Exchange Rates, Local Currency Pricing and International Tax Policies

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Abstract

Empirical evidence suggests that for many countries, retail prices of traded goods are sticky in national currencies. Movements in exchange rates then cause deviations from the law of one price, and exchange rate misalignment, which cannot be corrected by monetary policy alone. This paper shows that a state contingent international tax policy can be combined with monetary policy to eliminate exchange rate misalignment and sustain a fully efficient welfare outcome. But this monetary-fiscal mix cannot be decentralized with non-cooperative determination of monetary and fiscal policy. Non-cooperative use of taxes and subsidies introduces strategic spillovers which opens up a fundamental conflict between the goals of output gap and inflation stabilization and those of terms of trade manipulation in an open economy. The implementation of an efficient monetary-fiscal mix requires effective cooperation in fiscal policy, while leaving monetary policy to be determined non-cooperatively. In addition, while an efficient outcome requires state contingent taxes and subsidies to eliminate exchange rate misalignment, it is still necessary to have flexible exchange rates and independent monetary policy.

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Keywords: local currency pricing, international tax, exchange rate; policy coordination;

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1 Introduction

This paper is a theoretical exploration of the optimal combination of monetary and fiscal policy in a global economy with sticky prices, local currency pricing, and exchange rate misalignment. In this environment, monetary policy alone cannot achieve a fully efficient allocation. A combination of monetary and fiscal policy might do better. But in a world of independent policy-makers, the introduction of additional fiscal tools into the policy process can generate new strategic inefficiencies.

The benefit of flexible exchange rates represents a central pillar of open economy macroeconomics. Famously, Friedman (1953) argued for the ease of adjusting relative prices with nominal exchange rates as opposed to nominal prices in an environment of sticky prices. The extension of the Friedman case for flexible exchanges rate is that it allows for national monetary independence. With flexible exchange rates, individual countries can follow independent, or 'self-oriented' monetary policies (using the language of Obstfeld and Rogoff, 2002), without requiring international policy coordination.

The more recent New Keynesian open economy literature has articulated Friedman's insights in fully specified welfare-based DSGE models. In particular Clarida, Gali and Gertler (2002) and Obstfeld and Rogoff (2002) show that an optimal monetary policy requires flexible exchange rates, and in certain environments, self-oriented monetary policy-making can achieve a global optimum, without the need for (or any benefit from) international policy coordination.[1] Both these papers however follow the traditional assumption about traded goods pricing, notably that prices are set in producer's currency (PCP).

Recent contributions have qualified these arguments, based on the evidence that nominal exchange rate adjustment may fail to achieve efficient relative price adjustment. For instance, when traded goods prices are set in the currency of the buyer

[1]Many other papers have analyzed non-cooperative monetary policy in open economies. See for instance Corsetti and Pesenti, 2001, and Corsetti, Dedola and Leduc, 2010. We discuss the literature more fully below.

(local currency pricing, or LCP), movements in nominal exchange rates will generate deviations from the law of one price across countries. In this case, independent monetary policy and flexible exchange rates cannot fully undo the inefficiencies generated by nominal price stickiness. Engel (2011) constructs a New Keynesian open economy model with LCP, and shows that optimal monetary policy faces a trade-off between the output gap, inflation control, and exchange rate 'misalignment' due to deviations from the law of one price. Then even cooperative monetary policy-making cannot achieve a full global optimum.

Fujiwara and Wang (2017) extend Engel's model to the case of non-cooperative policy making. They identify a new set of strategic inefficiencies associated with non-cooperative policy-making in an environment of LCP, and show that in general there are positive gains to policy-coordination under LCP, even in the case where no such gains would exist with PCP.

A separate and more recent literature has widened the debate on the limits to monetary policy by exploring the possibility of using targeted fiscal instruments to achieve effective relative price adjustment even when nominal prices cannot move. One strand of this literature is motivated by the constraints of a single currency area, where by definition nominal exchange rates cannot respond to country specific shocks. For instance, Fahri, Gopinath and Itskhoki (2013) show that a set of taxes and subsidies can replicate an exchange rate devaluation under a fixed exchange rate regime. Other papers are motivated by the limits to monetary policy imposed by the zero lower bound (see for instance, Correa, Fahri, Nicolini, and Teles 2013). But local currency pricing also imposes limits on the ability of monetary policy to achieve fully efficient outcomes. Somewhat less attention has been paid to this case.[2]

[2]A notable exception is Adao Correa and Teles 2009, who derive a set of tax policies that can achieve an efficient global outcome independent of the type of nominal price stickiness. The key difference between their paper and ours, aside from using different instruments and a different assumption about financial markets (see below) is that we look at the implementability of these policies in a non-cooperative setting. We discuss their paper in more detail below.

Can these constraints be undone by targeted sets of taxes and subsidies?

This paper first outlines a set of import taxes and export subsidies that can eliminate the distortions imposed by deviations from the law of one price. Do these fiscal instruments then restore the efficacy of monetary policy and the benefits of flexible exchange rates, or alternatively, would they eliminate the need for exchange rate adjustment at all?

But the main question we address is whether the use of fiscal instruments restores the case for self-oriented policymaking (monetary independence). As noted above, Fujiwara and Wang (2017) show that there are losses from non-cooperative policy making under LCP. If policy makers have access to taxes and subsidies that can eliminate deviations from the law of one price (or exchange rate misalignment), does this imply that independent non-cooperative policy making can sustain full efficiency? Alternatively, one might conjecture that the addition of independent fiscal policy instruments into policy-making introduces a new set of strategic inefficiencies in independent policymaking.

We construct a two country open economy model under LCP along the lines of Engel (2011) and Fujiwara and Wang (2017). Each country is subject to random shocks to labour productivity. Generically, this environment is characterized by exchange rate misalignment, causing welfare losses due to deviations from the law of one price. We then identify a set of taxes and subsidies that can eliminate inefficiencies coming from these deviations from the law of one price. In particular, in response to a home country (positive) productivity shock, an optimal policy entails a positive home country tax on imports and a foreign country subsidy to exports, combined with the opposite response of the foreign import tax and the home export subsidy. This set of tax-subsidy responses can perfectly replicate the relative price movement that would take place under PCP, eliminating deviations from the law of one price. Intuitively, this tax-subsidy combination will lead consumers and producers to tilt their behaviour as if all prices were set in producer's currency and there existed full exchange rate pass-through in traded goods prices. The import

tax is set so that, given prices set by producers, consumers face the same price for a good across countries, while the export subsidy is set so that producer's price setting is not distorted by the import tax itself.

An interesting feature of this optimal policy mix is that it does not obviate the need for exchange rate adjustment. Conditional on the optimal taxes and subsidies, an optimal monetary rule requires that the exchange rate adjusts to productivity shocks exactly as would occur under PCP. Thus, the use of optimal taxes and subsides restores Friedman's 'case for flexible exchange rates'.

But the key question is whether this efficient policy mix is consistent with non-cooperative policy-making? In the absence of coordination, both taxes, subsidies, and monetary policy have to be chosen by individual authorities. Here, our results are quite striking. We show the choice of import taxes and export subsidies opens up a new strategic channel in non-cooperative policy making associated with terms of trade manipulation. Acting independently, each policymaker attempts to bias the tax-subsidy instruments so as to raise its expected terms of trade. We show that when the tax-subsidy choice is unrestricted, there is no equilibrium to the non-cooperative game consistent with finite inflation rates and output gaps.[3]

We address this dilemma in two ways. First, we show that if we impose a particular restriction on the set of import taxes and export subsidies, then the equilibrium of the non-cooperative game will coincide with the cooperative equilibrium, and will attain the flexible price equilibrium. In particular this condition requires that the home import tax be restricted to equal the foreign export subsidy.

But this restriction may seem somewhat arbitrary, and it is unclear how it would be imposed in a non-cooperative equilibrium. To resolve this, we conclude that an

[3]We note that the channel of terms of trade manipulation in optimal monetary policy has been explored extensively in the New Keynesian literature. See for instance Corsetti and Pesenti, 2001, and Clarida Gali and Gertler 2002 for early discussion. But our results are quite different from the conventional analysis. We show that this strategic inefficiency is generated solely by the use of state varying fiscal instruments in monetary policy. Without the use of fiscal instruments, the equilibrium under non-cooperative monetary policy is well defined, as in Fujiwara and Wang 2017.

efficient monetary-fiscal mix will require fiscal policy coordination. We define a new game in which taxes and subsidies are chosen by a cooperative fiscal authority maximizing world welfare, while monetary policy is determined independently by each monetary authority. We show that the equilibrium of this game will be the same as the cooperative equilibrium in which both fiscal and monetary policy are chosen by a single benevolent authority.

The implication of these results is then clear - an optimally chosen set of fiscal responses can eliminate the restrictions on monetary policy implied by LCP, and restore the benefits of flexible exchange rates. But in order for this to be consistent with independent 'self-reliance' in monetary policy, it is necessary to have effective coordination in fiscal policy. Alternatively, the message could be interpreted as saying that absent fiscal coordination, or effective restrictions on fiscal responses, the use of taxes and subsidies to correct deviations from the law of one price and support independent policy-making cannot be successful.

An interesting feature of our results is that the use of optimal tax-subsidies changes the nature of optimal monetary policy under LCP. Engel (2011) shows that with LCP, the monetary authority should target consumer price inflation instead of producer-price inflation, as this sustains more efficient risk-sharing, even when LCP prevents a fully efficient allocation. We show that, so long as fiscal instruments are set optimally so as to achieve efficient risk sharing and eliminating deviations from the law of one price, the monetary authority should once again target producer price inflation rather than CPI inflation, even in the presence of LCP.

The tax-subsidy mix that we highlight is not the only set of fiscal instruments that can achieve an efficient global outcome. In a later section of the paper, inspired by the paper of Adao et al. (2009), we show that an alternative set of tax instruments, namely goods-specific consumption taxes and a tax on labor income, can be used to sustain an efficient global allocation, eliminating deviations from the law of one price and at the same time achieving efficient risk-sharing.[4] But again,

[4]One important difference is that this set of policy tools requires a fixed nominal exchange rate,

we find that this allocation cannot be sustained by non-cooperative policy-making, for identical reasons as in our main model.

A final section of the paper presents a quantitative analysis of welfare gains. The welfare gains from correcting currency misalignments under a cooperative monetary policy are very small. But the welfare gains from an optimal monetary fiscal-mix, compared to a non-cooperative monetary policy equilibrium under LCP, while still small in absolute terms, are substantially larger.[5]

This paper is organized as follows. Section 2 discusses the related literature. Section 3 presents the benchmark dynamic model with staggered price setting under LCP, and establishes that a combination of import tariffs (or equivalently, consumption taxes on foreign goods) and a monetary policy that stabilizes producer prices can sustain a fully efficient outcome. Section 4 take a special case of the model in which all results can be derived analytically. Using this special case, we show that the set of optimal import taxes and export subsidies which sustain full efficiency cannot be achieved in a non-cooperative equilibrium. There are no finite tax-subsidy combinations that solve the non-cooperative game. Section 5 derives the results in the general dynamic model using second order approximations to country welfare functions. Then the main results on cooperative and non-cooperative policy-making in the dynamic model are derived. Section 6 discusses the results under an alternative set of taxes. Section 7 provides some welfare results. Finally section 8 presents some conclusions.

2 Related Literature

Our paper is related to the literature on optimal fiscal policy in open economies. Gali and Monacelli (2008) study how the government chooses the optimal level of

as explained in section (6)

[5]This is in accord with the results of Fujiwara and Wang (2017), who quantify the welfare gains from monetary policy cooperation under LCP.

public consumption in a monetary union with lump-sum taxes. They find that the choice of fiscal policy raises union welfare. Hevia and Nicolini (2013) consider a small open economy with flexible exchange rates and state-contingent assets. They find that flexible price equilibrium is implementable, but exchange rates must move across states. Benigno and Paoli (2010) also analyze optimal fiscal policy and in small open economy, but in their set-up, the optimal flexible price allocation cannot be achieved.

Our paper is complementary to Adao, Correia, and Teles (2009). They show that in an environment with nominal rigidities, whatever is the type of price setting (PCP or LCP), the exchange rate regime, whether flexible or fixed exchange rates, is irrelevant once fiscal policy instruments (both taxes on labor income and consumption of home and foreign goods) are taken into account. Hence fiscal policy instruments can replicate the flexible price equilibrium even under LCP. They derive these results using a Ramsey approach, which requires a benevolent social planner who can use the available policy instruments to replicate the flexible price allocation. This approach abstracts from the question of how to implement the optimal fiscal policy in a non-cooperative setting, which is the main focus of our paper. We show that in an environment where monetary policy is chosen by individual countries we can achieve a fully efficient flexible price equilibrium, so long as taxes and subsidies are chosen cooperatively.

Another important difference between our paper and theirs is related to the role of exchange rate flexibility. They find that the flexible price allocation can be achieved by fiscal and monetary policies that induce stable producer prices and without relying on exchange rate movements. In fact the exchange rate regime becomes irrelevant. But in our benchmark model, it is critical to allow for flexible exchange rates, in order to achieve complete risk sharing. The optimal response of import taxes in each country ensures that relative prices facing households respond in the right way to productivity shocks. For instance, after a home country productivity shock the home import tax should rise, while the foreign import tax should fall.

But on their own, this would imply an appreciation of the home real exchange rate. To counter this, monetary policy must facilitate a nominal depreciation in order to ensure efficient risk-sharing. Hence, the tax policies identified in our paper not only replicate the real variables under a flexible price allocation, but also replicate the efficient risk-sharing response of the exchange rate fluctuations under flexible prices.[6]

Our paper also belongs to a small but fast growing literature that emphasizes the role of fiscal policy in replacing monetary policy or exchange rate policy as a macro stabilization tool. Schmitt-Grohe and Uribe (2011) show that, when there are downward wage rigidity and inelastic labor supply, a payroll subsidy alone can replicate the effect of nominal exchange rate devaluation. Farhi, Gopinath and Itskhoki (2013) show that, when the exchange rate cannot be devalued, a small set of conventional fiscal instruments can robustly replicate the real allocation attained under a nominal exchange rate devaluation in a dynamic New Keynesian open economy environment. In both these papers, the assumption is that nominal exchange rate is fixed, perhaps due to membership of a single currency area. In contrast, the exchange rate regime is flexible in our model, but exchange rate changes are inefficient due to LCP.

As mentioned in the introduction, the addition of fiscal instruments to substitute or complement monetary policy may also introduce strategic spillover channels when we extend the analysis to study non-cooperative policy-making. A key result of our

[6]Adao, Correia, and Teles 2009 also differ from us in the nature of financial markets. They allow for two state-contingent domestic bonds, but in their model there are no state-contingent international bonds. So there is not risk-sharing across countries in their baseline model. When state-contingent bonds can be traded across countries, they show that an extra fiscal instrument, a state-contingent government bond, is needed to produce the irrelevance result. Our framework by contrast is based on the assumption of complete markets for cross-country risk-sharing. Section 6 below allows for a labor income tax and consumption tax in our model, and shows that while a cooperative equilibrium can sustain full efficiency, albeit with a *fixed exchange rate*, the non-cooperative game has the same features as in our benchmark model.

paper is that absent some additional constraints on the design of corrective taxes or subsidies, in an environment where policy-makers act independently, these strategic inefficiencies may render fiscal policy ineffective in correcting macro inefficiencies.

Finally, topic wise, this paper is also closely related to the literature on optimal monetary policy in open economy under LCP. This question is treated in Devereux and Engel (2003). As discussed above, Engel (2011) shows that even with policy coordination, optimal monetary policy cannot replicate the flexible price equilibrium, due to the currency misalignment induced by LCP. Fujiwara and Wang (2017) focus on a non-cooperative game under LCP in a two-country dynamic general equilibrium model. They find that in this case, policy makers face extra trade-offs regarding stabilizing real marginal cost induced by the deviations from law of one price. Both papers therefore emphasize the importance of currency misalignment in the optimal monetary policy. Our paper identifies the a monetary-fiscal mix that can correct this misalignment, but also the restrictions on independent policy-making required to implement such a policy. The main difference between our paper and Engel (2011) or Fujiwara and Wang (2017) is that we introduce two fiscal instruments so as to eliminate the distortions caused by LCP, an import tax on imported goods and an export subsidy on export goods.

3 Model

We first set out the baseline model, and show the general result that an optimal monetary policy combined with a tax-subsidy scheme can support the fully efficient flexible price equilibrium. The model is similar to Engel (2011) and Fujiwara and Wang (2017), who make special functional form assumptions. We follow these assumptions since they will be used to derive the results in the dynamic game using approximated welfare functions in subsequent sections. But the main results of this section hold in a much more general model, which we show in Technical Appendix Section (2).

There are two countries of equal size, denoted Home and Foreign, each populated with a continuum of households with population size normalized to unity. In each country, households consume both home and foreign goods with a symmetric home bias. They supply labor to firms in a competitive labor market. Firms are monopolistically competitive and produce differentiated goods. They set prices, in local currency, in a staggered manner, as in Calvo (1983). The government levies a lump-sum tax on households and subsidizes firms to eliminate steady-state distortions from monopolistic pricing. As in most of the existing literature we assume a complete financial market.

3.1 Household

The representative home household is assumed to maximize lifetime utility, defined as,

$$U = E_{t=0}^{\infty}\beta^t\left(\frac{C_t^{1-\rho}}{1-\rho} - \eta L_t + \chi \log\left(\frac{M_t}{P_t}\right)\right) \tag{3.1}$$

Consumption C_t is a Cobb-Douglas aggregation of home goods and foreign goods. $C_t = C_{ht}^{\frac{v}{2}} C_{ft}^{1-\frac{v}{2}}$, where $v \geq 1$ denotes the degree of home bias in consumption. Both home and foreign goods consumption is differentiated into a measure 1 of varieties with a constant elasticity of substitution among varieties equal to λ. The consumption-based price index is $P_t = \Theta^{-1} P_{hh,t}^{\frac{v}{2}}((1+t_{c,t})P_{fh,t})^{1-\frac{v}{2}}$, where $\Theta = (\frac{v}{2})^{\frac{v}{2}}(1-\frac{v}{2})^{1-\frac{v}{2}}$. P_{hht} and P_{fht} represent the (home currency) price set by home and foreign firms, respectively, for sale in the home market. $t_{c,t}$ is a state-contingent import tax imposed on foreign goods. It is standard in the literature to derive the equilibrium as $\chi \longrightarrow 0$, and hence ignore the role of money in welfare.

The demand for home and foreign goods is $C_{h,t}=\frac{v}{2}\frac{P_t C_t}{P_{hht}}$ and $C_{f,t}=(1-\frac{v}{2})\frac{P_t C_t}{P_{fh,t}(1+t_{c,t})}$. The budget constraint under complete markets is given by

$$P_t C_t + B_{ht+1} + \sum_{\zeta^{t+1}\in Z_{t+1}} B(\zeta^{t+1}|\zeta^t) D(\zeta^{t+1}) = W_t L_t + R_{t-1} B_{h,t} + \Pi_t + T_t + D(\zeta^t), \tag{3.2}$$

Where $D(\zeta^t)$ represents the household's payoff on state-contingent claims at state ζ^t and $B(\zeta^{t+1}|\zeta^t)$ is the price of a claim that pays one dollar in state ζ^{t+1}, conditional on state ζ^t occurring at time t. B_h is the household's holding of domestic currency bonds, and R_t is the domestic gross interest rate between period t and $t+1$. The consumption and leisure choice yields the labor supply equation

$$\eta C_t^{\rho} = \frac{W_t}{P_t} \tag{3.3}$$

Under the complete markets assumption, we have the following risk-sharing condition

$$\frac{C_t^{-\rho}}{P_t} = \Gamma \frac{C_t^{*-\rho}}{S_t P_t^*} \tag{3.4}$$

Where S_t is the nominal exchange rate, defined as the price of foreign currency in terms of domestic currency, and $P_t^* = \Theta^{-1}(P_{hf,t}^*)^{1-\frac{v}{2}} P_{ff,t}^{*\,\frac{v}{2}}$ is the foreign price level.[7] Here, Γ is the state-invariant weight, and in a symmetric model where securities trade takes place in advance of policy choices, $\Gamma = 1$.

3.2 Production

Each firm i in the home economy has the following production technology.

$$Y_t(i) = Z_t L_t(i) \tag{3.5}$$

where $Z_t = exp(\theta_t)$ is a country-specific shock, and θ_t is distributed with mean zero and variance σ_θ^2. Firms are monopolistically competitive. Each firm produces a differentiated good facing a downward-sloping individual demand curve with elasticity

[7]The risk-sharing condition implies that one dollar obtains the same marginal utility of consumption across countries. In the analysis below, we take this risk-sharing condition as given to the policy-maker, assuming that securities trading takes place in advance of policy determination, so that optimal monetary and fiscal policy is chosen conditional on (3.4). This is the assumption made in the Engel (2011) and Fujiwara and Wang (2016), and thus represents an appropriate specification for our paper. An alternative assumption, explored in Senay and Sutherland (2007,2013), is that policy choices are made in advance of security trade. The consequences of this alternative are discussed in the conclusions to their paper.

λ and chooses its optimal price along the demand curve. Export prices are assumed to be set in local currency (LCP).

In the home country, a firm resets its prices with probability $1-\kappa$ each period. When the firm changes prices, it will reset $P^o_{hh,t}(i)$ in home currency for sales in the home market, and $P^{o*}_{hf,t}(i)$ in foreign currency for sales in the foreign market. The firm maximizes the following objective function,

$$E_t \sum_{j=0}^{\infty} \kappa^j \beta_{t,t+j} \left[\begin{array}{c} ((1+\tau)P^o_{hht}(i) - MC_{t+j}(i))C_{ht+j}(i) \\ +(S_{t+j}(1+s_{e,t+j})(1+\tau)P^{o*}_{hft}(i) - MC_{t+j}(i))C^*_{ht+j}(i) \end{array} \right]$$

where $C_{ht}(i)$ and $C^*_{ht}(i)$ are the demands for the home good i from the home and foreign markets, respectively, and $\beta_{t,t+j} = \beta^j(\frac{C_{t+j}}{C_t})^{-\rho}(\frac{P_t}{P_{t+j}})$ is the firm's stochastic discount factor. $\tau = \frac{1}{\lambda-1}$ is a subsidy imposed by the government to eliminate the steady state monopolistic distortion. $s_{e,t}$ is a state-contingent export subsidy introduced to remove the distortion on production due to the presence of an import tax described above. The optimal pricing conditions are

$$\frac{P^o_{hht}(i)}{P_{hht}} = \frac{E_t \sum_{j=0}^{\infty}(\beta\kappa)^j \left(\frac{C_{t+j}}{C_t}\right)^{-\rho} (\frac{P_{hht+j}}{P_{hht}})^{\lambda} mc_{t+j} C_{ht+j}}{E_t \sum_{j=0}^{\infty}(\beta\kappa)^j \left(\frac{C_{t+j}}{C_t}\right)^{-\rho} (\frac{P_{hht+j}}{P_{hht}})^{\lambda-1} C_{ht+j} p_{hht+j}} \tag{3.6}$$

$$\frac{P^{o*}_{hft}(i)}{P^*_{hft}} = \frac{E_t \sum_{j=0}^{\infty}(\beta\kappa)^j \left(\frac{C_{t+j}}{C_t}\right)^{-\rho} (\frac{P^*_{hft+j}}{P^*_{hft}})^{\lambda} mc_{t+j} C^*_{ht+j}}{E_t \sum_{j=0}^{\infty}(\beta\kappa)^j e_{t+j}(1+s_{e,t+j}) \left(\frac{C_{t+j}}{C_t}\right)^{-\rho} (\frac{P^*_{hft+j}}{P^*_{hft}})^{\lambda-1} C^*_{ht+j} p^*_{hft+j}} \tag{3.7}$$

Here, we have normalized marginal cost and prices by the price level in the relevant country, so that mc_t denotes nominal marginal cost $MC_t = \frac{\eta W_t}{Z_t}$, divided by the domestic price level, p_{hht} is the price index for home good sales at home divided by the home price level, and p^*_{hft} is the price for home goods sales in the foreign market divided by the foreign price level. Finally, e_t is the real exchange rate.

The firm in the foreign country faces an analogous problem, and chooses $P^{*o}_{ff,t}$, in terms of foreign currency and $P^o_{fh,t}$, in terms of home currency.

3.3 Market Clearing Conditions and Equilibrium

The goods market clearing conditions for home and foreign goods are given by,

$$Y_t = \frac{v}{2}\frac{P_t C_t}{P_{hh,t}}\Delta_{hh,t} + (1-\frac{v}{2})\frac{P_t^* C_t^*}{P_{hf,t}^*(1+t_{c,t}^*)}\Delta_{hf,t}^* \tag{3.8}$$

$$Y_t^* = (1-\frac{v}{2})\frac{P_t C_t}{P_{fh,t}(1+t_{c,t})}\Delta_{fh,t} + \frac{v}{2}\frac{P_t^* C_t^*}{P_{ff,t}^*}\Delta_{ff,t}^* \tag{3.9}$$

where $\Delta_{xx,t} = \int_0^1 (\frac{P_{xx,t}(i)}{P_{xx,t}})^{-\lambda} di, xx \in \{hh, hf, fh, ff\}$, representing price dispersion coming from Calvo price adjustment. The gross inflation rates for each index are denoted as $\pi_{xx,t} = \frac{P_{xx,t}}{P_{xx,t-1}}$.

The price index for home goods sold in the home and foreign markets can be written as follows, respectively,

$$1 = [\kappa \pi_{hh,t}^{\lambda-1} + (1-\kappa)(\frac{P_{hht}^o}{P_{hht}})^{1-\lambda}]^{\frac{1}{1-\lambda}} \tag{3.10}$$

$$1 = [\kappa (\pi_{hf,t}^*)^{\lambda-1} + (1-\kappa)(\frac{P_{hht}^{*o}}{P_{hht}^*})^{1-\lambda}]^{\frac{1}{1-\lambda}} \tag{3.11}$$

We also have the two domestic bond markets clearing condition ($B_h = 0$ and $B_f^* = 0$) and the state-contingent bond market clearing condition. We define the real exchange rate, the terms of trade and deviation from the law of one price as below, respectively.

$$e_t = \frac{S_t P_t^*}{P_t}, Q_t = \frac{P_{fht}}{S_t P_{hft}^*} \tag{3.12}$$

$$d_t = \frac{S_t P_{hft}^*}{P_{hht}}, d_t^* = \frac{P_{fht}}{S_t P_{fft}^*} \tag{3.13}$$

3.4 Role of Fiscal Policy under LCP and Sticky Prices

In this subsection, we show that an import tax and an export subsidy can correct the distortions due to LCP and replicate a flexible price equilibrium in a sticky price

model.[8] We first describe the efficient allocation and then highlight the role that fiscal instruments play in eliminating the distortions due to LCP.

3.4.1 Flexible Price Equilibrium

The flexible price allocation is the efficient allocation in our analysis, since we remove the effects of monopolistic competition by a constant tax, as in Fujiwara and Wang (2017). We describe the flexible price equilibrium in the absence of import taxes or export subsidies. With flexible prices, profit maximization will imply that price equals marginal cost (post subsidy), so that $\frac{P_{hh,t}}{P_t} = \frac{\eta C_t^{\rho}}{Z_t}$. Without price rigidities, the law of one price will hold, so that $P_{fh,t} = S_t P^*_{ff,t}$ and $P_{hh,t} = S_t P^*_{hf,t}$. Using the above definitions, we have a one to one relationship between the terms of trade and the real exchange rate; $e_t = Q_t^{v-1}$. We can rewrite the real price of home and foreign goods as a function of the terms of trade, so that $\frac{P_{hh,t}}{P_t} = Q_t^{\frac{v}{2}-1}$; $\frac{P^*_{ff,t}}{P^*_t} = Q_t^{1-\frac{v}{2}}$.

We denote the flexible price allocation with superscript "fb". Then the flexible price allocation can be characterized by $\{C_t^{fb}, C_t^{*fb}, Q_t^{fb}\}$, which are determined by the following three equations (3.14)-(3.16), representing, respectively, the risk-sharing condition and production efficiency in the home and foreign country.

$$(C_t^{*fb})^{\rho} Q_t^{fb(v-1)} = (C_t^{fb})^{\rho} \tag{3.14}$$

$$Q_t^{fb(\frac{v}{2}-1)} = (C_t^{fb})^{\rho} \frac{\eta}{Z_t} \tag{3.15}$$

$$Q_t^{fb(1-\frac{v}{2})} = (C_t^{*fb})^{\rho} \frac{\eta}{Z_t^*} \tag{3.16}$$

3.4.2 Replicating the Flexible Price Equilibrium

We state our finding in the following Proposition.

[8] As noted above, this result holds true for more general preferences, such as CES aggregation of home and foreign goods, and a more general disutility of labor. This is shown in Technical Appendix Section (2)

Proposition 1 *With sticky prices and LCP, a global social planner can use a combination of monetary policy, import taxes and export subsidies to restore the flexible price equilibrium. Import taxes are chosen to correct deviations from the law of one price, d_t^* and d_t, whereas export subsidies are used to offset the corresponding distortion on price setting generated by import taxes.*

The proof is intuitive. First, the planner uses monetary policy to stabilize prices.[9] Let all the price levels be constant $P_{xxt} = \overline{P}_{xx0}$ for $xx \in \{hh, hf, fh, ff\}$. We let $\overline{P}_{hh0} = 1$ and $\overline{P}^*_{ff0} = 1$ without loss of generality. Second, the social planner set the level of $\{t_c, t_c^*\}$ such that the prices of goods are identical in the two countries.

$$\begin{aligned} P_{fht}(1 + t_{c,t}) &= S_t P^*_{fft} \\ S_t P^*_{hft}(1 + t^*_{c,t}) &= P_{hht} \end{aligned}$$

The currency misalignment is corrected by import taxes now. Given the fixed nominal prices, this also implies that, $(1 + t_{c,t}) = S_t$ and $S_t(1 + t^*_{c,t}) = 1$. We define $\widetilde{Q}_t = \frac{P_{fh,t}(1+t_{c,t})}{P_{hh,t}} = \frac{P^*_{fft}}{P^*_{hft}(1+t^*_{c,t})}$. Finally, the social planner chooses a set of export subsidies for each country such that $1 + s_{e,t} = 1 + t^*_{c,t}$ and $1 + s^*_{e,t} = 1 + t_{c,t}$.

From the labor supply equations, normalized marginal costs for the home country are

$$mc_t = \eta \frac{C_t^\rho}{Z_t}$$

Given the optimal taxes in place, the normalized price of the home good is

$$p_{hht} = \frac{P_{hht}}{P_t} = \frac{P^*_{hft}(1 + t^*_{c,t})S_t}{P_t} = \frac{1}{\widetilde{Q}_t^{(1-\frac{v}{2})}}$$

Conjecture now that price equals to marginal cost, and following the same steps for

[9] With constant prices, the optimal monetary rule requires adjusting interest rates to equal the 'natural real interest rate'. We omit the explicit description of the interest rate rule, since it is well known in the literature.

the foreign country, we get:

$$\widetilde{Q}_t^{\frac{v}{2}-1} = \frac{\eta}{Z_t}(C_t)^{\rho} \tag{3.17}$$

$$\widetilde{Q}_t{}^{1-\frac{v}{2}} = \frac{\eta}{Z_t^*}(C_t^*)^{\rho} \tag{3.18}$$

Together with the definition of real exchange rate and the risk sharing condition (3.14), we pin down the allocation of consumptions. These equations are identical to those under the flexible price allocation. Therefore, given the conjecture that price equals marginal cost for both countries, we have $C_t = C_t^{fb}$ and $C_t^* = C_t^{*fb}$, and $\widetilde{Q}_t = Q_t^{fb}$.

Given identical consumption and relative prices, it follows that labor supply will also be exactly the same as that in the flexible price allocation. In this sense, the fiscal instruments can correct the distortions and restore the economy to the flexible price equilibrium and achieve an efficient allocation.

It remains to verify that the constant nominal price is supported by the optimal pricing strategies when consumption, labor and the terms of trade are set to the flexible price equilibrium. If this is the case, then the conjecture that price equals marginal cost is verified, conditional on the optimal monetary policy and fiscal instruments in place. The optimal pricing equation for the domestic market is equation (3.6). At the flexible price equilibrium the normalized marginal cost is equal to $\frac{\eta C_t^{fb}}{Z_t}$, while the normalized price is equal to $p_{hht} = \widetilde{Q}_t^{\frac{v}{2}-1}$. Then from (3.6) the denominator and the numerator of the pricing equation are identical, so that $\frac{P_{hht}^o(i)}{P_{hht}} = 1$.

Similarly, from the pricing equation in the foreign market (3.7), here using the export subsidy definition, we have $e_t(1+s_{e,t})p_{hft}^* = \widetilde{Q}_t^{v-1}\frac{1}{S_t}S_t^{1-\frac{v}{2}} = \widetilde{Q}_t{}^{\frac{v}{2}-1}$, which again ensures that $\frac{P_{hft}^{o*}(i)}{P_{hft}^*} = 1$. An identical property holds for the foreign country pricing equations.

The import tax is used to correct the deviation from the law of one price, and the export subsidies eliminate the effect of the consumption tax on export pricing. Intuitively, the subsidy is needed because, given constant nominal prices, the planner

will need to adjust the nominal exchange rate to equal the efficient terms of trade. Under LCP, the firm would want to adjust its foreign price in inverse proportion to the nominal exchange rate, which lead to a deviation from the law of one price for home and foreign sales of the home good. The export subsidy exactly offsets the incentive for the home firm to do this.

Prices are constant over time, but the exchange rate is flexible, and import taxes respond to the exchange rate to ensure efficient relative price adjustment for prices facing households.[10]

Nominal wages will respond to productivity shocks and the allocation of consumptions and labor is not distorted.

In summary, a combination of monetary and fiscal policy can support the fully efficient allocation even when prices are set in local currency. Nevertheless, the key question is how to implement these fiscal policy when there is no international policy coordination. Below, we explore the implementation of the monetary and fiscal policy in a non-cooperative environment.

4 The Implementation Issue: An example

Before we develop our main results, we show the key intuition in a simplified case of the general model, which abstracts from the dynamics of staggered price adjustment and instead assumes one-period-ahead price setting, log utility, and i.i.d. log-normal productivity shocks.

Household preferences are

$$U = E_{t-1}(\ln C_t - \eta L_t)$$

The simplified labor supply equation and risk sharing conditions are

$$\eta C_t = \frac{W_t}{P_t}, \quad \frac{C_t^{-1}}{P_t} = \frac{C_t^{*-1}}{S_t P_t^*}. \tag{4.19}$$

[10]From (3.14)-(3.16), the solution for the nominal exchange rate is $S_t = \widetilde{Q}_t = \frac{Z_t}{Z_t^*}$.

If prices were fully flexible and optimal subsidies were in place to eliminate monopoly distortions, it is easy to show that in this special case we have the flexible price solution for home and foreign consumption and labor supply given by:

$$C_t^{fb} = \frac{1}{\eta} Z_t^{\frac{v}{2}} Z_t^{*(1-\frac{v}{2})}, \quad C_t^{*fb} = \frac{1}{\eta} Z_t^{*\frac{v}{2}} Z_t^{(1-\frac{v}{2})} \quad L_t^{fb} = L_t^{*fb} = \frac{1}{\eta}$$

If prices are set one period in advance, we replace the pricing conditions (where we also introduce import taxes and export subsidies) (3.6) and (3.7) with the following:

$$P_{hht} = E_{t-1}(\frac{\eta P_t C_t}{Z_t}), \quad P_{hft}^* = \frac{E_{t-1}(\frac{\eta P_t^* C_t^*}{(1+t_{ct}^*)Z_t})}{E_{t-1}(\frac{(1+s_{et})}{(1+t_{ct}^*)})} \tag{4.20}$$

Similarly, the pricing equations in the foreign country are:

$$P_{fft}^* = E_{t-1}(\frac{\eta P_t^* C_t^*}{Z_t^*}), \quad P_{fht} = \frac{E_{t-1}(\frac{\eta P_t C_t}{(1+t_{ct})Z_t^*})}{E_{t-1}(\frac{(1+s_{et}^*)}{(1+t_{ct})})} \tag{4.21}$$

Now assume that the two productivity shocks are log-normally distributed, i.i.d., and independent.[11] We assume a simple static monetary rule whereby the monetary authority targets nominal consumption in each country, so that $M_t = P_t C_t$, $M_t^* = P_t^* C_t^*$, where M_t and M_t^* can be defined as the domestic and foreign monetary policy (e.g. money supply).[12] The equilibrium with sticky prices may be easily characterized in terms of a pair of consumption levels and employment rates that satisfy these monetary policy rules, goods market clearing, and the risk sharing condition, for given pre-set prices, monetary and tax-subsidy policies.

Given that productivity shocks are log-normal, we can assume without loss of generality that monetary and tax policy rules may be expressed as

$$\log(M_t) = a_0 + a_1 u_t + a_2 u_t^*, \quad \log(M_t^*) = a_0^* + a_1^* u_t + a_2^* u_t^* \tag{4.22}$$

$$\log(1+t_{ct}) = b_0 + b_1 u_t + b_2 u_t^*, \quad \log(1+t_{ct}^*) = b_0^* + b_1^* u_t + b_2^* u_t^* \tag{4.23}$$

$$\log(1+s_{et}) = c_0 + c_1 u_t + c_2 u_t^*, \quad \log(1+s_{et}^*) = c_0^* + c_1^* u_t + c_2^* u_t^* \tag{4.24}$$

[11] Hence $Z_t = \exp(u_t),\ u_t \sim N(0, \sigma_u^2), \quad Z_t^* = \exp(u_t^*),\ u_t^* \sim N(0, \sigma_{u*}^2),\ \mathrm{cov}(u_t, u_t^*) = 0.$

[12] This is also consistent with a money market equilibrium representation, where the demand for money balances comes from the static equilibrium with preferences given by (3.1), and $\rho \to 1$ and $\chi = 1$ is assumed.

Optimal policy constitutes maximizing expected utility with respect to the parameters of these policy rules. Since the equilibrium is static, optimal policy can be evaluated separately for each period. Expected utility for the home country at any date t may be expressed as

$$\begin{aligned} & E_{t-1}(\log(C_t) - \eta L_t) \\ = \; & E_{t-1}\log(M_t) - \frac{v}{2}\log(P_{hht}) - (1-\frac{v}{2})\left(\log(P_{fht}) + E_{t-1}\log(1+t_{ct})\right) \\ & -(1-\frac{v}{2})E_{t-1}(\frac{1+s_{et}}{1+t^*_{ct}}) + \text{t.i.p.} \end{aligned} \tag{4.25}$$

Expected utility for the foreign country is defined analogously. We define a cooperative policy equilibrium as one where a planner chooses policy rules to maximize the equal weighted sum of home and foreign expected utility. A non-cooperative (Nash) policy equilibrium is defined by the condition that the home (foreign) policy-maker chooses the parameters of monetary and tax policy taking as given the policy rules chosen by the foreign (home) policy-maker.

We first focus on the equilibrium where both monetary policy, import taxes, and export subsidies are chosen by a cooperative planner. For this scenario, we can state:

Lemma 1 *Under a cooperative equilibrium where the policy-maker chooses both monetary policy, taxes and subsidies for both country's, the optimal policy may be expressed as:*

$$\begin{gathered} a_1 = 1,\ a_2 = 0, \quad a^*_1 = 0,\ a^*_2 = 1 \\ b_0 = c^*_0,\ b_1 = 1,\ b_2 = -1, \quad b^*_0 = c_0,\ b^*_1 = -1,\ b^*_2 = 1 \\ c_0 = b^*_0,\ c_1 = -1,\ c_2 = 1, \quad c^*_0 = b_0,\ c^*_1 = 1,\ c^*_2 = -1 \end{gathered}$$

This combination of monetary and tax-subsidy policies sustains the fully efficient flexible price equilibrium. The use of import taxes that respond to productivity shocks alters the relative prices facing consumers despite the presence of LCP. The

combination of consumption taxes and optimal monetary policy achieves efficient consumption risk sharing. The imposition of export subsidies ensures that firms set prices at their efficient level and there is no ex-post inefficiency from fixed nominal prices. Note that since $b_0 = c_0^*$ and $b_0^* = c_0$, the mean import taxes and export subsidies exactly offset each-other, so there is no systematic gain for either country in the equilibrium tax-subsidy choice.[13]

Can this efficient outcome can be implemented in a non-cooperative environment? In this simple example, we can show the following

Lemma 2 *There does not exist a non-cooperative equilibrium where policy-makers in each country choose monetary and tax-subsidy policies independently.*

This result implies that the set of monetary and tax-subsidy policies that sustain a fully efficient flexible price outcome in Lemma (1) cannot be implemented by independent policy-making. To see the logic of this result, we proceed as follows (the full proof is in the Technical Appendix Section (3)). Conjecture that the monetary and tax rules described in Lemma (2) are in place save for the values $b_0,\ b_0^*,\ c_0,\ c_0^*$. Then, for the home country, we may express expected utility as

$$E_{t-1}(\log C_t - \eta L_t) = -(1 - \frac{v}{2})b_0 - (1 - \frac{v}{2})\exp^{c_0 - b_0^*} + \text{t.i.p.}$$

Since $\frac{\partial E_{t-1}(\log C_t - \eta L_t)}{\partial b_0} < 0$ and $\frac{\partial E_{t-1}(\log C_t - \eta L_t)}{\partial c_0} < 0$, there are no finite values of b_0 and c_0 which satisfy the conditions for a non-cooperative equilibrium. [14]

The intuition behind this result comes from the incentive for the home country to choose a negative mean value of the import tax in order to manipulate its terms of trade and increase the home household's mean consumption level, while at the same time, choosing a negative mean value of the export subsidy in order to reduce

[13] In this case, the levels of $b_0,\ c_0,\ b_0^*$ and c_0^* are undefined, since they have no impact on welfare, given $b_0 = c_0^*$ and $b_0^* = c_0$.

[14] This result does not depend on the assumption that the other parameters of the monetary and tax-subsidy policies are at their efficient levels.

expected employment and the disutility of labor supply. Given any mean import tax rate chosen by the foreign country (b_0^*), the home country will attempt to set a mean export subsidy below that ($c_0 < b_0^*$). But since the foreign country behaves symmetrically, there will be no equilibrium in this game. Hence, unless some further restriction is applied to the tax and subsidy policies, no equilibrium exists.

These results imply that, in the absence of further restrictions, an efficient tax-subsidy policy cannot be implemented by independent policy-making. But this is not true for monetary policy determination. Again, using our simple static example, we can establish the following result

Lemma 3 *When optimal import taxes and export subsidies are chosen cooperatively, but monetary policy is chosen non-cooperatively, an equilibrium exists and sustains the full flexible price equilibrium.*

With cooperative determination of fiscal policy, the cooperative planner internalizes the negative effects of terms of trade manipulation and sets mean taxes and subsidies to exactly offset one another. But in addition, the planner will choose optimal import taxes so as to respond to domestic and foreign productivity shocks. Given this, the independent monetary policy maker will set monetary policy as if prices were adjusting according to PCP, and hence respond only to domestic productivity shocks. This sustains the fully efficient response of consumption and labour supply in each country. Finally the fiscal planner will choose export subsidies for both countries so as to insure efficient levels of preset prices for home and foreign goods.

5 Implementation of Fiscal Policies: Dynamic Model

In this section, we will explore the implementation of these fiscal policy in dynamic price setting model. Specifically, we derive the quadratic loss function under LCP and investigate both the cooperative game case and the non-cooperative game of

home and foreign fiscal and monetary policy authority. As illustrated in Section 3.4, in Ramsey setting it is possible to use fiscal policy to replicate the efficient flexible price equilibrium. So it is natural to use cooperative monetary and fiscal policy game as a benchmark for the non-cooperative game. We will explore if the solution to the international tax non-cooperative game exists. If not, then we ask what kind of condition on the fiscal instruments is needed to ensure the existence of a Nash international monetary and fiscal game and whether the solution to the Nash game accord with that to the cooperative game.

To solve for the optimal monetary and tax policy under both cooperative game and non-cooperative game, we need to follow Benigno and Woodford (2005) and Fujiwara and Wang (2017) and use second-order approximation methods to derive loss function and. In the following analysis, $\widehat{X_t} = \log(X_t) - \log(\overline{X})$ indicates the log-deviation of a variable from the respective steady state. All the nominal variables are normalized by the CPI. For example, the real price $p_{x,t} = \frac{P_{x,t}}{P_t}$ is the price level relative to CPI index; $mc_t = \frac{MC_t}{P_t}$ is the real marginal cost at Home.

5.1 Welfare analysis

In this section, we will sketch the main steps for the derivation of the loss function and leave the details to the Technical Appendix. The home household's life time expected utility is given by:

$$\begin{aligned} W_{h,0} &= E_t \sum_{t=0}^{\infty} (\beta)^t \left[\frac{C_t^{1-\rho}}{1-\rho} - \eta L_t \right] \\ &\approx E_t \sum_{t=0}^{\infty} (\beta)^t C_t^{1-\rho} \left[(\widehat{C}_t - \widehat{L}_t) + \frac{1-\rho}{2} \widehat{C}_t^2 - \frac{1}{2} \widehat{L}_t^2 \right] \end{aligned} \tag{5.26}$$

The third term in the bracket represents the log consumption volatility and the fourth term is just the output gap. Both can be derived from first-order approximation of the system. However, to get $\widehat{C}_t - \widehat{L}_t$ we need to do second order approximation. So we first log-linearize the system around the zero inflation, zero tax/subsidy

steady state without monopolistic distortion. Then using this log-linearized system, we can get the second-order approximation of the AS equations (the four price index) and the market clearing conditions, which will help us to express $\widehat{C}_t - \widehat{L}_t$ in terms of policy parameters and inflation.

The market clearing conditions (3.8) and (3.9) are approximated as

$$\widehat{Y}_t = \widehat{C}_t - \frac{v}{2}\widehat{p}_{hh,t} - \frac{2-v}{2}(\widehat{p}^*_{hf,t} + \widehat{t}^*_{c,t}) - \frac{2-v}{2}\frac{1}{\rho}\widehat{e}_t \tag{5.27}$$

$$\widehat{Y}^*_t = \widehat{C}^*_t - \frac{v}{2}\widehat{p}^*_{ff,t} - \frac{2-v}{2}(\widehat{p}_{fh,t} + \widehat{t}_{c,t}) + \frac{2-v}{2}\frac{1}{\rho}\widehat{e}_t \tag{5.28}$$

The terms $\widehat{p}^*_{hf,t} + \widehat{t}^*_{c,t}$ and $\widehat{p}_{fh,t} + \widehat{t}_{c,t}$ reflect the real cost faced by consumers when they choose to consume imported goods. The New Keynesian Phillips curves are

$$\pi_{hh,t} = \delta\left[\widehat{mc}_t - \widehat{p}_{hh,t}\right] + \beta E_t \pi_{hh,t+1} \tag{5.29}$$

$$\pi^*_{hf,t} = \delta\left[\widehat{mc}_t - \widehat{p}^*_{hf,t} - \widehat{e}_t - \widehat{s}_{e,t}\right] + \beta E_t \pi^*_{hf,t+1} \tag{5.30}$$

$$\pi^*_{ff,t} = \delta\left[\widehat{mc}^*_t - \widehat{p}^*_{ff,t}\right] + \beta E_t \pi^*_{ff,t+1} \tag{5.31}$$

$$\pi_{fh,t} = \delta\left[\widehat{mc}^*_t - \widehat{p}_{fh,t} + \widehat{e}_t - \widehat{s}^*_{e,t}\right] + \beta E_t \pi_{fh,t+1} \tag{5.32}$$

where $\delta = \frac{(1-\beta\kappa)(1-\kappa)}{\kappa}$. Equations (5.29) and (5.31) are Phillips curves for domestically produced goods. Equations (5.30) and (5.32) are Phillips curves for imported goods under local currency pricing. To understand the effect of tax and subsidy on real allocation and the price index, we present the log-linearized real marginal costs (relative to real producer price index). These terms are also important for the derivation of loss functions.[15]

$$\widehat{mc}_t - \widehat{p}_{hh,t} = \rho\widehat{Y}_t - \theta_t + \varkappa(\widehat{q}_t + \widehat{e}_t) + \frac{2-v}{2}(\widehat{d}_t + \widehat{t}^*_{c,t}) + \varkappa(\widehat{t}_{c,t} - \widehat{t}^*_{c,t}) \tag{5.33}$$

$$\widehat{mc}_t - \widehat{p}^*_{hf,t} - \widehat{e}_t = \rho\widehat{Y}_t - \theta_t + \varkappa(\widehat{q}_t + \widehat{e}_t) - \frac{v}{2}(\widehat{d}_t + \widehat{t}^*_{c,t}) + \varkappa(\widehat{t}_{c,t} - \widehat{t}^*_{c,t}) + \widehat{t}^*_{c,t} \tag{5.34}$$

$$\widehat{mc}^*_t - \widehat{p}^*_{ff,t} = \rho\widehat{Y}^*_t - \theta^*_t + \varkappa(\widehat{q}^*_t - \widehat{e}_t) + \frac{2-v}{2}(\widehat{d}^*_t + \widehat{t}_{c,t}) + \varkappa(\widehat{t}^*_{c,t} - \widehat{t}_{c,t}) \tag{5.35}$$

$$\widehat{mc}^*_t - \widehat{p}_{fh,t} + \widehat{e}_t = \rho\widehat{Y}^*_t - \theta^*_t + \varkappa(\widehat{q}^*_t - \widehat{e}_t) - \frac{v}{2}(\widehat{d}^*_t + \widehat{t}_{c,t}) - \varkappa(\widehat{t}_{c,t} - \widehat{t}^*_{c,t}) + \widehat{t}_{c,t} \tag{5.36}$$

[15] $\widehat{mc}_t$ is the log deviation of real marginal cost ($mc_t = \frac{MC_t}{P_t}$), $\widehat{p}_{hh,t} = \widehat{P}_{hh,t} - \widehat{P}_t$, and $\widehat{e}_t$ is the log deviation of real exchange rate, given by $\widehat{e}_t = \widehat{P}^*_t + \widehat{S}_t - \widehat{P}_t$.

where $\varkappa = \frac{(2-v)(1-\rho)}{2}$ and $\widehat{d}_t$, $\widehat{d}^*_t$ are the before-tax (log) deviation from law of one price in home and foreign.

$$\widehat{d}_t = \widehat{p}^*_{hf,t} + \widehat{e}_t - \widehat{p}_{hh,t} \tag{5.37}$$

$$\widehat{d}^*_t = \widehat{p}_{fh,t} - \widehat{e}_t - \widehat{p}^*_{ff,t} \tag{5.38}$$

And $\widehat{q}_t$ and $\widehat{q}^*_t$ are the (log) terms of trade.

$$\widehat{q}_t = \widehat{p}_{fh,t} - \widehat{p}^*_{hf,t} - \widehat{e}_t = -\widehat{q}^*_t \tag{5.39}$$

The log deviation of marginal cost terms are similar to those in Fujiwara and Wang (2017), but now they involve the import tax, $\widehat{t}^*_{c,t}$ and $\widehat{t}_{c,t}$. The intuition is straight forward, tax will distort the consumption choice and has impact on wage, which is eventually reflected in marginal cost. The first two terms represent the effect of output and productivity shock on production while the third term is related to the effect of terms of trade on marginal cost (relative to producer price index). The fourth term is the (after-tax) deviation from law of one price. Note that compared to Engel(2011), it now includes a log tax term due to the presence of import tax, which implies that we could possibly deal with deviation from LOOP using the tax scheme. The fifth term is the difference between import tax across countries. Comparing the third and the fifth term, we can see that the role of the tax rate difference on marginal cost is identical to that of term of trade. This is intuitive. Also, these two terms will only affect the marginal cost when $\rho > 1$. Finally, there exists a sixth term, the import tax, in Equations (5.34) and (5.36), implying the tax will affect marginal cost relative to the foreign producer price index directly. This is because when prices facing consumers are affected by the import tax (subsidy), the export firms' price setting will be distorted. The import taxes (subsidies), although correcting the deviations from the law of one price, distorts the production decision, which in turn affects the relative real marginal cost of imported goods. That is why we need to impose a producer subsidy (tax) on export firms to eliminate this distortion.

In the following analysis, we will first derive the global loss function with tax and subsidy for the cooperative game. We check if these fiscal instruments can correct the welfare loss due to deviation from LOOP and help to achieve the flexible price equilibrium. Note that in the dynamic model, the most desirable level to which monetary policy can deliver is the flexible price equilibrium level, which will be used as a target for international tax policies. Since we remove the monopolistic competition by a constant tax, it is also the efficient equilibrium, as that in Fujiwara and Wang (2017).

5.2 Cooperative Game

As discussed in Clarida, Gali and Gertler (2002), the terms of trade effect and the risk-sharing effect cancel out with each other when $\rho = 1$, which greatly simplifies the expression for the loss function. Since the effect of currency misalignment on marginal cost does not depend on whether ρ is greater, smaller, or equal to 1, we will look at the $\rho = 1$ first to simplify our analysis. The case with $\rho > 1$ will be discussed later. Countries are assumed to have equal size, so the global welfare loss in the cooperative game is $L_0 = L_{h,0} + L^*_{h,0}$, where $L_{h,0}$ and $L^*_{h,0}$ are the loss functions for the home and foreign countries, respectively.

5.2.1 The Cooperative Game when $\rho = 1$

In this case, it is assumed that there exists an authority who will choose monetary and fiscal instruments to maximize the joint (global) welfare of the home and foreign country. As shown in Section (4) of the Technical Appendix, the second-order approximation of global welfare L_0 is:

$$P(1) : E_{t_0} \sum_{t=t_0}^{\infty} \beta^{t-t_0} \left[\begin{array}{c} \frac{1}{2}(\widehat{Y}_t - \theta_t)^2 + \frac{1}{2}(\widehat{Y}^*_t - \theta^*_t)^2 \\ + \frac{\lambda v}{4\delta}\pi^2_{hh,t} + \frac{\lambda(2-v)}{4\delta}\pi^2_{fh,t} + \frac{\lambda v}{4\delta}(\pi^*_{ff,t})^2 + \frac{\lambda(2-v)}{4\delta}(\pi^*_{hf,t})^2 \\ + \frac{v(2-v)}{8}(\widehat{d}^*_t + \widehat{t}_{c,t})^2 + \frac{v(2-v)}{8}(\widehat{d}_t + \widehat{t}^*_{c,t})^2 \end{array} \right]$$

The first two terms are quadratic deviation from steady state output. The following four terms represent squared inflation rate of local as well as imported products, which capture price dispersions. For example, $\pi_{hh,t} = \pi_t + \widehat{p}_{hh,t} - \widehat{p}_{hh,t-1}$ is the deviation of inflation of home goods sold in home from the steady state ($\bar{\pi_{hh}} = 0$), and the other terms are defined analogously. The last two terms are related to the welfare loss due to deviations from law of one price (LOOP). Interestingly, if there are not tax policies, then the last two terms will become $\frac{v(2-v)}{8}(\widehat{d_t^*})^2 + \frac{v(2-v)}{8}(\widehat{d_t})^2$. This is exactly the currency misalignment problem emphasized in Engel(2011). Comparing to that in Engel (2011) and Fujiwara and Wang(2017), in our model with fiscal instruments, they show up in the loss function together with the import tax. As in Clarida, Gali and Gertler (2002), since we assume $\rho = 1$, terms of trade $\widehat{q_t} = \widehat{p}_{fh,t} - \widehat{e}_t - \widehat{p}^*_{hf,t}$ will not appear in the loss function.

The authority will maximize global welfare subject to the new Keynesian Phillips curve (NKPC) constraints (5.29)-(5.32) and the following resource constraints.

$$\widehat{Y}_t - \widehat{Y}_t^* = \frac{v}{2}\widehat{d}_t - \frac{v}{2}\widehat{d}_t^* + \widehat{q}_t + \frac{2-v}{2}(\widehat{t}_{c,t} - \widehat{t}^*_{c,t}) \tag{5.40}$$

The choice variables for the cooperative game are $\{\widehat{Y}_t - \theta_t, \widehat{Y}_t^* - \theta_t^*, \pi_{hh,t}, \pi^*_{hf,t}, \pi^*_{ff,t}, \pi_{fh,t}, \widehat{d}_t^*, \widehat{d}_t, \widehat{t}_{c,t}, \widehat{t}^*_{c,t}, \widehat{s}_{e,t}, \widehat{s}^*_{e,t}\}$. Solving the optimization problem gives us the following proposition. The domestic output gap is defined as the deviation from the natural level of output (the output level in the flexible price equilibrium) $\widetilde{Y}_t = \widehat{Y}_t - \widehat{Y}_t^f$, where notations with superscript "f" denote the variables in flexible price equilibrium.

Proposition 2 *In the cooperative game with $\rho = 1$, import tax rates are chosen to correct deviations from the law of one price $\widehat{d}_t^*$ and $\widehat{d}_t$, whereas export subsidy rates are used to offset the corresponding externality of the import tax. The optimal monetary policy requires monetary authorities to target zero PPI inflation and a*

zero output gap.

$$\widetilde{Y}_t = \widetilde{Y}_t^* = 0$$
$$\widehat{Y}_t = \widehat{Y}_t^f = \theta_t,\ \widehat{Y}_t^* = \widehat{Y}_t^{*f} = \theta_t^*$$
$$-\widehat{d}_t = \widehat{t}_{c,t}^* = \widehat{s}_{e,t},\ \ -\widehat{d}_t^* = \widehat{t}_{c,t} = \widehat{s}_{e,t}^*$$
$$\pi_{hh,t} = 0,\ \pi_{ff,t}^* = 0,\ \pi_{hf,t}^* = 0,\ \pi_{fh,t} = 0$$

The proof is given in Section 5.1 of the Technical Appendix. The global welfare loss comes from the output gap, inflation instability and the deviation from LOOP. Engel (2011) provides a solution for this cooperative game without tax and subsidy. He finds that the optimal solution is to target zero CPI inflation instead of PPI inflation, since policymakers cannot eliminate currency misalignment due to LCP. Thus, even with policy coordination the optimal monetary policy cannot replicate the flexible price equilibrium. In our model, however, once the international tax and subsidy scheme are introduced to correct the distortion induced by the deviation from LOOP, the social planner can achieve an efficient equilibrium, which is identical to that under flexible prices or PCP (under optimal monetary policy).

Given the above optimal policies, what exactly are the deviations of LOOP and the fiscal policies in this dynamic model? Zero PPI inflation, or $\pi_{hh,t} = \pi_{hf,t}^* = 0$, implies $\widehat{d}_t = \widehat{S}_t$.[16] Similarly, $\widehat{d}_t^* = -\widehat{S}_t$. Substituting this relation, solution to the cooperative game, and the expression for $\widehat{q}_t$ into Equation (5.40) gives $\widehat{d}_t = -\widehat{d}_t^* = \theta_t - \theta_t^*$ and tax schemes $\widehat{t}_{c,t} = -\widehat{t}_{c,t}^* = \theta_t - \theta_t^*$.[17] In other words, import tax rates are exactly the gap between home and foreign productivity shocks. The Phillips curves (5.30) and (5.32) indicate that the inflation dynamics of imported goods are directly affected by import tax rates. So to offset this externality, export subsidies $\widehat{s}_{e,t}$ and $\widehat{s}_{e,t}^*$ eliminate the impact of import taxes on inflation of imported goods. Finally,

[16]Substituting $\widehat{e}_t = \widehat{P}_t^* + \widehat{S}_t - \widehat{P}_t$, $\widehat{p}_{hf,t}^* = \widehat{P}_{hf,t} - \widehat{P}_t^*$, and $\widehat{p}_{hh,t} = \widehat{P}_{hh,t} - \widehat{P}_t$ into $\widehat{d}_t = \widehat{p}_{hf,t}^* + \widehat{e}_t - \widehat{p}_{hh,t}$ gives $\widehat{d}_t = \widehat{S}_t$.

[17]Tax rates are zero in steady state, so $\widehat{t}_{c,t} = t_{c,t}$ and $\widehat{t}_{c,t}^* = t_{c,t}^*$.

$\widehat{S}_t = \theta_t - \theta_t^*$ implies that the exchange rate is flexible and responds to productivity shocks in the same manner as that under PCP.

5.2.2 Cooperative Game when $\rho > 1$

As discussed above, when $\rho > 1$, the terms of trade effect and the risk-sharing effect will enter the loss function. There will also be some spillover effect of international productivity. In Section (7) of the Technical Appendix, we present the loss function and the constraints faced by the social planner for the cooperative game in the $\rho > 1$ case. The solutions to the cooperative game can almost identical to the case $\rho = 1$: the output gap is closed, and monetary authorities target zero PPI inflation, while tax instruments are used to correct $\widehat{d}_t$ and $\widehat{d}_t^*$. The only effect of $\rho > 1$ is on the production level, which are:

$$\begin{aligned}
\widehat{Y}_t &= \widehat{Y}_t^f = \theta_t + \frac{(1-\rho)}{\rho}\left(\theta_t - \frac{(2-v)v}{2}(\theta_t - \theta_t^*)\right) \\
\widehat{Y}_t^* &= \widehat{Y}_t^{*f} = \theta_t^* + \frac{(1-\rho)}{\rho}\left(\theta_t^* + \frac{(2-v)v}{2}(\theta_t - \theta_t^*)\right)
\end{aligned}$$

When $\rho > 1$, although there exists an international productivity spillover in the game, the import tax will still correct the deviation from LOOP and the export subsidy will still offset the distortion of import tax on allocation. Given that the currency misalignment induced by LCP is corrected by the tax, the optimal monetary policy will still target zero PPI inflation. Due to the presence of the international spillover, a country's equilibrium output does not reflect exactly the its corresponding productivity shock, but the output gap, properly defined, is still zero. Therefore, even when $\rho > 1$, we can still have the following result. The combination of international tax policy and an inward-looking monetary policy targeting PPI inflation can correct the currency misalignment and replicate the flexible price equilibrium.[18]

[18]If there is no home bias ($v = 1$), we can show that the optimal solutions are identical to the responses under flexible price equilibrium in the static model of Devereux and Engel (2003). The optimal output deviations from steady state values are $\widehat{Y}_t - \theta_t = \widehat{Y}_t^* - \theta_t^* = \frac{(1-\rho)}{\rho}(\theta_t +$

Having shown that these fiscal instruments can correct the currency misalignment due to LCP and deliver the flexible price equilibrium under the cooperative game, the next step is to explore the implementation of these international fiscal policies in non-cooperative environment.

5.3 Non-cooperative Game

Define the non-cooperative game as one where the policy-maker in each country independently chooses both monetary variables and fiscal variables. Again, first focus on the case $\rho = 1$. As shown in the Technical Appendix, in the non-cooperative game, when $\rho = 1$, the loss functions for home $L_{h,0}$ and foreign $L^*_{h,0}$ are given by, respectively

$$P(2) \quad : \quad L_{h,0} = E_t \sum_{t=0}^{\infty} (\beta)^t \left\{ \begin{array}{c} \frac{1}{2}(\widehat{Y}_t - \theta_t)^2 + \frac{v(2-v)}{8}(\widehat{d}_t + \widehat{t}^*_{c,t})^2 + \frac{\lambda}{2\delta}\left[\frac{v}{2}\pi^2_{hh,t} + \frac{(2-v)}{2}\pi^2_{fh,t}\right] \\ -\frac{2-v}{4}\left(\widehat{t}_{c,t} - \widehat{s}^*_{e,t}\right)^2 + \frac{2-v}{4}\left(\widehat{t}^*_{c,t} - \widehat{s}_{e,t}\right)^2 + \frac{2-v}{2}[(\widehat{t}_{c,t} - \widehat{s}^*_{e,t}) - (\widehat{t}^*_{c,t} - \widehat{s}_{e,t})] \\ +\frac{2-v}{4}\left((\widehat{Y}^*_t - \theta^*_t) - \frac{v}{2}(\widehat{d}^*_t + \widehat{t}_{c,t})\right)^2 - \frac{2-v}{4}\left((\widehat{Y}_t - \theta_t) - \frac{v}{2}(\widehat{d}_t + \widehat{t}^*_{c,t})\right)^2 \end{array} \right\}$$

$$: \quad L^*_{h,0} = E_t \sum_{t=0}^{\infty} (\beta)^t \left\{ \begin{array}{c} \frac{1}{2}(\widehat{Y}^*_t - \theta^*_t)^2 + \frac{v(2-v)}{8}(\widehat{d}^*_t + \widehat{t}_{c,t})^2 + \frac{\lambda}{2\delta}\left[\frac{v}{2}\pi^{*2}_{ff,t} + \frac{(2-v)}{2}\pi^{*2}_{hf,t}\right] \\ +\frac{2-v}{4}\left(\widehat{t}_{c,t} - \widehat{s}^*_{e,t}\right)^2 - \frac{2-v}{4}\left(\widehat{t}^*_{c,t} - \widehat{s}_{e,t}\right)^2 - \frac{2-v}{2}[(\widehat{t}_{c,t} - \widehat{s}^*_{e,t}) - (\widehat{t}^*_{c,t} - \widehat{s}_{e,t})] \\ -\frac{2-v}{4}\left((\widehat{Y}^*_t - \theta^*_t) - \frac{v}{2}(\widehat{d}^*_t + \widehat{t}_{c,t})\right)^2 + \frac{2-v}{4}\left((\widehat{Y}_t - \theta_t) - \frac{v}{2}(\widehat{d}_t + \widehat{t}^*_{c,t})\right)^2 \end{array} \right\}$$

The first three terms represent the welfare cost due to output gaps, deviation from the law of one price and price dispersion, respectively. The following four terms are welfare losses due to spillovers from non-cooperative behaviour. Note that $(\widehat{t}_{c,t} - \widehat{s}^*_{e,t})^2, (\widehat{t}^*_{c,t} - \widehat{s}_{e,t})^2, (\widehat{t}_{c,t} - \widehat{s}^*_{e,t})$ and $(\widehat{t}^*_{c,t} - \widehat{s}_{e,t})$ only appear in the non-cooperative loss but not in cooperative case. The last two terms represent an inefficiency from fluctuations in marginal cost, which represent the additional objectives of policy makers in the non-cooperative game, as emphasized in Fujiwara and Wang (2017).

θ^*_t) and consumption deviations are $\widehat{C}_t = \widehat{C}^*_t = \frac{1}{2\rho}(\theta_t + \theta^*_t)$. The global welfare loss is $L^W = E_t \sum_{t=0}^{\infty} \beta^t \frac{\rho-1}{4\rho}(\theta_t + \theta^*_t)^2$.

The home policy maker is subject to the NKPC constraints (5.29) and (5.32) as well as the resource constraint (5.40). Similarly, the constraints for the foreign country are (5.30),(5.31) and (5.40). In the Nash game without restriction, the home country chooses $\{\widehat{Y}_t - \theta_t, \pi_{hh,t}, \pi_{fh,t}, \widehat{d}_t, \widehat{t}_{c,t}, \widehat{s}_{e,t}, \widehat{q}_t\}$, while foreign country chooses $\left\{\widehat{Y}^*_t - \theta^*_t, \pi^*_{hf,t}, \pi^*_{ff,t}, \widehat{d}^*_t, \widehat{t}^*_{c,t}, \widehat{s}^*_{e,t}, \widehat{q}^*_t\right\}$. First order conditions are reported in the Technical Appendix. From an analysis of these first order conditions, we find remarkably that the Nash game equilibrium does not exist.

Proposition 3 *An equilibrium of the Nash game with finite inflation and output gaps does not exist.*

The proof is given in Section (6) of the Technical Appendix. When deriving the loss function of each country, the linear terms $\widehat{C}_t - \widehat{L}_t$ are replaced by not only the price dispersion terms $\widehat{\Delta}_t$ but also the terms of trade $-\widehat{q}_t$ which is absent in the closed economy. Thus, each central bank in an open economy has an incentive to strategically manipulate the terms of trade in its favour. This represents the term of trade externality as analyzed in Corsetti and Pesenti (2001), Benigno (2002) and Benigno and Benigno (2006). In our framework with fiscal instruments, we have the expression of $\widehat{C}_t - \widehat{L}_t$ in the following way:

$$\begin{aligned}\widehat{L}_t - \widehat{C}_t &= \frac{v(2-v)}{8}(\widehat{d}_t + \widehat{t}^*_{c,t})^2 + \frac{\lambda(1+\alpha)}{4\delta}\left[\frac{v}{2}\pi^2_{hh,t} + \frac{(2-v)}{2}\pi^2_{fh,t}\right] \\ &-\frac{(2-v)}{4}\left(\widehat{t}_{c,t} - \widehat{s}^*_{e,t}\right)^2 + \frac{(2-v)}{4}\left(\widehat{t}^*_{c,t} - \widehat{s}_{e,t}\right)^2 + \frac{(2-v)}{2}\left((\widehat{t}_{c,t} - \widehat{s}^*_{e,t}) - (\widehat{t}^*_{c,t} - \widehat{s}_{e,t})\right) \\ &+\frac{(2-v)}{4}\left((\widehat{Y}^*_t - \theta^*_t) - \frac{v}{2}(\widehat{d}^*_t + \widehat{t}_{c,t})\right)^2 - \frac{(2-v)}{4}\left((\widehat{Y}_t - \theta_t) - \frac{v}{2}(\widehat{d}_t + \widehat{t}^*_{c,t})\right)^2\end{aligned} \tag{5.41}$$

Therefore, the linear terms $(\widehat{t}_{c,t} - \widehat{s}^*_{e,t})$ and $(\widehat{t}^*_{c,t} - \widehat{s}_{e,t})$ are part of term of trade externality. Each country has the incentive to manipulate this term and increase domestic households' welfare. From the home loss function P(2), we see that at the initial point where $(\widehat{t}^*_{c,t} - \widehat{s}_{e,t}) = 0$, the home country would have an incentive to increase $E(\widehat{t}^*_{c,t} - \widehat{s}_{e,t})$, which would reduce its expected loss, since this would

raise its expected terms of trade. This is reflected in the first order condition under noncooperative behaviour when the government chooses the optimal subsidy $\widehat{s}_{e,t}$.

$$-\frac{(2-v)}{2}\left(\widehat{t}^{*}_{c,t}-\widehat{s}_{e,t}\right)+\frac{(2-v)}{2}=0 \tag{5.42}$$

So the home government would wish to have $E(\widehat{t}^{*}_{c,t}-\widehat{s}_{e,t})>0$. But from (**??**), at $\widehat{Y}^{*}_{t}-\theta^{*}_{t}=0$ and $\widehat{d}^{*}_{t}+\widehat{t}_{c,t}=0$, this would imply that $\pi_{fh,t}$ cannot converge to zero, even in the absence of productivity shocks. In fact, as shown in the technical appendix, any solution to the non-cooperative game must have $\pi_{fh,t}$ diverging to infinity. Therefore, there is no equilibrium with finite inflation rates. As a result there is a fundamental inconsistency between the policymakers goal of inflation control and the desire to exploit its terms of trade advantage in the non-cooperative game where each policymaker has responsibility for both monetary policy and fiscal instruments.

5.4 Implementability in a Three-player Nash Game

Is there any restriction that could help to regain the Nash equilibrium? Obviously, from the analysis above, one natural restriction would be $\widehat{s}_{e,t}=\widehat{t}^{*}_{c,t}$ and $\widehat{s}^{*}_{e,t}=\widehat{t}_{c,t}$. By artificially imposing a restriction on tax policy such that the home import tax exactly equals the export subsidy for foreign exporters, the terms of trade externality due to international tax competition externality can be avoided. After this restriction is imposed, there will be a solution to the restricted Nash game and it replicates the flexible price equilibrium.

Proposition 4 *With the restriction that* $\widehat{t}^{*}_{c,t}=\widehat{s}_{e,t}$ *and* $\widehat{t}_{c,t}=\widehat{s}^{*}_{e,t}$, *the non-cooperative equilibrium exists. It also replicates the flexible equilibrium. That is, the solutions to the restricted Nash game are the same as those in the cooperative game.*

Proofs are given in Section (6) of the Technical Appendix. Thus, we conclude that even under the non-cooperative game, the international tax policy combined

with the import tax and export subsidy can be used to replicate the flexible price equilibrium and improve global welfare.

How can this condition be rationalized? We now define a mixed environment where there is coordination in fiscal policy but non-cooperative monetary policy.

To achieve this goal, we distinguish between fiscal authorities and monetary authorities. Instead of assuming that the monetary authorities choose the level of tax or subsidies, we assume that they take the tax and subsidies policy rules as given, but choose inflation and output gaps independently (non-cooperatively). Meanwhile, the fiscal authorities choose the optimal responses of tax and subsidies. But to avoid the terms of trade externality in the choice of fiscal instruments, fiscal policies must be chosen cooperatively. Hence, we define a 3 player Nash game, where there are two monetary authorities and a global fiscal alliance.

The objective functions and constraints of the home and foreign monetary authorities are identical to the problem characterized by P(2), the only difference is that $\left\{\widehat{t}_{c,t}, \widehat{s}_{e,t}\right\}$ and $\left\{\widehat{t}^{*}_{c,t}, \widehat{s}^{*}_{e,t}\right\}$ are not their choice variables. The objective function of global fiscal authorities, as well as the constraint, is identical to the problem characterized by P(1) but they can only choose the tax and subsidies instruments.

Proposition 5 *The solution to the 3 player Nash game is the same as those in the cooperative game. In other words, effective fiscal policy coordination in tax policies among governments is necessary for non-cooperative (or self-oriented) monetary policy to sustain an efficient outcome.*

Proofs are given the Technical Appendix. Intuitively, fiscal authorities can use the import tax to correct the welfare costs due to currency misalignment and ensure that this import tax will not affect the inflation rate, by using export subsidies. The governments can implement this fiscal scheme without coordinating with the monetary authorities. In effect, coordination between fiscal authorities is more desirable than coordination between monetary authorities, from the perspective of correcting

currency misalignment.[19]

Clarida, Gali and Gertler (2002) show that when $\rho = 1$, there is no gain from policy coordination under PCP framework. In our model, once the deviation of the law of one price due to LCP is corrected by the international tax coordination there is no extra gain from monetary policy coordination. This implication differs from Fujiwara and Wang (2017), where they find that there is some policy coordination gain from monetary policy coordination under LCP. This is because, in our model, once the currency misalignment is corrected, the optimal monetary policy can again target producer price stability, as in the case of PCP. Therefore, the optimal monetary and fiscal policy mix delivers the same results under both the cooperative game and non-cooperative game, which is the flexible price equilibrium under PCP. In our model, the key policy coordination gain is from the fiscal policy coordination. We discuss this in Section 7, where we define the welfare gain as the difference between welfare under the LCP case without fiscal policy and the flexible price equilibrium.

5.4.1 $\rho > 1$ case

We also check if the results discussed above hold when $\rho > 1$. Section (8) and (9) of the Technical Appendix give the loss function and constraints faced by players for the restricted Nash game and for the three-player Nash game. We show that both Nash games deliver exactly the same solution as that in the cooperative game. The proof is given in the Technical Appendix. This implies that for a more general setup, we can still show that the combination of monetary policy and state-contingent taxes and subsidies can be used to eliminate the inefficiency caused by LCP and replicate the flexible price equilibrium.

[19]We note again that fiscal policy to deal with the welfare loss due to local currency pricing is also proposed by Adao, Correia, and Teles (2009). The key difference here however it that optimal tax policy is derived from three-player Nash game among coordinated fiscal alliance, home and foreign money authorities.

In summary, we show that even under the non-cooperative Nash game, a state-contingent tax policy combination of import tax (subsidy) and export subsidy (tax) can fully correct the currency misalignment due to LCP. But critically, this requires coordination in fiscal policy. The independent determination of taxes and subsidies, while allowing policymakers to eliminate currency misalignment, opens up a new strategic channel through the terms of trade externality which, as we have shown, is inconsistent with the desire to eliminate output gaps and achieve zero inflation.

6 Discussion of Other Tax Instruments

In this subsection, we introduce some other tax instruments discussed in the literature. In particular, we allow for a labor income tax and a consumption tax on both home and foreign goods. The model specification is similar to the benchmark dynamic model, so we only list a few key equations which change when these additional tax instruments are considered. [20]

The amended household budget constraint now becomes:

$$\begin{aligned} & (1+t_{h,t})P_{hht}C_{h,t} + (1+t_{f,t})P_{fht}C_{f,t} + M_{t+1} + B_{ht+1} + \sum_{\zeta^{t+1}\in Z_{t+1}} B(\zeta^{t+1}|\zeta^t)D(\zeta^{t+1}) \\ = \; & (1-\tau_t)W_tL_t + R_{t-1}B_{ht} + \Pi_t + M_t + T_t + D(\zeta^t) \end{aligned} \tag{6.43}$$

where $t_{h,t}$ and $t_{f,t}$ are the import tax on home and foreign goods, respectively; and τ_t is the labor income tax. The labor supply curve becomes:

$$(1-\tau_t)W_t\frac{C_t^{-\rho}}{P_t} = \eta \tag{6.44}$$

[20] The instruments here are the same as those used in used in Adao, Correia, and Teles (2009), although some key features of the market structure differ. They show that a labor income tax and consumption taxes on both home goods and foreign goods can be used to replicate the flexible price equilibrium. And given these taxes, they find that the exchange rate regime and the currency of pricing is irrelevant. But since we assume complete risk sharing, our setting differs from theirs in terms of asset market completeness.

Demand for home and foreign goods are now given by:

$$C_{h,t} = \frac{v}{2}\frac{P_t C_t}{P_{hht}(1+t_{h,t})} \tag{6.45}$$

$$C_{f,t} = (1-\frac{v}{2})\frac{P_t C_t}{P_{fht}(1+t_{f,t})} \tag{6.46}$$

Note that firms' pricing equations are now the same as those in the standard literature since export subsidies are no longer considered.

Finally, the home market clearing condition is

$$Y_t = \frac{v}{2}\frac{P_t C_t}{P_{hht}(1+t_{h,t})}\Delta_{hh,t} + (1-\frac{v}{2})\frac{P_t^* C_t^*}{P_{hft}^*(1+t_{h,t}^*)}\Delta_{hf,t}^* \tag{6.47}$$

The foreign counterparts are defined analogously. We then check if these instruments can replicate the flexible price equilibrium. For simplicity and the purpose of comparison, we focus on the case where $\rho = 1$. We first look at the cooperative game. As shown in the Technical Appendix Section (10), the solution to the cooperative game is as follows:

$$\pi_{hh,t} = \pi_{hf,t}^* = \pi_{ff,t}^* = \pi_{fh,t} = 0$$
$$\widehat{Y}_t - \theta_t = 0; \widehat{Y}_t^* - \theta_t^* = 0$$
$$\widehat{t}_{h,t} = \widehat{t}_{h,t}^* = -\widehat{\tau}_t$$
$$\widehat{t}_{f,t} = \widehat{t}_{f,t}^* = -\widehat{\tau}_t^*$$
$$\widehat{d}_t^* = \widehat{d}_t = \widehat{S}_t = 0$$

This solution indeed establishes that the flexible price equilibrium can be achieved using these instruments under a cooperative game. This is consistent with Adao, Correa and Teles (2009), although we have a different international financial market structure in our model. However, two things should be noted. First, the level of the home and foreign labor income tax is indeterminate. The need to eliminate currency misalignment requires for instance that $d_t + \widehat{t}_{h,t}^* - \widehat{t}_{h,t} = 0$ and $\widehat{t}_{h,t} + \widehat{\tau}_t = 0$, but we cannot uniquely pin down the individual tax rates. Both home and foreign consumers are subject to the same tax responses on home goods, and similarly for the

tax responses on foreign goods. The labor income tax is used to offset the supply effects of the tax rates, similar to the role of the export subsidy in our previous model. But what matters in terms of adjusting relative demand efficiently is the difference between the tax on home goods and that on foreign goods, not the individual tax rates.

Second, the exchange rate has to be fixed. Once the responses of taxes on home and foreign goods have been put in place, nominal prices do not move, and since the taxes respond identically for both home and foreign consumers, any movement in the exchange rate would in fact generate a deviation from the law of one price. To eliminate this, we require the exchange rate to be fixed.

We then explore if the flexible price equilibrium can be supported in the non-cooperative Nash game. As discussed in Section 10.1 of the Technical Appendix, it cannot. In fact, there does not exist a solution to the Nash equilibrium. The derivation of the non-existence condition is very similar to that in our main benchmark model. Like in the benchmark model with import tax and export subsidy, in the home and foreign loss function there exist linear terms of labor income taxes and consumption taxes. Intuitively, individual authorities would wish to have a non-zero expected labor tax to manipulate terms of trade, which leads to no finite equilibrium level of inflation and non-existence of Nash equilibrium. Hence, as in our main model, these instruments cannot be used to replicate the flexible price equilibrium in a non-cooperative fiscal policy game. Some further restrictions or international coordination would be needed.

7 Quantitative Welfare Gain

In this section, we give a quantitative evaluation of the gains to employing state contingent fiscal policies to correct currency misalignment. We can define the welfare gain as the welfare achieved under the fully efficient allocation (which can be supported under the 3 player Nash game), relative to the welfare under a non-

cooperative monetary policy equilibrium, without the use of fiscal policies. This latter equilibrium is that analyzed by Fujiwara and Wang (2017).

As shown above, when optimal, state-contingent fiscal policies are used, the economy can achieve the fully efficient allocations. Hence, from one perspective, the welfare loss of currency misalignment in Engel (2011), which cannot be eliminated by the optimal monetary policy (CPI targeting in his paper), can be taken as the welfare improvement of our policy mix, relative to the optimal cooperative monetary policy derived in Engel (2011). To obtain a quantitative welfare improvement, we conduct a simple exercise to compare the welfare gain (in terms of steady state consumption) under the cooperative monetary policy and that in the flexible price equilibrium. All parameters are documented in Table 2 and identical to that in Engel (2011). The welfare loss under the efficient, flexible price equilibrium is -0.0168% while the loss under optimal cooperative monetary policy in our model is -0.0442%. The difference is due to the presence of currency misalignment, which implies that even under the cooperative game the households have to give up 0.0274% of their steady state consumption compared with the welfare under the flexible price allocation.[21] Moreover, if we compare our result with that in Fujiwara and Wang (2017), the non-cooperative monetary game under LCP, the welfare gain from fiscal policy, or more specifically fiscal coordination, is actually even higher, equal to around 0.0468% of consumer's steady state consumption.

Figure 1 and Figure 2 illustrate the relative welfare gains of optimal taxes and subsidies to correct misalignment under LCP, using the welfare loss under flexible price equilibrium (-0.0168%) as the benchmark. Figure 1 indicates that the welfare gains by correcting the "currency misalignment" are larger when the frequency to change price is lower. Figure 2 documents that the welfare gains relative to cooperative monetary policy are largest when there is no home bias ($v = 1$). As shown

[21] When calculating the optimal monetary policy under both cooperative and non-cooperative monetary policy, we limit our policy instrument to the PPI inflation and the output gap in home and foreign countries.

Table 1: Parameter values (Baseline)

Parameter	Description	Value
β	discount factor	0.99
η	preference weight on labor	2
ρ	inverse of elasticity of intertemporal substitution	2
κ	degree of price stickiness	0.75
λ	elasticity of substitution across individual goods	11
v	home country size and weight on home produced	1.5
ρ_θ	persistence of productivity shock	0.95
σ	productivity shock size	0.01

in the cooperative game, the welfare loss due to currency misalignment is simply given by $\frac{v(2-v)}{8}[(\widehat{d}_t)^2 + (\widehat{d}_t^*)^2]$. Therefore, when $v = 1$, the welfare loss reaches the maximum. Also, from this equation, when the economy is closed (at $v = 0$ or $v = 2$), and only consumes one good, the welfare loss is zero, since there is no distortion from "currency misalignment".

The relationship between home bias and the welfare gain relative to the non-cooperative monetary policy[22] contrasts with that for the cooperative monetary policy case and is non-monotonic in the parameter v.

8 Conclusion

This paper shows that international tax policy can be used to correct the inefficiency problem due to nominal rigidities and local currency pricing in the open economy.

[22]It should be noted that for some values of ν, the non-cooperative monetary game with PPI inflation and output gap cannot be evaluated as the solution exhibits indeterminacy. Here we only report results for those values of ν under which the solution to the non-cooperative monetary game is unique.

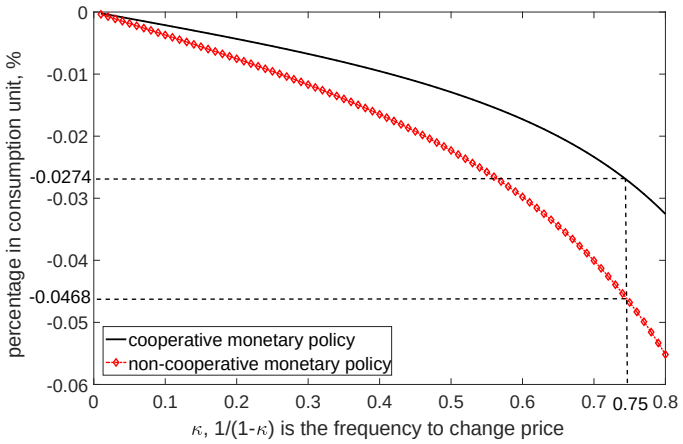

Figure 1: Welfare Gain from Fiscal Policy Coordination as Functions of κ

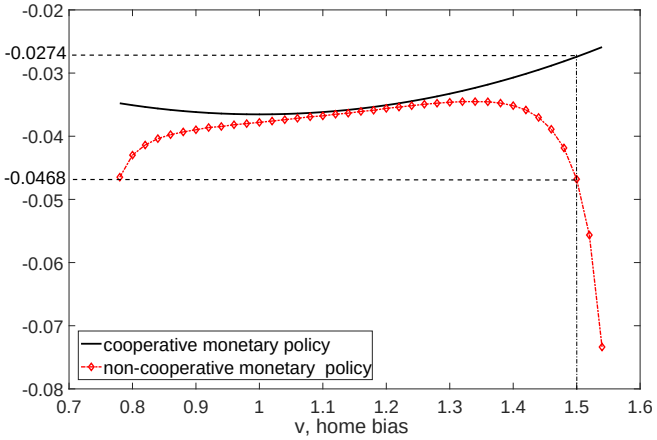

Figure 2: Welfare Gain from Fiscal Policy Coordination as Functions of v

We find that a state-contingent tax policy combination of import tax (subsidy) and export subsidy (tax) can fully eliminate the problem of currency misalignment (deviations from the law of one price), and combined with a monetary policy that leads the exchange rate to respond to productivity shocks, achieves the flexible price allocation. But this monetary fiscal mix cannot be decentralized in an environment of

fully 'self-reliant' monetary and fiscal policy. The reason is that the non-cooperative use of taxes and subsidies to offset the inefficiencies of currency misalignment opens up a strategic inefficiency in a non-cooperative setting which leads to a fundamental conflict between the goals of output gap and inflation stabilization and terms of trade manipulation. The implementation of an efficient monetary-fiscal mix requires effective coordination in fiscal policy, while leaving monetary policy to be determined non-cooperatively.

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