.456	−1.432	−1.437
Welfare loss (%)	0.000	2.659	5.874	5.559	4.719	2.439	2.908
				$\phi = 25$			
$d_r = d_r^*$	–	–	0.000	–	1.000	3.200	2.556
$\tau = \tau^*$	0.000	0.000	0.208	0.179	0.106	−0.050	−0.015
$C = C^*$	0.326	0.295	0.283	0.285	0.289	0.298	0.296
$L = L^*$	1.000	0.921	0.910	0.910	0.913	0.928	0.923
Utility	−1.407	−1.434	−1.466	−1.461	−1.448	−1.432	−1.433
Welfare loss (%)	0.000	2.659	5.725	5.223	4.002	2.436	2.553
				$\phi = 60$			
$d_r = d_r^*$	–	–	0.000	–	1.000	2.500	2.156
$\tau = \tau^*$	0.000	0.000	0.201	0.162	0.074	−0.053	−0.030
$C = C^*$	0.326	0.295	0.284	0.286	0.291	0.298	0.297
$L = L^*$	1.000	0.921	0.910	0.911	0.914	0.929	0.925
Utility	−1.407	−1.434	−1.465	−1.458	−1.443	−1.432	−1.432
Welfare loss (%)	0.000	2.659	5.591	4.937	3.516	2.435	2.478

'FB' denotes the first-best equilibrium ($\theta = 1$ and $\tau = \tau^* = 0$), 'FT' the free-trade equilibrium without a subsidy ($\theta < 1$ and $\tau = \tau^* = 0$), 'PPI' the case of PPI targeting ($d_r = d_r^* = 0$), 'FXR' the case of a fixed exchange rate, 'CPI' the case of CPI targeting ($d_r = d_r^* = 1$), 'Coop.' the case of a welfare-maximizing inflation target discussed in Section 6, and 'Nash' the non-cooperative design of targeting rules. All welfare losses are computed against the first-best equilibrium.

Table .2: Calibrated parameters.

Relative size of the US	$n = 0.186$
Relative productivity	$A^*/A = 1/3$
Discount factor	$\beta = 0.99$
Relative risk-aversion	$\sigma = 1$
Labor disutility	$\chi = 1$
Labor supply elasticity	$\psi^{-1} = 0.4$
Share of int. goods in production	$\alpha = 0.4$
Trade elasticity	$\lambda = 5$
Home bias US	$\gamma = \gamma_x = 0.9802$
Home bias China	$\gamma^* = \gamma_x^* = 0.9657$
US tariff on Chinese exports	$\tau = 0.03$
Chinese tariff on US exports	$\tau^* = 0.08$

Table .3: Estimation results.

Structural parameters	Priors Distr.	Priors Mean	Priors Std	Posteriors Mean	Posteriors Inf.	Posteriors Sup.
Port. adj. cost (ν)	*IG*	0.01	0.01	0.0091	0.0031	0.0157
Rotemberg parameter US (ϕ)	*IG*	120.0	10.0	101.67	89.999	112.88
Rotemberg parameter China (ϕ^*)	*IG*	120.0	10.0	94.715	84.968	104.71
Taylor rule parameter US (μ_π)	*IG*	1.25	0.10	2.0414	1.7848	2.2911
Taylor rule parameter China (μ_π^*)	*IG*	1.25	0.10	1.1635	1.0307	1.2847
CPI weight US (d_r)	*IG*	1.00	0.25	0.6673	0.5150	0.8111
CPI weight China (d_r)	*IG*	1.00	0.25	0.9762	0.6328	1.3154
Weight on fixed ER China (ϖ)	*B*	0.50	0.15	0.3041	0.2344	0.3737
Shocks' persistence						
Productivity US (ρ_a)	*B*	0.80	0.15	0.9468	0.9098	0.9900
Productivity China (ρ_a^*)	*B*	0.80	0.15	0.8748	0.8209	0.9271
Discount factor US (ρ_b)	*B*	0.80	0.15	0.7886	0.7384	0.8350
Discount factor China (ρ_b^*)	*B*	0.80	0.15	0.9348	0.9120	0.9592
Monetary policy US (ρ_m)	*B*	0.80	0.15	0.8721	0.8452	0.9090
Monetary policy China (ρ_m^*)	*B*	0.80	0.15	0.1439	0.0597	0.2225
Financial shock (ρ_ξ)	*B*	0.80	0.15	0.5452	0.2659	0.9022
Exch. rate regime shock (ρ_x)	*B*	0.80	0.15	0.9900	0.9899	0.9900
Sd. of shocks						
Productivity US (σ_a)	*IG*	0.01	∞	0.0038	0.0031	0.0044
Productivity China (σ_a^*)	*IG*	0.01	∞	0.0218	0.0156	0.0280
Discount factor US (σ_b)	*IG*	0.01	∞	0.0035	0.0029	0.0042
Discount factor China (σ_b^*)	*IG*	0.01	∞	0.0022	0.0015	0.0028
Monetary policy US (σ_m)	*IG*	0.01	∞	0.0045	0.0037	0.0052
Monetary policy China (σ_m^*)	*IG*	0.01	∞	0.0096	0.0079	0.0112
Financial shock (σ_ξ)	*IG*	0.01	∞	0.0024	0.0017	0.0030
Exch. rate regime shock (σ_x)	*IG*	0.01	∞	0.0057	0.0031	0.0081
Marginal data density						
Modified Harmonic Mean					2142.8	

Notes: Results based on 500 000 replications of the MH algorithm where the scale parameter is adjusted to target a 1/3 acceptance rate. *B* and *IG* respectively denote Beta and Inverse Gamma distributions. *Inf* and *Sup* refer to 90% lower and upper values of the confidence intervals.

Table .4: Quantification of the US-China Trade War.

			Baseline trade war		Alternative trade war		
	FB	FT	Pre-2018	Post-2020	PPI	CPI	Large d_r
d_r	-	-	0.6673	0.6673	0	1	50
d_r^*	-	-	0.9762	0.9762	0	1	50
τ^{US} (model)	0	0	0.0300	0.1506	0.1517	0.1500	0.0706
τ^{US} (data)	-	-	*0.0300*	*0.1930*		*0.1930*	
τ^{China} (model)	0	0	0.0800	0.1787	0.1799	0.1786	0.1183
τ^{China} (data)	-	-	*0.0800*	*0.2110*		*0.2110*	
C^{US}	0.3260	0.2954	0.2951	0.2947	0.2947	0.2947	0.2949
C^{China}	0.0521	0.0472	0.0472	0.0470	0.0470	0.0470	0.0471
L^{US}	1.0000	0.9211	0.9209	0.9205	0.9205	0.9205	0.9207
L^{China}	1.0000	0.9211	0.9203	0.9200	0.9200	0.9200	0.9202
$\mathcal{S}$	0.9783	0.9783	1.0042	0.9911	0.9911	0.9913	1.0020
Welfare loss / FB US (%)	-	2.6594	2.7658	2.8525	2.8539	2.8524	2.7954
Welfare loss / FB China (%)	-	2.6593	2.6355	2.8857	2.8879	2.8845	2.7193
Welfare loss / Pre-2018 US (%)	-	-	-	0.0866	0.0880	0.0866	0.0295
Welfare loss / Pre-2018 US (%)	-	-	-	0.2501	0.2524	0.2489	0.0838

All parameters are equal to their estimated or calibrated value unless specified otherwise. 'FB' denotes the first-best equilibrium ($\theta = 1$ and $\tau = \tau^* = 0$), 'FT' the free-trade equilibrium without a subsidy ($\theta < 1$ and $\tau = \tau^* = 0$), 'Pre-2018' is the pre-war equilibrium with $\tau = 0.03$ and $\tau^* = 0.08$, 'Post-2020' is the trade-war equilibrium predicted by our model, 'PPI', 'CPI' and 'Large d_r' are the alternative trade war equilibria.