Optimal monetary policy cooperation with a global shock and dollar standard

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Abstract

Contrary to the consensus in the literature, we demonstrate that there exist the welfare gains from monetary policy cooperation when the world is hit by a global shock. We reach our conclusion in a two-country New Keynesian model with a global oil price shock and dollar standard. When exporters in both countries and oil producer which is modeled as a third party such as OPEC price goods in the home currency, the U.S. dollar, the status of home and foreign monetary policy is asymmetric. Specifically, home monetary policy can influence the welfare levels of the households in the world while foreign monetary policy can only affect the welfare level of the domestic household. By internalizing the negative externality of home monetary policy to foreign country, world planner can achieve the welfare gains from monetary policy cooperation. In addition, unlike what is found in the literature, we show that not all countries are willing to take part in monetary policy cooperation, unless the world planner transfers part of the welfare gains from the country which benefits from the monetary policy cooperation to the one which loses.

Key words: A global shock, Dollar standard, Monetary policy cooperation, Welfare gains

JEL classification: E5, F3, F4

1. Introduction

Whether there exist the gains from monetary policy cooperation has been one of the central questions in international monetary economics. Especially, in recent years, the concern about the spillovers from monetary policy has been increasing among policymakers, but there is a gap between the recent policy discussion and the academic research. The academic researchers are supposed to contribute more productively to the policy debate on this important topic. [1]

In the literature on monetary policy cooperation, Obstfeld and Rogoff (2002) conclude that there are no welfare gains from monetary policy cooperation, when the shocks are global. The

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[1] See Engel (2016) for an important survey of the literature on international monetary policy cooperation.

conclusion holds for any strictly positive value of the coefficient of relative risk aversion.[2] Corsetti and Pesenti (2005) further confirm Obstfeld and Rogoff $(2002)'s$ conclusion. They find that there are no welfare gains from monetary policy cooperation in three cases: (1) all shocks being global; (2) producer-currency pricing (PCP); (3) local-currency pricing (LCP). [3] In addition, Corsetti and Pesenti (2005) conclude that, except for the extreme cases in which the exchange rate pass-through elasticities in home and foreign countries are equal to zero or unity simultaneously (LCP or PCP), there exist the welfare gains from monetary policy cooperation. However, whether these gains are sizable, they leave it as an open issue. Thus, the existing literature has reached a consensus that, when a global shock hits the world, there are no welfare gains from monetary policy cooperation.

In this paper, we revisit this topic and demonstrate that, when the world is hit by a global shock, in general, there exist the welfare gains from monetary policy cooperation. In addition, we aim to answer the open issue left by Corsetti and Pesenti (2005) by describing the welfare gains from monetary policy cooperation, when the exchange rate pass-through elasticity is zero in the home country but unity in the foreign country.

We follow the new directions initiated by Obstfeld and Rogoff (2000, 2002), and Devereux and Engel (2003) to examine optimal monetary policy cooperation in a two-country New Keynesian model with one-period nominal stickiness. To capture a global shock, we assume the existence of a third party, except for home and foreign countries, such as OPEC, which exports oil to both countries, and the oil price is a common exogenous shock to both countries. Obstfeld and Rogoff (2000, 2002) assume that the exporters in both countries set prices in the currency of the producer (PCP). As a comparison, except for PCP, Devereux and Engel (2003) also allow for the LCP case in which exporters set prices in the currency of the consumer. However, the empirical evidence shows that the U.S. dollar plays a dominant role in the invoicing of U.S. exports and imports.[4] It implies that the U.S. exporters set prices in the currency of the producer (PCP), and its trading parters set prices in the currency of the consumer (LCP). Following the empirical evidence and Devereux et al. (2007, 2010), Wang and Zou (2015), and Casas et al (2016), we analyze optimal monetary policy cooperation between the U.S. (the home country) and the rest of the world (the foreign country). Thus, in our model, the U.S. dollar plays the role of a global currency, all exporters (including OPEC) set prices in it. In both PCP and LCP cases, the degree of exchange rate pass-through is the same for both countries. [5]When a global currency exists, the exchange rate pass-through is asymmetric. For the U.S., the exchange rate pass-through is zero; for its trading partners, the exchange rate pass-through is complete.

The asymmetry of the exchange rate pass-through can change the design of monetary policy greatly. Prior to the occurrence of the oil price shock, monetary policymakers announce policy rules to the public and can commit themselves to the announced policy rules. In the Nash case, if a positive oil price shock occurs, home monetary policymaker needs to stabilize the marginal costs of the consumption goods purchased by domestic households to lower their preset prices. By this

[2]Proposition 2 in Obstfeld and Rogoff (2002) states that, when the shocks are global, for any strictly positive value of the coefficient of relative risk aversion, the Nash monetary policy is identical to the cooperative one. In addition, both Nash and cooperative monetary policies can replicate the flexible-wage allocations. Thus, it means that, when a global shock hits the world, there are no welfare gains from monetary policy cooperation.

[3]See subsection 4.1 of Corsetti and Pesenti (2005).

[4]See Goldberg and Tille (2008, 2009).

[5]In PCP case, the law of one price holds for tradable goods and the exchange rate pass-through is complete. The movement in the nominal exchange rate causes the expenditure-switching effect. In LCP case, the exchange rate pass-through is 0 percent. Thus, the expenditure-switching effect of the nominal exchange rate disappears.

way, home monetary policymaker increases home households' purchasing power, thus the welfare level. The marginal cost of home producers depends on the domestic nominal wage level and the oil price. By flexibly adjusting the nominal wage, home monetary policy can stabilize the marginal cost of home producers when a positive oil price shock occurs. Why can home monetary policy stabilize the marginal cost of imported consumption goods. Remember that the foreign exporters set price in the U.S. dollar which is a fixed mark-up over the expected marginal cost expressed in the U.S. dollar. Normally, foreign exporters' marginal cost expressed in the U.S. dollar depends on the wage level in the foreign country, the oil price, and the nominal exchange rate. The nominal exchange rate plays a dual role in converting foreign exporters' marginal cost in terms of domestic currency into the U.S. dollar. For one thing, it affects the oil price facing foreign exporters; and for another, it affects the U.S. dollar value of the marginal cost of foreign producers. The combination of two effects of the nominal exchange rate results in foreign exporters' marginal cost in terms of the U.S. dollar being determined by the U.S. dollar price of the oil and foreign nominal wage expressed in terms of the U.S. dollar. Since home and foreign households can use the complete financial market to achieve risk sharing, the nominal wage levels in both countries are identical when they are converted to the same currency. Thus, when the U.S. dollar acts as a global currency, it is the U.S. monetary policymaker, not the foreign monetary policymaker, can influence foreign exporters' marginal cost expressed in the U.S. dollar. After a positive oil price shock occurs, home monetary policymaker decreases money supply to stabilize the marginal cost of home producers and that of foreign exporters to increase home households' purchasing power, thus their welfare level.

The situation is different in the foreign country. When a positive oil price shock occurs, a decrease in home money supply can stabilize the marginal cost of home exporters since they preset price in the U.S. dollar. However, a decrease in home money supply will lead to an appreciation of home currency which increases the price of imported oil facing foreign producers supplying consumption goods domestically, thus destabilize their marginal cost. It is certain that foreign monetary policy can influence the marginal cost of domestic producers which supply consumption goods domestically, but the influence depends on home monetary policy. In the Nash case, home monetary policymaker reduces money supply to maximize home households' welfare level without taking its adverse effect on the foreign country into account. The only thing that the foreign monetary policymaker can do is to reduce money supply as well to lower domestic nominal wage level and, to some degree, appreciate its own currency to lower the price of imported oil as far as it can.

Thus, in our model, the effects of monetary policies are asymmetric. Due to the dominant status of home currency, home monetary policy can influence the welfare levels of households in both countries. As a comparison, foreign monetary policy can only influence the welfare level of domestic households. In the cooperative case, a world planner, aiming to maximize a weighted average of home and foreign households' welfare levels, will internalize the negative externality produced by home monetary policy to the foreign country.

After a positive oil price shock occurs, the world planner faces a trade-off. To stabilize the marginal cost of home producers and that of foreign exporters, the world planner needs to reduce home money supply. However, the tightness of home money supply will destabilize the marginal cost of foreign producers which supply consumption goods domestically. Clearly, the magnitude of the negative externality produced by home monetary policy to foreign country is governed by the expenditure share of foreign producers on oil. When the expenditure share of foreign producers on oil is strictly greater than its home counterpart, the degree of the tightness of home money supply in the cooperative case is lower than that in the Nash case. Thus, in general, the Nash solution is not identical to the cooperative solution and the welfare gains from monetary policy cooperation emerge. [6]

Corsetti and Pesenti (2005) point out that, except for the PCP and LCP cases, a country can in general do better than simply 'keeping its own house in order' by engaging in binding international agreements. It implies that a country can benefit from, and thus is willing to taking part in, monetary policy cooperation. However, they do not prove the conclusion. In this paper, we show that not all countries are willing to take part in monetary policy cooperation, even if there exist the welfare gains from monetary policy cooperation. To arrive at a clear answer, we consider a special case in which the expenditure shares of home and foreign households on nonenergy consumption goods are identical, the degrees of home-bias in consumption choices between home and foreign households are the same, and the expenditure shares of home and foreign firms on oil are not identical. In this case, we show that, due to the dominant status of home currency, home country is willing to take part in monetary policy cooperation. On the contrary, due to the subordinate status of foreign currency, foreign country is unwilling to take part in. But if the world planner can transfer part of the welfare gains from the home to foreign households, both countries can benefit from taking part in the monetary cooperation.

This paper is related to a large literature on optimal monetary policy in open economies based on the New Keynesian framework. The literature is classified into two strands by the duration of the nominal stickiness. The first assumes that nominal rigidities last for one period; the second adopts Calvo-type staggered price-setting. A partial list of the first strand of the literature includes Obstfeld and Rogoff (2000, 2002), Benigno (2002), Devereux and Engel (2003, 2007), Benigno and Benigno (2003), Corsetti and Pesenti (2005), Canzoneri et al. (2005), Sutherland (2006), Duarte and Obstfeld (2008), Devereux et al. (2007, 2010), Wang and Zou (2013, 2015), Gong et al. (2017). A partial list of the second strand of the literature includes Clarida et al. (2002), Pappa (2004), Benigno (2004, 2009), Gali and Monacelli (2005, 2008, 2016), Benigno and Benigno (2006), Liu and Pappa (2008), Devereux and Sutherland (2008), Paoli (2009*a*, 2009*b*), Engel (2011), Rabitsch (2012), Bhattarai et al. (2015), Gong et al. (2016), Fujiwara and Wang (2017).[7] Except for Obstfeld and Rogoff (2002), and Corsetti and Pesenti (2005), the above-mentioned authors do not study the question of whether there exist the welfare gains from monetary policy cooperation when the world is hit by a global shock. By introducing a global oil price shock and dollar standard, we overthrow the conclusion reached by Obstfeld and Rogoff (2002), and Corsetti and Pesenti (2005) and demonstrate that, in general, there exist the welfare gains from monetary policy cooperation. In addition, we calculate the size of the welfare gains from monetary policy cooperation, thus, we provide an answer to the open issue left by Corsetti and Pesenti (2005).

The rest of the paper is organized as follows. Section 2 lays out the model. Section 3 discusses optimal monetary policy in the Nash and cooperative cases, and derives the welfare gains from monetary policy cooperation. Section 4 concludes.

2. The model

The world consists of two equally sized countries: the home country H and the foreign country F, each of which is inhabited by a continuum of households of unit mass $[0, 1]$. In each country,

[6] Except for the special case in which the expenditure share of foreign producers on oil is equal to its home counterpart.

[7] For a comprehensive survey of optimal monetary policy in open economies, see Corsetti et al. (2011).

there is a continuum of monopolistic firms of measure one. A home representative firm indexed by $j \in [0, 1]$ employs domestic labor and imported oil to produce product j, which is then consumed by both home and foreign households. The foreign country's production and trade structure is similar. To capture a global shock, we model the oil inputs as imported from a third party such as OPEC, thus both home and foreign firms take the oil price as exogenous.[8]

Following Devereux et al. (2007, 2010), Wang and Zou (2015), and Casas et al. (2016), we model the home country as the U.S., whose currency is used globally: households in both countries trade in a complete set of state-contingent bonds denominated in the home currency; both home and foreign exporters price their goods in the home currency; oil is also priced in the home currency.

To simplify the analysis, we only consider a single-period model with oil price shock.[9] The single period is divided into two sub-periods by the oil price shock. To be clear, we describe the timing of the model. In the first sub-period, households in both countries trade in the complete asset market to achieve risk sharing; firms in both countries set prices which are sticky throughout the whole period; then monetary policymakers announce policy rules to the public. After the realization of the oil price shock, households choose optimal labor supply and consumption; firms input labor and imported oil to produce goods; and the exchange rate is determined. Throughout the period, we assume that monetary policymakers can commit to the announced monetary policy rules.

In the following, asterisks denote foreign variables.

2.1. Households

The home representative household maximizes the following expected utility function

$$U = \mathbf{E}\left[\ln C + \chi \ln \frac{M}{P} - \eta L\right] \tag{1}$$

in which C is home real consumption index, $\frac{M}{P}$ are real money balances, L is the labor supply, and χ and η are positive parameters. Following Bodenstein et al. (2008), the real consumption index C is composed of nonenergy consumption C_T and energy O_{Hh}, according to a Cobb-Douglas function:

$$C = \frac{C_T^n O_{Hh}^{1-n}}{n^n (1-n)^{1-n}}, \tag{2}$$

where the parameter n is the expenditure share on nonenergy consumption. Foreign real consumption index has a similar form but the expenditure share of a foreign representative household on nonenergy consumption is n^*.

The nonenergy consumption index C_T is an Armington aggregate of home and foreign consumption subindexes,

$$C_T = \frac{C_H^\gamma C_F^{1-\gamma}}{\gamma^\gamma (1-\gamma)^{1-\gamma}} \tag{3}$$

in which γ is the expenditure share of a home representative household on home consumption. Foreign nonenergy consumption index has a similar form but the expenditure share of a foreign

[8] We use oil and energy interchangeably in the following.

[9] The conclusions in the current model still hold in an infinite horizon model. The main reason, given by Devereux et al. (2007, 2010), is that there is a complete asset market.

representative household on home consumption C_H^* is γ^*. Thus, unlike Engel (2011) and Gong et al. (2016) , we assume that the degrees of home-bias in consumption choices between home and foreign households are different. Consumption subindexes C_H and C_F are CES aggregates over a continuum of goods produced in each country:

$$C_H = \left[\int_0^1 C_H(j)^{\frac{\lambda-1}{\lambda}} dj\right]^{\frac{\lambda}{\lambda-1}}, C_F(h) = \left[\int_0^1 C_F(j^*)^{\frac{\lambda-1}{\lambda}} dj^*\right]^{\frac{\lambda}{\lambda-1}}, \tag{4}$$

where $\lambda > 1$ is the elasticity of substitution between varieties of nonenergy consumption goods within each country.

Solving home representative household's expenditure-minimization problem gives rise to

$$C_H(j) = \gamma n \left(\frac{P_{HH}(j)}{P_{HH}}\right)^{-\lambda} \left(\frac{P_{HH}}{P_T}\right)^{-1} \left(\frac{P_T}{P}\right)^{-1} C, \tag{5}$$

$$C_F(j^*) = (1-\gamma) n \left(\frac{P_{FH}(j^*)}{P_{FH}}\right)^{-\lambda} \left(\frac{P_{FH}}{P_T}\right)^{-1} \left(\frac{P_T}{P}\right)^{-1} C, \tag{6}$$

where $P_{HH} = \left(\int_0^1 P_{HH}(j)^{1-\lambda} dj\right)^{\frac{1}{1-\lambda}}$ and $P_{FH} = \left(\int_0^1 P_{FH}(j^*)^{1-\lambda} dj^*\right)^{\frac{1}{1-\lambda}}$ are the CES aggregates over home and foreign prices of individual varieties respectively, $P_T = P_{HH}^{\gamma} P_{FH}^{1-\gamma}$ is home nonenergy price index, and $P = P_T^n Q^{1-n}$ is home CPI. The oil price Q is priced in the home currency and follows log normal distribution

$$\ln Q = q, \ q \tilde{} N\left(0, \sigma_q^2\right) \tag{7}$$

Since home currency (the dollar) plays a dominant role in the world economy, both home and foreign exporters set prices in the home currency. Foreign nonenergy price index is $P_T^* = \left(\frac{P_{HF}}{S}\right)^{\gamma^*} P_{FF}^{*1-\gamma^*}$, where P_{HF} and P_{FF}^* are the CES aggregates over the prices charged by home and foreign firms which sell products in foreign markets respectively, and S is the nominal exchange rate representing the home currency price of one unit of foreign currency. Foreign CPI price index is $P^* = P_T^{*n^*} \left(\frac{Q}{S}\right)^{1-n^*}$.

The home representative household maximizes the expected utility function subject to the following budget constraint

$$P(z) C(z) + M(z) + \sum_{z' \in Z} q\left(z'\right) B\left(z'\right) = W(z) L(z) + \Pi(z) + B(z) + M_0 + T(z),$$

where $z \in Z$ is a particular natural state, and Z is the set of all states. $B\left(z'\right)$ is the amount of bond held by the home household which entitles her to receive B units of home currency when state z' occurs, and $q\left(z'\right)$ is the home currency price of the state-contingent bond, $W(z) L(z)$ is nominal wage income, $\Pi(z)$ represents profits from the ownership of home firms which distribute their profits among domestic households equally, $T(z)$ is a lump-sum transfer from home government, M_0 is initial holdings of nominal money balances. Home government rebates it's seigniorage revenue to home households equally in the form of a lump sum transfer, thus $M(z) - M_0 = T(z)$.

The first-order condition for labor supply is given by

$$W = \eta PC. \tag{8}$$

Equation (8) implies that the marginal rate of substitution between leisure and consumption is equal to real wage.

Home household's money demand equation is described by

$$M = \chi PC. \tag{9}$$

Equation (9) implies that the marginal utility obtained by acquiring an additional unit of money is equal to the marginal cost which is measured by forgone current consumption.

The trade in the state-contingent bond between home and foreign households leads to the following risk-sharing condition

$$\Gamma PC = SP^* C^*, \tag{10}$$

in which Γ is the ratio of home and foreign households' Lagrange multipliers which is determined by an equilibrium condition in time-0 market for state-contingent bond. In the Appendix of Devereux and Engel (2003) , they show that, when utility function of consumption is logarithmic, $\Gamma = 1$. Equation (10) implies that home household's marginal utility form holding one unit of nominal state-contingent bond is equal to her foreign counterpart in all states of the world.

2.2. Oil market

We model the oil sector as a third party such as OPEC in the spirit of Devereux et al. (2010) , OPEC is endowed with an exogenous oil supply and takes the U.S. dollar as the standard to price oil. [10] Households in both countries import oil from OPEC to satisfy their consumption needs, and firms in both countries import oil from OPEC as production input. Both households and firms in the world take the dollar price of oil as exogenous. The oil price, given in equation (7) , follows log normal distribution.

2.3. Firms

A home representative firm $j \in [0, 1]$ inputs domestic labor and imported oil to produce product j, according to the following production function

$$Y(j) = \frac{L(j)^{\varepsilon} O_{Hf}(j)^{1-\varepsilon}}{\varepsilon^{\varepsilon}(1-\varepsilon)^{1-\varepsilon}}, \tag{11}$$

in which ε is the expenditure share of the firm $j \in [0, 1]$ on home labor input. Foreign production function has a similar form but the expenditure share on domestic labor input is ε^*.

Solving firm $j's$ cost-minimization problem, we can obtain its marginal cost function

$$MC = W^{\varepsilon} Q^{1-\varepsilon}. \tag{12}$$

Equation $(12)'\,s$ foreign counterpart is

[10] In the literature, it is standard practice to model oil supply as exogenous. Among many others, see Bodenstein et al. (2011, 2012, 2013) , and Gavin et al. (2015) .

Table 1: Optimal prices

$P_{HH} = \widehat{\lambda}\mathbf{E}\,(MC)$	$P_{HF} = \widehat{\lambda}\mathbf{E}\,(MC)$
$P_{FH} = \widehat{\lambda}\mathbf{E}\,(SMC^{*})$	$P_{FF}^{*} = \widehat{\lambda}\mathbf{E}\,(MC^{*})$

$$MC^{*} = (W^{*})^{\varepsilon^{*}} \left(\frac{Q}{S}\right)^{1-\varepsilon^{*}}. \tag{13}$$

Due to the fact that OPEC prices oil in the home currency, oil price affects home and foreign marginal costs asymmetrically. For home firms, oil can be taken as a domestic production input with an exogenous price. As a comparison, for foreign firms, both exogenous oil price and the nominal exchange rate affect its marginal cost. Specifically, the depreciation of foreign currency will increase foreign firms' oil cost.

Following Obstfeld and Rogoff (2000, 2002), Devereux and Engel (2003), all firms set prices before the realization of the oil price shock, and price rigidities last for the whole period. [11] Solving profit-maximizing problems facing home and foreign firms, we can derive their optimal pricing rules, which are given in Table 1.

In Table 1, $\widehat{\lambda} \equiv \frac{\lambda}{\lambda-1}$ is the mark-up arising from firms' monopolistic power. Since the home currency is used by both home and foreign exporters to price goods, all firms in the home country preset nominal prices in the currency of the producer (PCP), all firms in the foreign country choose nominal prices in consumers' currency (LCP). In PCP case, a home firm charges domestic and foreign households a single price, in the U.S. dollar, which is a fixed mark-up over its expected marginal cost. As a comparison, in LCP case, a foreign firm charges its own country's households one price, in domestic currency, which is also a fixed mark-up over its expected marginal cost. Simultaneously, the firm charges U.S. households another price, in the U.S dollar, which is a fixed mark-up over its expected marginal cost expressed in the U.S. dollar.

2.4. The flexible-price equilibrium

When prices are flexible, both home and foreign firms set prices after the oil price shock occurs. It implies that the expectation operators disappear in Table 1. Thus, the flexible-price allocation does not depend on the currency with which the exporters choose to price their goods.

Before proceeding to solve for the flexible-price equilibrium, we need market-clearing conditions to close the model. Home market-clearing condition is

$$L = \varepsilon \left(\frac{Q}{W}\right)^{1-\varepsilon} \left(\gamma n \frac{PC}{P_{HH}} + \gamma^{*} n^{*} \frac{SP^{*}C^{*}}{P_{HF}}\right) \tag{14}$$

The flexible-price equilibrium consists of 15 equations: 4 optimal prices, 2 money demand equations, 2 labor supply equations, 2 CPI price indexes, 2 nonenergy price indexes, 2 market-clearing conditions, and 1 risk sharing condition. We will determine 15 endogenous variables: $P_{HH}, P_{HF}, P_{FH}, P_{FF}^{*}, P_{T}, P_{T}^{*}, P, P^{*}, C, C^{*}, W, W^{*}, L, L^{*}, S$. All endogenous variables are functions

[11] Among many others, the assumption that nominal prices are set one period in advance is also taken in the following literature: Benigno and Benigno (2003), Corsetti and Pesenti (2005), Devereux et al. (2007, 2010), Duarte and Obstfeld (2008), Wang and Zou (2013, 2015), Gong et al. (2017).

of money supplies M and M^*, and the exogenous oil price shock Q. In the following, a variable with a tilde represents the value in the flexible-price equilibrium.

The terms of trade in the flexible-price equilibrium are given by

$$\widetilde{\tau} = \left(\frac{\chi Q}{\eta \widetilde{M}} \right)^{\varepsilon - \varepsilon^*}. \tag{15}$$

An increase in home money supply leads to a rise in home nominal wage. In the case in which $\varepsilon > \varepsilon^*$, the wage share in the home marginal cost function is greater than that in the foreign country. Thus, facing a higher nominal wage, home firms charge a higher price than their foreign counterparts. Consequently, home terms of trade improve. When $\varepsilon > \varepsilon^*$, oil share in foreign marginal cost function is greater than that in the home country. Thus, when oil price goes up exogenously, foreign firms respond to charge a higher price than their counterparts in U.S., which results in the deterioration of home terms of trade.

Home CPI price index follows from optimal prices, home and foreign first-order conditions for labor supply and money demand, and the risk-sharing condition, it can be expressed as

$$\widetilde{P} = \left(\frac{\eta}{\chi} \right)^{[\varepsilon\gamma + \varepsilon^* (1-\gamma)] n} \left(\widehat{\lambda} \right)^n Q^{(1-n) + [(1-\varepsilon)\gamma + (1-\varepsilon^*)(1-\gamma)] n} \widetilde{M}^{[\varepsilon\gamma + \varepsilon^* (1-\gamma)] n}. \tag{16}$$

Since households consume energy directly, a rise in energy price will push home CPI price index up. The direct effect of an increase in energy price on home CPI price index is measured by $1 - n$, the expenditure share of home households on energy consumption. In addition, when an positive oil price shock occurs, home and foreign firms will increase prices of nonenergy consumption goods sold in the home country, which also pushes home CPI price index up indirectly. The degrees of the indirect effect are measured by $(1 - \varepsilon)\gamma n$ and $(1 - \varepsilon^*)(1 - \gamma) n$ respectively. An increase in money supply causes a higher nominal wage in each country, which pushes home CPI price index up. The effect of the increase in home money supply on home CPI price index is measured by $\varepsilon\gamma n$. As a comparison, the effect of the increase in foreign money supply on home CPI price index is measured by $\varepsilon^* (1 - \gamma) n$.[12]

Substituting equation (16) into home money demand equation and then rearranging the resulting equation, we can obtain home consumption in the flexible-price equilibrium, which is given by

$$\widetilde{C} = \chi^{-1} \left(\frac{\chi}{\eta} \right)^{[\varepsilon\gamma + \varepsilon^* (1-\gamma)] n} \left(\widehat{\lambda} \right)^{-n} Q^{-(1-n) - [(1-\varepsilon)\gamma + (1-\varepsilon^*)(1-\gamma)] n} \widetilde{M}^{1 - [\varepsilon\gamma + \varepsilon^* (1-\gamma)] n}. \tag{17}$$

Intuitively, a rise in the energy price pushes home CPI price index up and lowers the purchasing power of the nominal wage obtained by supplying one unit of labor, thus, the aggregate consumption in the flexible-price equilibrium decreases. When home money supply rises, home nominal wage increases proportionately. As explained previously, an increase in home money supply also pushes home CPI price index up. Thus, following a rise in home money supply, the moving direction of the home households' real wage is ambiguous. When $1 > [\varepsilon\gamma + \varepsilon^* (1 - \gamma)] n$, the real wage goes up. Consequently, home aggregate consumption in the flexible-price equilibrium increases.

[12] Note that $M = SM^*$.

Substituting optimal flexible prices, home and foreign first-order conditions for labor supply, and the risk-sharing condition into home market-clearing condition, we can express home employment as

$$\widetilde{L} = \varepsilon\eta^{-1}\left(\widehat{\lambda}\right)^{-1}(\gamma n + \gamma^* n^*) \tag{18}$$

3. Optimal monetary policy rules

Before the oil price shock occurs, monetary policymakers announce policy rules to the public, we assume that they can commit themselves to the announced policy rules. Following Devereux and Engel (2003) , and Devereux et al. (2007, 2010) , monetary policy rules are log-linear functions of the oil price shock and given by

$$m = aq, m^* = bq, \tag{19}$$

in which $m = \ln M, m^* = \ln M^*$. Hereafter, we use a lower–case letter to denote logarithmic value of a variable.

3.1. The Nash case

In the Nash case, the monetary policymaker in each country maximizes the expected utility of its own country's representative household, taking its counterpart's choice as given. Following the literature,[13] we assume that χ is not too large, which implies that the derived utility from real balances is relatively small as a share of total utility. Thus we only need to solve for the expected utility from consumption and employment.

Substituting home labor supply equation (8) , the risk-sharing condition (10) , and the expressions for P_{HH} and P_{HF} into home market-clearing condition (14) , then rearranging the resulting equation and taking expectations of both sides of it, we can obtain

$$\mathbf{E}L = \varepsilon\eta^{-1}\left(\widehat{\lambda}\right)^{-1}(\gamma n + \gamma^* n^*) \tag{20}$$

From the expressions for P_{HH} and P_{FH}, home labor supply equation (8) and its foreign counterpart, the risk-sharing condition (10) , and home money demand function (9) , we can express home CPI price index as

$$P = \left(\widehat{\lambda}\right)^{n}\left(\frac{\eta}{\chi}\right)^{\varepsilon\gamma n + \varepsilon^* n(1-\gamma)}\left[\mathbf{E}\left(M^{\varepsilon}Q^{1-\varepsilon}\right)\right]^{\gamma n}\left[\mathbf{E}\left(M^{\varepsilon^*}Q^{1-\varepsilon^*}\right)\right]^{n(1-\gamma)}Q^{1-n}. \tag{21}$$

In our model, the oil shock follows log normal distribution, thus, all endogenous variables have log normal distribution as well. Taking log of both sides of equation (21) , we have

[13] See, among many others, Obstfeld and Rogoff (1995, 2000, 2002) ,Corsetti and Pesenti (2001, 2005) , Devereux and Engel (2003) , Benigno and Benigno (2003) , Devereux et al. (2007, 2010) , Duarte and Obstfeld (2008) , Wang and Zou (2013, 2015) , Gong et al. (2017) .

$$p = n \ln \left(\widehat{\lambda}\right) + \left[\varepsilon \gamma n + \varepsilon^* n \left(1-\gamma\right)\right] \ln \left(\frac{\eta}{\chi}\right) + \left(1-n\right) q +$$
$$\frac{\gamma n \left[\varepsilon a + \left(1-\varepsilon\right)\right]^2 + n\left(1-\gamma\right)\left[\varepsilon^* a + \left(1-\varepsilon^*\right)\right]^2}{2} \sigma_q^2. \tag{22}$$

Taking expectations of both sides of equation (22), we can obtain

$$\mathbf{E}p = n \ln \left(\widehat{\lambda}\right) + n\left[\varepsilon \gamma + \varepsilon^* \left(1-\gamma\right)\right] \ln \left(\frac{\eta}{\chi}\right) +$$
$$\frac{\gamma n \left[\varepsilon a + \left(1-\varepsilon\right)\right]^2 + n\left(1-\gamma\right)\left[\varepsilon^* a + \left(1-\varepsilon^*\right)\right]^2}{2} \sigma_q^2. \tag{23}$$

From home money demand function, we know that $\mathbf{E}c = -\ln \chi - \mathbf{E}p$. Thus, we can obtain home representative household's expected utility, it is given by

$$\begin{aligned} \mathbf{E}U &= \mathbf{E}c - \eta \mathbf{E}L \\ &= -\ln \chi - \varepsilon \left(\widehat{\lambda}\right)^{-1} \left(\gamma n + \gamma^* n^*\right) - n\left[\varepsilon \gamma + \varepsilon^* \left(1-\gamma\right)\right] \ln \left(\frac{\eta}{\chi}\right) - \\ & n \ln \left(\widehat{\lambda}\right) - \frac{\gamma n \left[\varepsilon a + \left(1-\varepsilon\right)\right]^2 + n\left(1-\gamma\right)\left[\varepsilon^* a + \left(1-\varepsilon^*\right)\right]^2}{2} \sigma_q^2. \end{aligned} \tag{24}$$

Note that, in the home country, when both home and foreign exporters set prices in the home currency before the oil price shock occurs and price rigidities last for the whole period, foreign monetary policy does not influence home representative household's expected utility.

Following the same steps as deriving home representative household's expected utility $\mathbf{E}U$, we can obtain its foreign counterpart $\mathbf{E}U^*$, which has the following expression

$$\begin{aligned} \mathbf{E}U^* &= \mathbf{E}c^* - \eta \mathbf{E}L^* \\ &= -\ln \chi - \varepsilon^* \left(\widehat{\lambda}\right)^{-1} \left[\left(1-\gamma\right) n + \left(1-\gamma^*\right) n^*\right] - n^* \left[\varepsilon \gamma^* + \varepsilon^* \left(1-\gamma^*\right)\right] \ln \left(\frac{\eta}{\chi}\right) - \\ & n^* \ln \left(\widehat{\lambda}\right) - \frac{\gamma^* n^* \left[\varepsilon a + \left(1-\varepsilon\right)\right]^2 + n^* \left(1-\gamma^*\right)\left[b + \left(1-\varepsilon^*\right)\left(1-a\right)\right]^2}{2} \sigma_q^2. \end{aligned} \tag{25}$$

An inspection of equations (24) and (25) reveals that the dominant status of home currency causes the asymmetric effects of monetary policies. Different from the case in the home country, both home and foreign monetary policy can affect foreign representative household's expected utility.

Monetary policy rules in a Nash equilibrium $\left\{a^N, b^N\right\}$ solve problem $(P1)$:

$$\max_a \mathbf{E}U\left(a, b^N\right), \max_b \mathbf{E}U^*\left(a^N, b\right) \tag{P1}$$

The solution to problem $(P1)$ is given by proposition 1.

Proposition 1. *The solution to problem* $(P1)$ *is*
$a^N = -\frac{\gamma\varepsilon(1-\varepsilon)+(1-\gamma)\varepsilon^*(1-\varepsilon^*)}{\gamma\varepsilon^2+(1-\gamma)(\varepsilon^*)^2}, b^N = -\frac{(1-\varepsilon^*)[\gamma\varepsilon+(1-\gamma)\varepsilon^*]}{\gamma\varepsilon^2+(1-\gamma)(\varepsilon^*)^2}.$
Proof. *See Appendix.*[14] ■

When firms in both countries use both labor and oil as inputs, i.e. $0 < \varepsilon < 1$, and $0 < \varepsilon^* < 1$, optimal monetary policy rules require both countries to decrease money supply following a positive oil price shock. In addition, when the expenditure shares of the firms in the world on oil are identical, optimal monetary policy rules in our model are the same as those given by Devereux et al. (2010).[15]

Though firms set prices one period in advance, wages can be adjusted flexibly. When monetary policymakers inject money into the economy, workers adjust the nominal wage proportionately to strike a balance between money holdings and labor supply. [16]Since OPEC prices oil in the home currency, it is natural that the marginal cost of home firms, $W^{\varepsilon}Q^{1-\varepsilon}$, is only affected by home monetary policy. As a comparison, the marginal cost of foreign firms is $(W^*)^{\varepsilon^*}\left(\frac{Q}{S}\right)^{1-\varepsilon^*}$, it is obvious that home monetary policy can affect the marginal cost of foreign firms by changing oil price facing foreign firms through influencing the nominal exchange rate. In addition, since foreign exporters preset the price in the currency of the consumer (LCP), home monetary policy can also affect their marginal cost expressed in the home currency, $S\,(W^*)^{\varepsilon^*}\left(\frac{Q}{S}\right)^{1-\varepsilon^*}$,through the expenditure switching mechanism of the nominal exchange rate. Due to the asset market's risk-sharing function, the nominal wage levels in both countries are identical when they are compared according to the same currency.[17] In the aggregate, foreign exporters' marginal cost, when expressed in the home currency, is only determined by home monetary policy and the oil price and has nothing to do with foreign monetary policy. [18]

Thus, the marginal costs of the consumption goods purchased by home households are only influenced by home monetary policy. To reduce the effect of oil price volatility on home representative household's expected utility, home monetary policymaker needs to stabilize the marginal costs which finally affect home households' purchasing power. Specifically, when oil price rises, home monetary policymaker decreases money supply to lower home nominal wage to keep home firms' marginal cost stabilized. At the same time, a decrease in home money supply also stabilizes foreign exporters' marginal cost when it is expressed in the home currency. Thus, through stabilizing the marginal costs which finally affect home households' purchasing power, home monetary policymaker maximizes home households' welfare level.

For foreign country, the situation is different. Since home exporters set prices in the currency of the producer (PCP), the marginal cost of home exporters is determined only by home monetary policy. However, due to the fact that OPEC prices oil in the U.S. dollar, both home and foreign monetary policies can influence the marginal cost of foreign firms which supply consumption goods

[14]Which is available upon request.

[15]When $\varepsilon = \varepsilon^*$, $a^N = b^N = -\frac{1-\varepsilon}{\varepsilon}$. In Devereux et al. (2010), $a^0 = b^0 = -\frac{\alpha}{1-\alpha}$, where a^0 is home monetary policymaker's response coefficient to oil price shock, its foreign counterpart is b^0, and α is the expenditure share of the firm on imported oil input.

[16]From equations (8) and (9), we have $W = \frac{\eta}{\chi}M$.

[17]From equation (8) and its foreign counterpart, and equation (10), we know that $SW^* = W$.

[18]It is verified as follows: $SMC^* = S\,(W^*)^{\varepsilon^*}\left(\frac{Q}{S}\right)^{1-\varepsilon^*} = (SW^*)^{\varepsilon^*}Q^{1-\varepsilon^*} = W^{\varepsilon^*}Q^{1-\varepsilon^*} = \left(\frac{\eta}{\chi}M\right)^{\varepsilon^*}Q^{1-\varepsilon^*}$.

domestically. The only way foreign monetary policymaker can improve domestic households' welfare is to stabilize domestic firms' marginal cost which finally affects domestic households' purchasing power. However, the stabilization effect is influenced by home monetary policy which can change the oil price facing foreign firms. After a positive oil price shock occurs, home monetary policymaker decreases money supply, which results in the appreciation of the home currency, thus oil price facing foreign firms goes up further. To reduce the adverse effect, foreign monetary policymaker also decreases money supply, which leads to the depreciation of the U.S. dollar directly and diminishes the degree of the increase in the oil price from the appreciation of the U.S. dollar. In addition, the tightness of the foreign monetary policy also lowers foreign nominal wage. Both the decrease in the nominal wage and the depreciation of the U.S. dollar can stabilize the marginal cost facing foreign firms which supply consumption goods domestically.

3.2. The cooperative case

Recently, monetary policy cooperation has been a topic discussed actively by academic researchers and policymakers. However, except for several exceptions (Liu and Pappa 2008, Rabitsch 2012), most of the literature finds that, even if there are cross-border spillovers, there is no need for monetary policy cooperation or the gains from monetary policy cooperation are small.[19] Especially, the existing literature mainly focuses on whether there exist the gains from monetary policy cooperation when the countries are hit by idiosyncratic shocks. Whether there exist the gains from monetary policy cooperation when the countries are hit by a global shock remains a relatively unexplored area. To the best of our knowledge, Obstfeld and Rogoff (2002) is the first to discuss the gains from monetary policy cooperation when a global shock occurs. They find that, for any strictly positive value of the coefficient of relative risk aversion, the Nash monetary equilibrium coincides with the cooperative monetary equilibrium, and both of which can replicate the flexible-wage equilibrium. It implies that there are no gains from monetary policy cooperation when a global shock occurs. Obstfeld and Rogoff $(2002)'s$ conclusion is based on the assumption that the exporters in both countries set the nominal prices in the currency of the producer (PCP). In this case, the exchange rate pass-through is complete. In a model with the exchange rate pass-through elasticity, Corsetti and Pesenti (2005) find that, independent of the exchange rate pass-through elasticity, there are no gains from monetary policy cooperation when a global shock occurs.

However, In reality, the U.S. dollar plays a role of global currency in the sense that the majority of trade is invoiced in it. It is widely documented in the literature, see, among many others, Gopinath and Rigobon (2008) ,Goldberg and Tille (2008, 2009) . In this paper, we incorporate a global currency into a two-country New Keynesian model to examine the gains from monetary policy cooperation when the two countries are hit by a global shock.

In the cooperative case, a supranational monetary institution, i.e. a world planner, simultaneously chooses monetary policies $\{a, b\}$ to maximize a weighted average of home and foreign households' welfares. Since, except for the status of the currency, two countries are symmetric in our model, we assume that the weights assigned by the world planner to each country's welfare are equal.

Monetary policy rules in a cooperative equilibrium $\{a, b\}$ solve problem $(P2)$:

[19] See, among many others, Obstfeld and Rogoff (2002) , Corsetti and Pesenti (2005) , Pappa (2004) , Benigno and Benigno (2006) , Fujiwara and Wang (2017) .

$$\max_{a,b} \mathbf{E}V = \frac{1}{2}\mathbf{E}U(a,b) + \frac{1}{2}\mathbf{E}U^*(a,b) \tag{P2}$$

The solution to problem $(P2)$ is given by proposition 2.

Proposition 2. *The solution to problem* $(P2)$ *is*
$a^C = -\frac{\gamma n\varepsilon(1-\varepsilon)+n(1-\gamma)\varepsilon^*(1-\varepsilon^*)+\gamma^* n^*\varepsilon(1-\varepsilon)}{\gamma n\varepsilon^2+n(1-\gamma)(\varepsilon^*)^2+\gamma^* n^*\varepsilon^2}, b^C = -\frac{(1-\varepsilon^*)[\gamma n\varepsilon+n(1-\gamma)\varepsilon^*+\gamma^* n^*\varepsilon]}{\gamma n\varepsilon^2+n(1-\gamma)(\varepsilon^*)^2+\gamma^* n^*\varepsilon^2}$.
Proof. *See Appendix.*[20] ■

Similar to the Nash case, when the firms in the two countries use both labor and oil as inputs, i.e. $0 < \varepsilon < 1$, and $0 < \varepsilon^* < 1$, the world planner will reduce money supply in both countries after a positive oil price shock occurs. When the expenditure shares of the firms on oil are identical in the two countries, the world planner chooses the same monetary policy response in two countries.[21]

A comparison of a^N with a^C reveals that, when the expenditure share of home firms on oil is less than its foreign counterpart, the degree of the reduction in home money supply in the cooperative equilibrium is smaller than that in the Nash equilibrium.[22] Why? In the cooperative case, the world planner aims to stabilize the global marginal costs to maximize the world welfare. When the exporters in both countries set the prices in the home currency, the roles played by home and foreign currencies are asymmetric. Specifically, after a positive oil price shock occurs, a decrease in home money supply can stabilize the marginal cost of home firms, no matter where they sell their consumption goods.[23] As discussed previously, a decrease in home money supply can also stabilize the marginal cost of foreign exporters. However, a decrease in home money supply results in the depreciation of the foreign currency, which pushes the oil price facing the foreign firms up indirectly. Thus, the same monetary policy that can stabilize the marginal cost of home firms and that of foreign exporters will destabilize the marginal cost of foreign firms which supply consumption goods domestically.[24] In this sense, a required decrease in home money supply aiming to maximize home households' welfare in the Nash case produces a negative externality to the foreign country. In the cooperative case, the world planner will internalize the externality. It is clear that the magnitude of the negative externality is governed by the expenditure share of foreign firms on oil. When the expenditure share of foreign firms on oil is greater than its counterpart in the U.S., a decrease in home money supply leads to a greater negative externality. To alleviate the negative effect, in the cooperative case, the world planner decreases home money supply but the degree of the reduction is smaller than that in the Nash case. Otherwise, when the expenditure share of foreign firms on oil is lower than its counterpart in the U.S., a decrease in home money supply produces a smaller negative externality. In this circumstance, the welfare gains from stabilizing the marginal

[20] Which is available upon request.

[21] From Proposition 2, we know that, when $\varepsilon = \varepsilon^*, a^C = b^C = -\frac{1-\varepsilon}{\varepsilon}$.

[22] After a simple calculation, we know that $a^C - a^N = \frac{\gamma^*(1-\gamma)n^*\varepsilon\varepsilon^*(1-\varepsilon)(\varepsilon-\varepsilon^*)}{[\gamma n\varepsilon^2+n(1-\gamma)(\varepsilon^*)^2+\gamma^* n^*\varepsilon^2][\gamma\varepsilon^2+(1-\gamma)(\varepsilon^*)^2]}$.Thus, when $\varepsilon > \varepsilon^*$, $a^C > a^N$ follows.

[23] Under PCP, home exporters and the firms which supply consumption goods domestically face the same marginal cost which is given by $MC = W^\varepsilon Q^{1-\varepsilon} = \left(\frac{\eta}{\chi}M\right)^\varepsilon Q^{1-\varepsilon}$.

[24] Under LCP, foreign firms which supply consumption goods domestically face the following marginal cost $MC^* = (W^*)^{\varepsilon^*}\left(\frac{Q}{S}\right)^{1-\varepsilon^*} = \left(\frac{\eta}{\chi}\right) Q^{1-\varepsilon^*} M^* M^{\varepsilon^*-1}$.

cost facing home firms and that of foreign exporters are greater than the welfare losses incurred from destabilizing the marginal cost of foreign firms which sell consumption goods domestically. Thus, the degree of the reduction in home money supply in the cooperative case is greater than that in the Nash case.

As a comparison, foreign monetary policy can only influence the marginal cost of the domestic firms which supply consumption goods in their own country, and the influence depends on home monetary policy. [25]When the degree of the reduction in home money supply is small, foreign money supply also decreases with a smaller degree to stabilize the marginal cost of the local firms which sell consumption goods domestically. Thus, when the expenditure share of foreign firms on oil is greater than its counterpart in the U.S., the degree of the reduction in foreign money supply in the cooperative case is also smaller than that in the Nash case.[26]

3.3. The gains from monetary cooperation

Are there gains from monetary policy cooperation? If there exist, how large are such gains? Recently, Obstfeld and Rogoff (2002) find that, when the world is hit by idiosyncratic shocks, except for the special case in which the coefficient of relative risk aversion is unity, there exist the gains from monetary policy cooperation. However, the gains from monetary policy cooperation are relatively small. As a comparison, when the world is hit by a global shock, there are no welfare gains from monetary policy cooperation for any value of the coefficient of relative risk aversion. As emphasized previously, Obstfeld and Rogoff (2002) assume that the exporters in both countries set the nominal prices in the currency of the producer (PCP). After defining the exchange rate pass-through elasticity, Corsetti and Pesenti (2005) can discuss the optimal monetary policy in various cases, including PCP, LCP, the dollar standard, and other intermediate cases. They find that, there are no gains from monetary policy cooperation in three cases: (1) all shocks being global; (2) PCP; (3) LCP. Except for PCP and LCP, they conclude that there exist the gains from monetary policy cooperation in intermediate cases, including the dollar standard. However, they leave the study on the size of the gains as an open issue. Thus, both Obstfeld and Rogoff (2002) , and Corsetti and Pesenti (2005) conclude that there are no gains from monetary policy cooperation, when the world is hit by a global shock.

In contrast with what is found by Obstfeld and Rogoff (2002) , and Corsetti and Pesenti (2005) , in this paper, we demonstrate that, in the case in which the exporters set prices in the U.S. dollar, [27]there exist the gains from monetary policy cooperation, when the world is hit by a global shock. Furthermore, we provide an answer to the open issue came up by Corsetti and Pesenti (2005) .

A casual inspection of Proposition 1 and Proposition 2 reveals that, except for a special case in which the expenditure share of home firms on oil is equal to its foreign counterpart, the Nash solution is different from the cooperative one, which means that, in general, there exist the gains from monetary policy cooperation.

Proposition 3. *If the expenditure share of home firms on oil is not equal to its foreign counterpart, there exist the gains from monetary policy cooperation.*

[25]Note that $b^N = -(1-\varepsilon^*)\left(1-a^N\right)$,and $b^C = -(1-\varepsilon^*)\left(1-a^C\right)$.

[26]From the derivation of the previous two propositions, we know that, $b^C - b^N = (1-\varepsilon^*)\left(a^C - a^N\right)$, in addition, we also know, when $1-\varepsilon < 1-\varepsilon^*$, $a^C > a^N$, thus $b^C > b^N$.

[27]It corresponds to one intermediate case discussed by Corsetti and Pesenti (2005) .

Proof. *Substituting home monetary policy in the Nash equilibrium into home households' expected utility function given by equation* (24) *, we have*

$$\mathbf{E}U^N = -\varepsilon \left(\widehat{\lambda}\right)^{-1} (\gamma n + \gamma^* n^*) - n \left[\varepsilon\gamma + \varepsilon^* (1-\gamma)\right] \ln\left(\frac{\eta}{\chi}\right) - \ln\chi - n\ln\left(\widehat{\lambda}\right) - \frac{\gamma n (1-\gamma)(\varepsilon-\varepsilon^*)^2}{2\left[\gamma\varepsilon^2 + (1-\gamma)(\varepsilon^*)^2\right]}\sigma_q^2. \tag{26}$$

Similarly, substituting home and foreign monetary policy in the Nash equilibrium into foreign households' expected utility function given by equation (25) *, we have*

$$\mathbf{E}U^{*N} = -\varepsilon^* \left(\widehat{\lambda}\right)^{-1} \left[(1-\gamma) n + (1-\gamma^*) n^*\right] - n^* \left[\varepsilon\gamma^* + \varepsilon^* (1-\gamma^*)\right] \ln\left(\frac{\eta}{\chi}\right) - \ln\chi - n^*\ln\left(\widehat{\lambda}\right) - \frac{n^*\gamma^* (\varepsilon^*)^2 (1-\gamma)^2 (\varepsilon-\varepsilon^*)^2}{2\left[\gamma\varepsilon^2 + (1-\gamma)(\varepsilon^*)^2\right]^2}\sigma_q^2. \tag{27}$$

As a comparison, in the cooperative case, substituting home and foreign monetary policy into the weighted average of home and foreign households' welfares, we can obtain the aggregate welfare level in the world

$$2\mathbf{E}V = -\varepsilon \left(\widehat{\lambda}\right)^{-1} (\gamma n + \gamma^* n^*) - n \left[\varepsilon\gamma + \varepsilon^* (1-\gamma)\right] \ln\left(\frac{\eta}{\chi}\right) - \ln\chi - n\ln\left(\widehat{\lambda}\right) - \varepsilon^* \left(\widehat{\lambda}\right)^{-1} \left[(1-\gamma) n + (1-\gamma^*) n^*\right] - n^* \left[\varepsilon\gamma^* + \varepsilon^* (1-\gamma^*)\right] \ln\left(\frac{\eta}{\chi}\right) - \ln\chi - n^*\ln\left(\widehat{\lambda}\right) - \frac{n (\gamma n + \gamma^* n^*)(1-\gamma)(\varepsilon-\varepsilon^*)^2}{2\left[\gamma n\varepsilon^2 + n(1-\gamma)(\varepsilon^*)^2 + \gamma^* n^* \varepsilon^2\right]}\sigma_q^2. \tag{28}$$

The gains from monetary policy cooperation can be expressed as

$$2\mathbf{E}V - \left(\mathbf{E}U^N + \mathbf{E}U^{*N}\right) = \frac{\left[\gamma^* n^* \varepsilon\varepsilon^* (1-\gamma)(\varepsilon-\varepsilon^*)\right]^2}{2\left[\gamma n\varepsilon^2 + n(1-\gamma)(\varepsilon^*)^2 + \gamma^* n^* \varepsilon^2\right]\left[\gamma\varepsilon^2 + (1-\gamma)(\varepsilon^*)^2\right]^2}\sigma_q^2, \tag{29}$$

which is strictly greater than zero, when $\varepsilon \neq \varepsilon^*$*. Thus, except for the case in which* $\varepsilon = \varepsilon^*$*, there exist the gains from monetary policy cooperation.* ■

Traditionally, the academic researchers emphasize the importance of the terms-of-trade externality in analyzing the gains from monetary policy cooperation. [28] In our model, since foreign exporters set price in the U.S. dollar one period in advance, the terms of trade in the home country

[28] Among many others, see, Corsetti and Pesenti (2001), Benigno (2002), and Benigno and Benigno (2006).

are fixed. The situation is different in the foreign country, due to the fact that home exporters set price in the currency of their own country, the terms of trade in the foreign country move with the nominal exchange rate. However, the expected effect of the nominal exchange rate on the terms of trade is zero. It means that the monetary policymaker in each country expects that the terms of trade do not affect the expected welfare level, which the monetary policymaker aims to maximize. Thus, it is not the mechanism of the terms-of-trade externality that generates the gains from monetary cooperation in our paper.

The key to produce the gains from monetary policy cooperation in our model is the asymmetric status of the currency in world trade system. As analyzed previously, home monetary policy can influence the marginal costs of the firms in both countries. As a comparison, foreign monetary policy can only influence the marginal cost of the domestic firms which sell consumption goods domestically. All the firms in our model set prices one period in advance, according to a fixed mark-up over the expected marginal costs. Thus, a higher expected marginal cost is passed on and leads to a higher expected price, which moves inversely with the households' expected welfare level. [29] Thus, home monetary policy can influence both home and foreign households' welfare levels, however, foreign monetary policy can only influence domestic welfare level and the influence depends on home monetary policy. In other words, due to fact that all exporters in the world, including OPEC, set prices in the U.S. dollar, U.S. monetary policy produces an externality and the size of the externality depends on the relative expenditure share of foreign and home firms on oil input.

When world oil price rises, in the Nash case, home monetary policymaker reduces money supply to lower domestic nominal wage to stabilize the marginal cost of the home firms and that of the foreign exporters. The tightness of home monetary policy causes the depreciation of the foreign currency, which further increases the oil cost facing foreign firms which sell consumption goods domestically. The more they spend on oil, the greater the U.S. monetary policy affects their marginal cost. However, when playing the Nash game, home monetary policymaker just disregards the adverse effect. In the cooperative case, when choosing the degree of tightness of home monetary policy, the world planner needs to make a trade-off between the benefits of stabilizing the marginal costs of consumption goods purchased by home households and the losses of destabilizing the marginal cost of foreign firms which supply consumption goods domestically. When the expenditure share of foreign firms on oil is greater than its counterpart in the home country, the losses dominate and the degree of the tightness of home monetary policy in the cooperative case is lower than that in the Nash case. Otherwise, the benefits dominate and the degree of the tightness of home monetary policy in the cooperative case is higher than that in the Nash case. In both cases, there exist the gains from monetary policy cooperation. The welfare gains from monetary policy cooperation increase with the difference between the expenditure shares of the firms in both countries on oil. In a special case in which two expenditure shares are identical, the welfare gains from monetary policy cooperation vanish.

In Corsetti and Pesenti (2005) , the authors point out that, in intermediate cases, a country can in general do better than simply 'keeping its own house in order' by engaging in binding international agreements. In other words, they believe that each country can benefit from, and thus is willing to taking part in, the monetary policy cooperation. However, they do not verify the conclusion. Is it true? In the following, we check their conclusion in a special case in which the expenditure

[29] Remember that $\mathbf{E}c = -\ln\chi - \mathbf{E}p$.

shares of the households in both countries on nonenergy consumption are identical, and the degrees of home-bias in consumption choices between home and foreign households are the same, and the expenditure shares of the firms in both countries on oil are not identical, i.e. $n = n^*$, $\gamma = \gamma^*$, and $\varepsilon \neq \varepsilon^*$. [30]

Proposition 4. *When $n = n^*$, $\gamma = \gamma^*$, and $\varepsilon \neq \varepsilon^*$, home country is willing to take part in monetary policy cooperation, but foreign country is unwilling to take part in.*
Proof. *From equation* (26), *we know that home households' welfare level in the Nash case is* [31]

$$\mathbf{E}U^N = -\frac{\gamma n (1-\gamma)(\varepsilon - \varepsilon^*)^2}{2\left[\gamma \varepsilon^2 + (1-\gamma)(\varepsilon^*)^2\right]}\sigma_q^2. \tag{30}$$

As a comparison, from equation (28), *we know that home households' welfare level in the cooperative case is*

$$\mathbf{E}V = -\frac{\gamma n (1-\gamma)(\varepsilon - \varepsilon^*)^2}{2\left[2\gamma \varepsilon^2 + (1-\gamma)(\varepsilon^*)^2\right]}\sigma_q^2. \tag{31}$$

After taking part in monetary policy cooperation, home country can gain

$$\mathbf{E}V - \mathbf{E}U^N = \frac{n(1-\gamma)\gamma^2\varepsilon^2(\varepsilon - \varepsilon^*)^2}{2\left[2\gamma \varepsilon^2 + (1-\gamma)(\varepsilon^*)^2\right]\left[\gamma \varepsilon^2 + (1-\gamma)(\varepsilon^*)^2\right]}\sigma_q^2 > 0. \tag{32}$$

Thus, home country is willing to take part in monetary policy cooperation.
From equation (27), *we know that foreign households' welfare level in the Nash case is*

$$\mathbf{E}U^{*N} = -\frac{n\gamma(\varepsilon^*)^2(1-\gamma)^2(\varepsilon - \varepsilon^*)^2}{2\left[\gamma \varepsilon^2 + (1-\gamma)(\varepsilon^*)^2\right]^2}\sigma_q^2. \tag{33}$$

Similarly, foreign households' welfare level in the cooperative case is given by equation (31). *After taking part in monetary policy cooperation, foreign country can gain*

$$\mathbf{E}V - \mathbf{E}U^{*N} = -\frac{n(1-\gamma)(\varepsilon - \varepsilon^*)^2\gamma^3\varepsilon^4}{2\left[2\gamma \varepsilon^2 + (1-\gamma)(\varepsilon^*)^2\right]\left[\gamma \varepsilon^2 + (1-\gamma)(\varepsilon^*)^2\right]^2}\sigma_q^2 < 0. \tag{34}$$

Thus, foreign country is unwilling to take part in monetary policy cooperation. ■

Proposition 4 shows that not all countries are willing to take part in monetary policy cooperation. Thus, Corsetti and Pesenti $(2005)'s$ conclusion that a country can in general do better than simply 'keeping its own house in order' by engaging in binding international agreements needs to be modified.

[30] For the general case in which $n \neq n^*$, $\gamma \neq \gamma^*$, and $\varepsilon \neq \varepsilon^*$, we cannot give a clear answer by the simple comparison between the welfare level obtained in the Nash case and that in the cooperative case.
[31] Note that we take an affine transformation to equation (26), and we take the same measure in the following.

In our model, in both Nash and cooperative cases, foreign monetary policy depends on home monetary policy. To some degree, due to the U.S. dollar's dominant role in world trade system, the autonomy of monetary policy in the other country is impaired. Intuitively, when the expenditure shares of home and foreign firms on oil are not identical, the world planner can increase the aggregate welfare level in the world by internalizing the adverse effect of home monetary policy on foreign households' welfare level. By reaping all of the increased welfare and obtaining an extra bonus from exerting the effect of home monetary policy on foreign monetary policy,[32] home households are strictly better off in the cooperative case. As a comparison, foreign monetary policy cannot reap the welfare gains by influencing home households' welfare. On the contrary, due to the subordinate status of foreign currency, foreign households are strictly worse off in the cooperative case.

Due to foreign country's reluctance to take part in monetary policy cooperation, it cannot come true. However, the world planner can encourage foreign country to take part in by transferring part of the gains from the home to foreign households. If the transfer is within the interval

$$\left[\frac{n\left(1-\gamma\right)\left(\varepsilon-\varepsilon^{*}\right)^{2}\gamma^{3}\varepsilon^{4}}{2\left[2\gamma\varepsilon^{2}+\left(1-\gamma\right)\left(\varepsilon^{*}\right)^{2}\right]\left[\gamma\varepsilon^{2}+\left(1-\gamma\right)\left(\varepsilon^{*}\right)^{2}\right]^{2}},\frac{n\left(1-\gamma\right)\gamma^{2}\varepsilon^{2}\left(\varepsilon-\varepsilon^{*}\right)^{2}}{2\left[2\gamma\varepsilon^{2}+\left(1-\gamma\right)\left(\varepsilon^{*}\right)^{2}\right]\left[\gamma\varepsilon^{2}+\left(1-\gamma\right)\left(\varepsilon^{*}\right)^{2}\right]}\right],$$

both countries are willing to take part in monetary policy cooperation.[33]

4. Conclusion

Obstfeld and Rogoff (2002) and Corsetti and Pesenti (2005) conclude that there are no gains from monetary policy cooperation, when the world is hit by a global shock. In this paper, we demonstrate that there exist the gains from monetary policy cooperation in the same circumstance. We obtain our conclusion in a two-country New Keynesian model with one-period price stickiness. Firms in both countries input both domestic labor and oil as production inputs. To capture a global shock, we model the oil inputs as imported from a third party such as OPEC, thus both home and foreign firms take the oil price as exogenous. Similar to U.S. dollar, home currency plays a role of global currency. In other words, home exporters set prices in the currency of the producer (PCP), and foreign exporters set prices in the currency of the consumer (LCP). In addition, oil is also denominated in the home currency.

We solve for the Nash equilibrium and the cooperative equilibrium respectively, and find that, except for a special case in which the expenditure shares of home and foreign firms on oil are identical, optimal monetary policy in the Nash case is not equal to that in the cooperative equilibrium. It means that, except for the special case, there exist the gains from monetary policy cooperation. The welfare gains arise from the asymmetric status of the currencies in both countries. The global currency status of the home currency enables home monetary policy to influence the marginal costs of the firms in both countries. As a comparison, foreign currency can only influence the marginal cost of the domestic firms which sell consumption goods in their own country. Since all firms set

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[32] Note that $\left(\mathbf{E}V-\mathbf{E}U^{N}\right)-\left[2\mathbf{E}V-\left(\mathbf{E}U^{N}+\mathbf{E}U^{*N}\right)\right]=\frac{n(1-\gamma)\left(\varepsilon-\varepsilon^{*}\right)^{2}\gamma^{3}\varepsilon^{4}}{2\left[2\gamma\varepsilon^{2}+(1-\gamma)(\varepsilon^{*})^{2}\right]\left[\gamma\varepsilon^{2}+(1-\gamma)(\varepsilon^{*})^{2}\right]^{2}}>0.$

[33] We assume that a country is willing to take part in monetary policy cooperation, if the welfare level in the cooperative case is not lower than that obtained in the Nash case.

price according to a fixed mark-up over its expected marginal cost, monetary policy can influence households' purchasing power, thus the welfare level.

When a global oil price shock occurs, by lowering the money supply, home monetary policymaker can stabilize the marginal costs of home firms and that of foreign exporters, but the appreciation of home currency destabilizes the marginal cost of foreign firms which supply consumption goods domestically by pushing up the oil price facing them. In Nash case, home monetary policymaker only aims at its policy's stabilization effect in the home country and disregards the destabilization effect in the other country. By internalizing the adverse effect of home monetary policy on foreign households' welfare level, a world planner can achieve the welfare gains from monetary policy cooperation. Obviously, the adverse effect of home monetary policy on foreign households' welfare level is governed by the expenditure share of foreign firms on oil. When the expenditure share of foreign firms on oil is greater or smaller than its counterpart in the home country, there exist the gains from monetary policy cooperation.

Corsetti and Pesenti (2005) believe that every country can benefit from, thus is willing to taking part in, the monetary policy cooperation. However, they do not verify the conclusion. In our model, we show that the home country is willing to take part in monetary policy cooperation, but the foreign country is not. By transferring part of the welfare gains from the home to foreign households, a world planner can achieve the monetary policy cooperation from which both countries can benefit.

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Reference

Benigno, P., 2002. A simple approach to international monetary policy coordination. J. Int. Econ. 57, 177-196.

Benigno, P., 2004. Optimal monetary policy in a currency area. J. Int. Econ. 63, 293-320.

Benigno, G., Benigno, P., 2003. Price stability in open economies. Rev. Econ. Stud. 70, 743-764.

Benigno, G., Benigno, P., 2006. Designing targeting rules for international monetary policy cooperation. J. Monet. Econ. 53, 473-506.

Benigno, P., 2009. Price stability with imperfect financial integration. J. Money Cred. Bank. 41, 121-149.

Bhattarai, S., Lee, J.W., Park, W.Y., 2015. Optimal monetary policy in a currency union with interest rate spreads. J. Int. Econ. 96, 375-397.

Bodenstein, M., Erceg, C.J., Guerrieri, L., 2008. Optimal monetary policy with distinct core and headline inflation rates. J. Monet. Econ. 55, S18–33.

Bodenstein, M., Erceg, C.J., Guerrieri, L., 2011. Oil shocks and external adjustment. J. Int. Econ. 83, 168-184.

Bodenstein, M., Guerrieri, L., Kilian, L., 2012. monetary policy responses to oil price fluctuations. IMF Econ. Rev. 60, 470-504.

Bodenstein, M., Guerrieri, L., Gust, C.J., 2013. Oil shocks and the zero bound on nominal interest rates. J. Int. Money. Finan. 32. 941-967.

Canzoneri, M.B., Cumby, R.E., Diba, B.T., 2005. The need for international policy coordination: what's old, what's new, what's yet to come? J. Int. Econ. 66, 363-384.

Casas, C., Diez, F.J., Gopinath, G., Gourinchas, P.O., 2016. Dominant currency paradigm. NBER working paper no. 22943.

Clarida, R., Gali, J., Gertler, M., 2002. A simple framework for international monetary policy analysis. J. Monet. Econ. 49, 879-904.

Corsetti G, Pesenti P 2001. Welfare and macroeconomic interdependence. Q J Econ 116(2): 421-446.

Corsetti, G., Pesenti, P., 2005. International dimensions of optimal monetary policy. J. Monet. Econ. 52, 281-305.

Corsetti, G., Dedola, L., Leduc, S., 2011. Optimal monetary policy in open economies, in: Friedman, B.M., Woodford, M. (Eds.), Handbook of monetary economics, Vol. 3. Elsevier, pp.861-934.

Devereux, M.B., Engel, C., 2003. Monetary policy in the open economy revisited: price setting and exchange rate flexibility. Rev. Econ. Stud. 70, 765-783.

Devereux, M.B., Engel, C., 2007. Expending switching versus real exchange rate stabilization: competing objectives for exchange rate policy. J. Monet. Econ. 54, 2346-2374.

Devereux, M.B., Kang, S., Juanyi, X., 2007. Global monetary policy under a dollar standard. J. Int. Econ. 71, 113-132.

Devereux, M.B., Kang, S., Juanyi, X., 2010. Oil currency and the dollar standard: a simple analytical model of an international trade currency. J. Money Cred. Bank. 42, 521-550.

Devereux, M.B., Sutherland, A., 2008. Financial globalization and monetary policy. J. Monet. Econ. 55, 1363-1375.

Duarte, M., Obstfeld, M., 2008. Monetary policy in the open economy revisited: the case for exchange-rate flexibility restored. J. Int. Money. Finan. 27, 949-957.

Engel, C., 2011. Currency misalignments and optimal monetary policy: a reexamination. Am. Econ. Rev. 101, 2796-2822.

Engel, C., 2016. International coordination of central bank policy. J. Int. Monet. Finan. 67, 13-24.

Fujiwara, I., Wang J., 2017. Optimal monetary policy in open economies revisited. J. Int. Econ. 108, 300-314.

Gali, J., Monacelli, T., 2005. Monetary policy and exchange rate volatility in a small open economy. Rev. Econ. Stud. 72, 707-734.

Gali, J., Monacelli, T., 2008. Optimal monetary and fiscal policy in a currency union. J. Int. Econ. 76, 116-132.

Gali, J., Monacelli, T., 2016. Understanding the gains from wage flexibility: the exchange rate connection. Am. Econ. Rev. 106, 3829-68.

Gavin, W.T., Keen, B.D., Kydland, F.E., 2015. Monetary policy, the tax code, and the real effects of energy shocks. Rev. Econ. Dyn. 18, 694-707.

Goldberg L, Tille C 2008. Vehicle currency use in international trade. J. Int. Econ. 76, 177-192

Goldberg L, Tille C 2009. Macroeconomic interdependence and the international role of the dollar. J. Monet. Econ. 56: 990-1003.

Gong LT, Wang C, Zou HF 2016. Optimal monetary policy with international trade in intermediate inputs. J. Int. Money. Finan. 65: 140-165.

Gong LT, Wang C, Zou HF 2017. Optimal exchange-rate policy in a model of local-currency pricing with vertical production and trade. Open. Econ. Rev. 28: 125-147.

Gopinath G, Rigobon R 2008. Sticky borders. Q. J. Econ. 123 (2): 531-575

Liu, Z., Pappa, E., 2008. Gains from international monetary policy coordination: Does it pay to be different? J. Econ. Dyn. Cont. 32, 2085-2117.

Obstfeld M, Rogoff K 1995. Exchange rate dynamics redux. J. Polit. Econ. 103: 624-660

Obstfeld, M., Rogoff, K., 2000. New directions for stochastic open economy models. J. Int. Econ. 50, 117-153.

Obstfeld, M., Rogoff, K., 2002. Global implications of self-oriented national monetary rules. Q. J. Econ 117, 503-535.

Paoli, B.D., 2009a. Monetary policy and welfare in a small open economy. J. Int. Econ. 77, 11-22.

Paoli, B.D., 2009b. Monetary policy under alternative asset market structures: the case of a small open economy. J. Money Cred. Bank. 41, 1301-1330

Pappa, E., 2004. Do the ECB and the fed really need to cooperate? optimal monetary policy in a two-country world. J. Monet. Econ. 51, 753-779.

Rabitsch, K., 2012. The role of financial market structure and the trade elasticity for monetary policy in open economies. J. Money Cred. Bank. 44, 603-629.

Sutherland, A., 2006 The expenditure-switching effect, welfare and monetary policy in a small open economy. J. Econ. Dyn. Contr. 30, 1159-1182.

Wang, C., Zou, H.F., 2013. On the efficiency of monetary and fiscal policy in open economies. Annals of Economics and Finance 14, 179-206.

Wang, C., Zou, H.F., 2015. Optimal monetary policy under a global dollar standard: the effect of vertical trade and production. Open Econ. Rev. 126, 121-137.