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Dollar Hegemony and China's Economy

Kai Liu

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Abstract: this paper models the US dollar as a global currency and focuses on the effects of US money supply shock upon China's economy. The special roles of US dollar as a global currency and the special institutional arrangements of China are investigated. Given a positive US money supply shock, both the inflation and real GDP of China will be below their steady state levels in the medium term; while for the US there is no inflation pressure. Welfare calculation shows that a positive 10% US money supply shock will result in a positive 1.25% welfare gain for China, a positive 0.06% welfare gain for US, but a 0.21% welfare loss for the rest of the world. Given that the US dollar's hegemony is not weakened, the regime with liberalized capital accounts and an exchange rate peg to the US dollar for China is best for the Chinese households under the US money supply shock. However, when the US dollar is no longer the global reserve currency but instead a supranational reserve currency replaces it, then for China this regime is the worst kind of reform, no matter whether or not the dollar standard in international trade is maintained.

Key words: US dollar, global currency, capital control, exchange rate, business cycle

JEL classification codes: E32, E42, E51, F31, F41, F44

[†] Kai Liu, Faculty of Economics, University of Cambridge/School of Economics, Renmin University of China.
Email: kl363@cam.ac.uk

1.   INTRODUCTION

On September 13th of 2012, the Federal Reserve decided to launch a new $40 billion per month and open-ended bond purchasing program, which is called QE3, in order to stimulate the US economy. On December 12th of 2012, the Federal Reserve announced an increase in the amount of open-ended purchases from $40 billion to $85 billion per month. Like QE1 and QE2, this unconventional monetary policy triggered fierce debates not only inside the US but also worldwide. One reason why people care so much about QE of US is that US dollar serves as both US national currency and a "world currency". In spite of the rise of Euro, US dollar is the only one that could be regarded as a global currency, as we will explain afterwards. Researches on QE at least have two dimensions. One is of domestic concern, to discuss this kind of unconventional monetary policy under the situation when the nominal interest rate reaches its zero lower bound. The other is of international concern, to study the spillover effects of US QE on other economies, especially on developing countries.

The main question this paper explores is how US money supply affects China's business cycles. This is a question about the nature of money, specifically about the nature of US dollar as a global currency. There is a consensus in macroeconomics: money is not neutral at least in the short run. This statement should not be confined in the context of a closed economy. Monetary policies within one country could influence, at least in the short run, the economy of another country at least through international trade and global financial markets. The monetary policies of US, as the provider of a world currency called US dollar and the biggest economy of the world, are supposed to have strong externality on other economies. Those who are against US QEs hold a point that the externality of US QE is significantly negative on their economies. For example, QE rounds by the Federal Reserve are criticized by BRIC countries (Brazil, Russia, India and China). They share the argument that such actions amount to protectionism and competitive devaluation. As net exporters whose currencies are partially pegged to US dollar, they protest that it causes their inflation to rise and penalizes their industry.

US money supply could influence the global economy in several ways. First of all, it has an impact on US macro economy through channels such as the aggregate price level within US, and the demand and interest rate of US government bonds if the newly created US dollar is used to buy them. Since the global economy is linked through international trade and international financial markets, the fluctuation of US economy will naturally affect other economies. Secondly, oil and many other important commodities in global markets are priced by US dollar. Therefore, a sudden increase of US money supply means dollar's depreciation to some degree, which will lead to the fluctuations of commodities' prices denominated in US dollar. Given the existence of exchange rate targeting for some countries, international trade and then the global economy will be further influenced. Third, changes in dollar's value and many countries' net exports and current accounts, caused by the change in US money supply, will alter these countries' holdings of dollar assets, such as US government bonds, as their foreign exchange reserves. This consequently will again have impacts

on US domestic economy and the global economy. One should bear in mind that the channels above about how US money supply affects the world economy are just first-round effects. There exist second-round and even third-round effects, since different economies are interdependent and closely linked.

Although US dollar plays such an important role in the global economy, the US monetary authority adjusts US monetary policies,[1] such as US money supply, only according to its national economic and financial conditions prevailing in the United States, not in the whole world. Schulmeister (2000) discusses the double role of the US dollar as both national currency and world currency and the relevant conflict between the need for stable monetary conditions for the world economy as a whole and the national monetary need inside the US. He argues that the most important events in postwar economic development---ranging from the oil price shocks in the 1970s to the financial crises in Latin America in the 1980s and in East Asia in the late 1990s---could be related to US dollar's double role. This kind of conflict generates some new questions for China's economy: does an increase in US money supply will harm or benefit China's economy? Does this kind of externality depend or not on the special institutional arrangements of China, such as exchange rate targeting and strict capital controls? Will this kind of externality be attenuated when China' GDP share in the world becomes larger and larger? What is the scenario if US dollar were not a world currency?

To answer these questions, this paper first does an empirical exercise by using a GVAR model in which US money supply is viewed as a domestic variable for US but a global variable for other economies. The GVAR result shows that when there is a positive shock to US money supply, China will have higher inflation rate and lower GDP level. This empirical GVAR model can give us some hint, but there are some patent shortcomings of it. For example, it is not micro-founded and then the transmission mechanisms are not clear.

Then I build a multi-country New Keynesian global DSGE model with a world currency. In the benchmark model, three asymmetric economies have different institutional arrangements and interact with each other, US dollar serves as a world currency and US national currency as well, and China's economy is featured with Chinese characteristics such as capital controls, compulsory exchange settlement and sales, and exchange rate pegging. Our global DGSE model finds the following results: when a positive US money supply shock hits the global economy, the nominal interest rate of China will be lowered down (the spillover of liquidity effect); in the medium term both China's real output and its inflation rate are below the steady state levels; and both the terms of trade and nominal net export for China will be push up on impact, but be below their steady state levels in the medium term. Several kinds of sensitivity analysis are implemented, and the above results are quite robust. Cost-push effect and relative price effect are employed to discuss the transmission mechanism.

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[1] For the spillover effects of other US monetary policy shocks such as nominal interest rate shock on other economies there are at least three strands of literature. One is to use small open economy DSGE models, such as Uribe and Yue (2006) and Chang *et al.* (2013); the second is to use GVAR models, such as Pesaran, Schuermann and Smith (2009a); and the last is to use other econometric tools, for example, structural VAR, such as Mackowiak (2007).

Welfare calculation for the benchmark model shows that a positive 10% US money supply shock will result in a positive 1.25% welfare gain (as a fraction of the steady state consumption) for Chinese households, a positive 0.06% welfare gain for US, but a 0.21% welfare loss for the rest of the world.

I also examine the relationship between the persistence of US money supply shock and its influence on China's economy. The more persistent US money supply shock is, the larger the responses of China's aggregate variables would be. It is also found that: the response of China's economy to US money supply shock will not become smaller when the share of China's GDP in the global economy becomes larger (even when it is double of US' GDP), as long as the US dollar remains as the world currency and there is no reform to China's institutional arrangements.

Counterfactual analyses are implemented in two ways: to reform China's institutional arrangements or to weaken the global roles of US dollar. For China's liberalization reform, three cases are considered: a partial lifting of capital controls with maintenance of the exchange rate peg, allowing the exchange rate of Renminbi to float while keeping the capital account closed, and the full liberalizing reform. For weakening the US dollar's global roles, we assume the dollar pricing in the international trade is replaced by producer currency pricing (PCP), or assume there is another international bond to replace US bond as the global reserve asset. Given that US dollar's hegemony is not weakened, the regime with liberalized capital accounts and exchange rate pegging US dollar for China is best for the Chinese households under US money supply shock. However, when US dollar is no longer the global reserve currency but instead a supranational reserve currency replaces it, then for China this regime is the worst kind of reform, no matter whether or not the dollar standard in international trade is maintained. For China, to maintain the status quo (nominal exchange rate targeting and capital controls) cannot always achieve the first best, but can guarantee a second best under US money supply shock. When US dollar serves only as the domestic currency for US, then for China a floating exchange rate regime or pegging the supranational currency can make China's economy nearly unaffected by US money supply shock, no matter whether or not its capital account is opened.

The recent global financial and economic crisis has generated a renewed interest in the implications of capital controls and exchange rate pegs, especially for emerging countries. Since it is not clear that financial integration can reduce macroeconomic fluctuation or not, under a certain condition capital controls or fixed exchange rate regime may be preferred by policy makers. Farhi and Werning (2012) argue that capital controls can alleviate the influence of excess international capital movements resulted from risk premium shocks. Our paper could provide some insight for Chinese policy makers for their consideration of capital control policies as well as exchange rate reforms, particularly when the effects of US money supply shock should not be ignored.

The rest of this paper is arranged as follows: Section 2 provides some stylized facts, based on which some assumptions will be made for the benchmark model of this paper; Section 3 shows some results from an empirical GVAR model and explains

the shortcomings of this method; in Section 4 we build the benchmark model; Section 5 and 6 is the calibration and impulse response analysis of the benchmark model; in Section 7 and 8 we implement some counterfactual analyses and do the welfare comparison; finally we conclude.

2. SOME STYLIZED FACTS

Before our quantitative and theoretical analyses of US dollar as a global currency in global frameworks, we need to clarify some stylized facts, which will justify some assumptions of the following econometric and theoretical models in this paper and can give some hints about our final results as well.

Krugman (1984) lists and explains the six roles of US dollar as an international currency in detail: medium of exchange, unit of account and store of value for both private sector and central banks. Goldberg (2010) suggests that in spite of the emergence of the Euro, changes in the dollar's value, and the fact that the financial market crisis has posed a significant challenge to the dollar's long-standing position in world markets, the US dollar has retained its standing in key roles, according to an empirical study of the dollar across critical areas of international trade and finance. Galati and Wooldridge (2006) tell a similar story.

A. US dollar is the central invoicing currency for international trade.

The New Open Economy Macroeconomics (NOEM) literature after Obstfeld and Rogoff (1995) usually assumes that the prices of traded goods are rigid in the currency of producers: firms set export prices in domestic currency, letting the foreign price of their product vary with the exchange rate. This hypothesis is called producer currency pricing (PCP), under which exchange rate pass-through on import prices is complete. However, the PCP assumption is questioned by another strand of the literature, such as Betts and Devereux (2000), taking a different view that firms preset prices in domestic currency for the domestic market and in foreign currency for the market of export destination. This hypothesis is called local currency pricing (LCP), under which exchange rate pass-through is zero for a firm not re-optimizing its price.

But in reality the dollar pricing is widely used. Goldberg and Tille (2008) show that: the dollar is overwhelmingly used for invoicing both export and import prices for the US economy and other economies. Table 1 presents some data regarding US dollar invoicing in overall trade flows for selected countries. Another empirical finding of international trade is that exports of primary commodities, including oil, are substantially priced in US dollar. Devereux *et al*. (2010) point out: among 81 raw material price series published by the UNCTAD, only 5 are not dollar denominated; in the construction of the Rogers International Commodities Index, only 5 out of 35 commodity contracts comprising the index are not denominated in US dollar, and the weighting of non-dollar denominated commodity in the index is only 2.02%. Devereux *et al*. (2010) build a model and show that a dollar standard in international trade is the equilibrium of firms' choices, given some reasonable assumptions. Goldberg and Tille (2009) use a simple center-periphery model to show that US

dollar's global role as the dominant international trade invoicing currency magnifies the exposure of periphery countries to the US monetary policy shock, even when their trade flows with US are limited.

Table 1. US dollar use in invoicing imports and exports for selected countries (in percent)

Country	Observation year	US dollar share in export invoicing	US dollar share in import invoicing
US	2003	99.8%	92.8%
Japan	2001	52.4%	70.7%
Korea	2001	84.9%	82.2%
Australia	2007	74.3%	52.0%
UK	2002	26.0%	37.0%

Source: Devereux *et al*. (2010).

B. US dollar plays a prominent role in the portfolios of foreign exchange reserve accounts.

Figure 1 depicts the currency composition of official foreign exchange reserves from 1999 when the euro was created. US dollar and the euro make up above 85% of official foreign exchange reserves globally, while the former is always above 60% and more than double of the latter. Due to the euro crisis in 2009, the share of the euro reserves declined from 27.7% to 23.7% in 2013. Meanwhile, the share of US dollar reserves was quite stable.
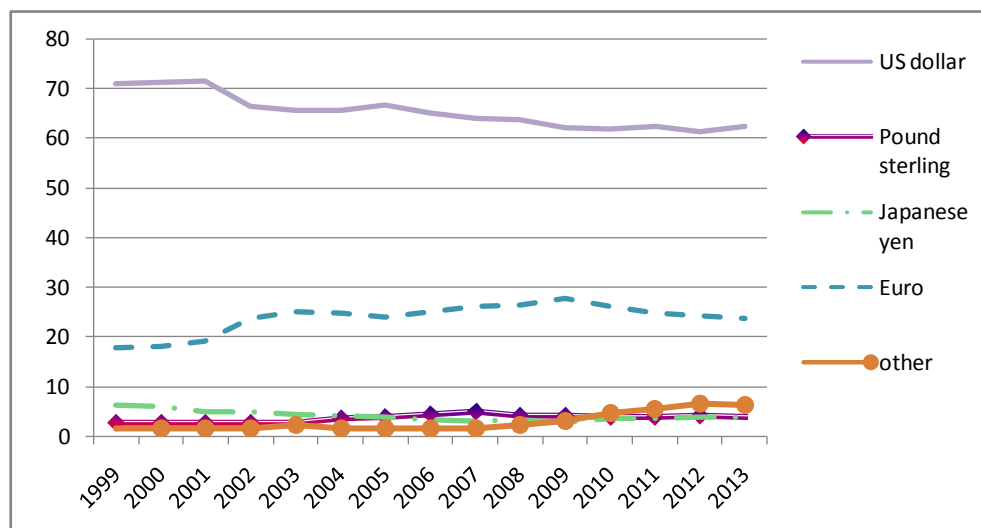
Figure 1. Currency composition of official foreign exchange reserves (COFER) (in percent)
(Data source: IMF Statistics Department COFER database and International Financial Statistics[2])

Besides the above two stylize facts, the dollar is a leading transaction currency in the foreign exchange markets as well. With about 86% share of foreign exchange transaction volume --- more than twice the share of the euro --- US dollar continues to

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[2] The website is http://www.imf.org/external/np/sta/cofer/eng/glossary.htm. The 2013 data is preliminary and only for the first quarter.

dominate these markets (Goldberg, 2010).

Generally speaking, US dollar has still been playing a central and dominant role in international trade and finance as both a store of value and a medium of exchange, and no other currencies rival it. US dollar is the only currency that can be viewed as a global currency in the world economy. Therefore, in the following GVAR model, we will incorporate US money supply as a global factor; and in the following global DSGE model, US dollar plays two key roles as the global currency: the only invoicing currency for international trade and the only foreign exchange reserve currency.

C. Foreign exchange reserves are now the major component of the total assets on the balance sheet of China's central bank.
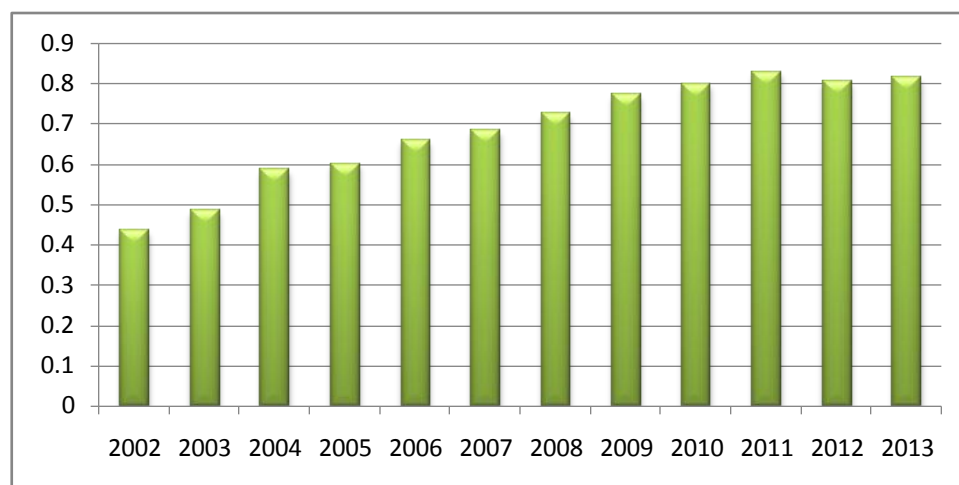
Figure 2. Foreign reserves as a share of total assets for the People's Bank of China
(Data source: People's Bank of China. The value for 2013 is based on the data up to August.)

Figure 2 shows the foreign exchange reserves as a share of total assets for the People's Bank of China (PBOC). Before 2003 this share was below 50%, but after 2009, the share of foreign reserves was stably around 80%. Due to continuous large trade surplus, strict capital controls and compulsory exchange settlement and sales, the expansion of the PBOC's balance sheet is mainly achieved by absorbing foreign capital inflows and accumulating foreign exchange reserves, primarily dollar reserves. Although the capital control for China is not as strict as before, and after 2008 China has abandoned the system of compulsory exchange settlement and sales, in reality the Chinese households are still not completely free to buy foreign assets and they also are not willing to do so currently because of the significant difference between home and foreign interest rates.

Therefore, in our benchmark model below, we assume for China that there are strict capital controls and compulsory exchange settlement and sales, Chinese households are prohibited from holding foreign assets, and firms are required to swap their foreign-currency revenues (if there are any) with the central bank for domestic currency. Thus if there is a positive current account for China, the money supply of Chinese currency will be passively expanded. And given the stylized facts A and B

above, the PBOC is assumed to use all the absorbed US dollars to buy US government bonds. In other papers such as Change *et al.* (2013), a concept "sterilization" is discussed, which means that a subset of the central bank's purchase of foreign assets can be financed by selling domestic bonds and then does not result in an expansion of domestic money supply. Bacchetta *et al.* (2013) study, in a semi-open economy where the central bank has access to international capital markets but the private sector does not, the optimal policy of the central bank when they can choose the levels of both international reserves and domestic public debt. Considering the reality of China, especially the huge share of foreign reserves in the PBOC's balance sheet, we do not take into account the central bank's sterilization activity in the benchmark model.

D. In the post-crisis period the expansion of US monetary base is almost entirely achieved by the Federal Reserve' buying of US Federal government's debt.

Figure 3 depicts the evolving paths of US monetary base and the US Federal debt held by the Federal Reserve. There was a jump for US monetary base in the third quarter of 2008. After that, US monetary base expanded from 1693 billion dollars to 3218 billion (a total 1525 billion increase), while the US Federal debt held by the Federal Reserve increased from 476 billion to 1937 billion (a total 1461 billion increase). So nearly the entire expansion of US monetary base is achieved by the Federal Reserve' QE operations. To reflect this kind of money creation feature of US and also to simplify the model, in the benchmark model we assume that a US money supply shock is accompanied by an equal amount of change to the Federal Reserve' holdings of US government bonds.
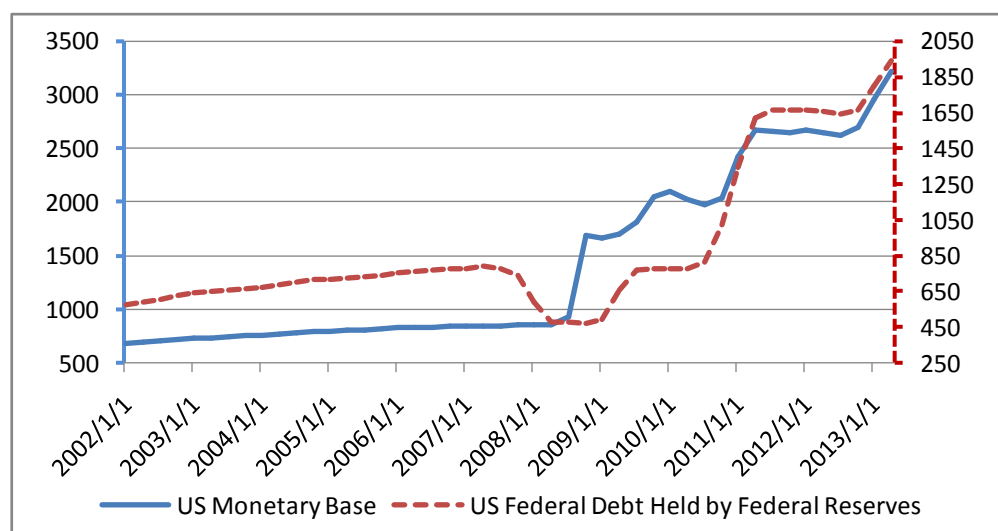
Figure 3. US monetary base and US Federal debt held by the Federal Reserve (billion $)

(Data source: Federal Reserve Bank of St. Louis)

3.   AN EMPIRICAL INVESTIGATION: GVAR APPROACH

There are some researches empirically examining the international impact of US money supply on some specific country, even though they are not global discussions.

Farrell (1980) examines the international impact of US money supply on the economy of Mexico and advises the Mexico's policymakers to keep an eye on the course of US money supply. Bailey (1989) studies the effects of weekly U.S money supply releases on the Canada's financial markets and finds that Canadian stock index, bond prices and short-term interest rate change with surprises in the announced level of U.S. M1.

Another kind of literature focuses on the effects of US money supply announcements or QE on the financial markets inside and beyond the United States. They usually use high-frequency intraday data. Bailey (1990) examines the responses of equity values across Pacific Rim countries to US M1 announcement surprises and finds that the stock market's response to US M1 is better explained by the country's degree of financial integration than real economic integration (through international trade) with the United States. Neely (2010) evaluates the effect of large-scale asset purchases (LSAP) on international long-term bond yields and exchange rates, and gets the result that the LSAP announcements substantially reduces international long-term bond rates and the spot value of the dollar.

In this section we are going to empirically study the influences of US money supply shock on the global economy, especially on China's economy, by employing a GVAR model in which US money supply is incorporated as a global factor. The GVAR framework is pioneered in Pesaran, Schuermann and Weiner (2004) and further developed in Dees, di Mauro, Pesaran, and Smith (2007) (henceforth DdPS), Dees, Holly, Pesaran, and Smith (2007) and Pesaran, Schuermann and Smith (2009a). The methodology we employ in this paper is mainly based on DdPS.

3.1. Preliminary specification

Following DdPS, we consider 26 developed and emerging market economies whose GDP is about 90% of the world output. Euro area (EA), which includes Austria, Belgium, Finland, France, Germany, Italy, Netherlands, and Spain, is treated as a single economy.

The variables under consideration are real GDP (GDP_t^j), inflation rate (Π_t^j), real equity price (eq_t^j), real exchange rate (ex_t^j), nominal short-term interest rate (R_t^j), nominal long-term interest rate (LR_t^j), oil price ($Poil_t$), and US money supply (M_t^{US}), where the subscript j denotes country and t denotes time.

3.2. Country-specific VARX* models

The country-specific VARX*(p_j, q_j) could be written as:

$$\Phi_j\left(L, p_j\right)X_t^j = \alpha_0^j + \alpha_1^j \cdot t + \Upsilon_j\left(L, q_j\right)d_t + \Lambda_j\left(L, q_j\right)X_t^{j*} + u_t^j$$

for $j = 0, 1, \ldots, N = 25$, where X_t^j is the vector of domestic variables, X_t^{j*} is the vector of foreign variables, d_t is the vector of observed global factors, L is the lag operator, Φ_j, Υ_j and Λ_j are the polynomials of L with order p_j, q_j and q_j respectively, α_0^j and α_1^j are the coefficients for the deterministic trend, u_t^j is the idiosyncratic country-specific shock, $j = 0$ denotes US and $j = 1, 2, \ldots, 25$ denote

other 25 economies. We assume both p_j and q_j are not bigger than two. Country-specific vector of foreign variables X_t^{j*} is constructed as follows:

$$X_t^{j*} = \sum_{k=0}^{N} w_{jk} X_t^k$$

where $w_{jj} = 0$ and $\sum_{k=0}^{N} w_{jk} = 1$ for any j. The weight w_{jk} captures the importance of country k for country j's economy, and here is calculated as a fixed number over time by using bilateral trade data from 2006 to 2008[3].

With the exception of US model, in the country-specific VARX* model for all other countries vector X_t^j includes GDP_t^j, Π_t^j, eq_t^j, ex_t^j, R_t^j, and LR_t^j when the relevant data are available for this country, vector X_t^{j*} includes GDP_t^{j*}, Π_t^{j*}, eq_t^{j*}, R_t^{j*}, and LR_t^{j*}, and vector d_t contains $Poil_t$ and M_t^{US}. In the case of US model when $j = 0$, vector X_t^0 includes GDP_t^0, Π_t^0, eq_t^0, R_t^0, LR_t^0, $Poil_t$ and M_t^{US} where oil price and US money supply are viewed as endogenous variables, X_t^{0*} includes GDP_t^{0*}, Π_t^{0*}, ex_t^{0*} and R_t^{0*} where foreign financial variables eq_t^{0*} and LR_t^{0*} are omitted due to the importance of US financial variables in the global economy, and there is no global variable for US, as given in Table 2 below.

Table 2. VARX* model specifications

Economy	Domestic Variables	Foreign Variables	Global Variables
US	GDP_t^0, Π_t^0, eq_t^0, R_t^0, LR_t^0, $Poil_t$, M_t^{US}	GDP_t^{0*}, Π_t^{0*}, ex_t^{0*}, R_t^{0*}	None
Others	GDP_t^j, Π_t^j, eq_t^j, ex_t^j, R_t^j, LR_t^j where available	GDP_t^{j*}, Π_t^{j*}, eq_t^{j*}, R_t^{j*}, LR_t^{j*}	$Poil_t$, M_t^{US}

We consider at most a VARX*(2, 2) specification for each country model, which in error correction form can be expressed as follows:

$$\Delta X_t^j = c_0^j - a_j \beta_j' \left[z_{t-1}^j - \gamma_j (t-1) \right] + \Upsilon_{j0} \Delta d_t + \Lambda_{j0} \Delta X_t^{j*} + \Upsilon_{j1} \Delta d_{t-1} + \Gamma_j \Delta v_{t-1}^j + u_t^j$$

where $z_t^j = \left((X_t^j)', (X_t^{j*})', (d_t)' \right)'$, $v_t^j = \left((X_t^j)', (X_t^{j*})' \right)'$, a_j and β_j are both full column rank matrices, and the error correction term is defined as:

$$\beta_j' \left[z_t^j - \gamma_j \cdot t \right] = \beta_j' \left[\left((X_t^j)', (X_t^{j*})', (d_t)' \right)' - \gamma_j \cdot t \right]$$

which allows for the possibility of co-integration within domestic variables and between domestic and foreign variables.

3.3. The GVAR model

After each country's VARX* model is estimated, all the endogenous variables X_t^j $(j = 0, 1, \ldots, N = 25)$ are collected in the global vector:

$$X_t = \left((X_t^0)', (X_t^1)', \ldots, (X_t^N)' \right)'$$

Then there is a linear relationship between X_t and z_t^j:

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[3] A robust analysis in which the time-varying weights are used could be done, just as in DdPS.

$$z_t^j = W_j X_t$$

Substitute this equation into the country-specific VARX* model, we can get:

$$A_j W_j X_t = \alpha_0^j + \alpha_1^j \cdot t + u_t^j$$

where $A_j = (\Phi_j, -\Lambda_j, -\Upsilon_j)$ is a polynomial of lag operator L with order less than or equal to two. If we define

$$G = ((A_0 W_0)', (A_1 W_1)', \dots, (A_N W_N)')'$$
$$\alpha_0 = (\alpha_0^{0'}, \alpha_0^{1'}, \dots, \alpha_0^{N'})'$$
$$\alpha_1 = (\alpha_1^{0'}, \alpha_1^{1'}, \dots, \alpha_1^{N'})'$$
$$u_t = (u_t^{0'}, u_t^{1'}, \dots, u_t^{N'})'$$

then we obtain a GVAR model for the global system:

$$G \cdot X_t = \alpha_0 + \alpha_1 \cdot t + u_t$$

Given the GVAR model, the generalized impulse response functions (GIRFs), proposed by Koop *et al.* (1996) and further developed by Pesaran and Shin (1998), are based on the definition:

$$GIRF(X_t; u_{lt}^j, n) = \mathbb{E}\left(X_{t+n} | u_{lt}^j = \sqrt{\sigma_{jl}^2}, I_{t-1}\right) - \mathbb{E}(X_{t+n} | I_{t-1})$$

where I_{t-1} is the information set at time $t-1$, σ_{jl}^2 is the diagonal element of the variance-covariance matrix Σ_u corresponding to the lth equation for the jth country, and n is the horizon.

3.4. Model estimation result

Except for M_t^{US}, the quarterly data for all other variables are originally from DdPS and further updated in Pesaran, Schuermann and Smith (2009b) and Smith and Galesi (2010), which cover the period from 1979Q2 to 2009Q4. All the values of these variables are in the same logarithmic forms as in DdPS. The data for US money supply M_t^{US} is from the website of Federal Reserve Bank of St. Louis[4], and the quarterly data is computed as the average of the monthly data. Here we use M0 as the indicator of US money supply. In fact, the monetary base of US dollar is a better variable to indicate the expansion of the Federal Reserve's balance sheet; nevertheless, it is not a money supply indicator. And M1 is normally broader than the monetary base. The correlation between M0 and the monetary base of US dollar (in logarithm) is 0.99, and in the period before 2008Q4 the ratio of M0 to the monetary base is very stable around 80%.

All the tests (including the weak exogeneity test) and estimations are implemented by the GVAR Toolbox 1.0, provided by Smith and Galesi (2010).[5] We focus on the GIRFs, for China's aggregate variables, of a positive one standard error shock to US money supply, which are shown in Figure 4. A positive one standard error shock to US money supply is equivalent to an increase of about 0.4% per quarter.

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[4] The website address is *http://research.stlouisfed.org/fred2/categories/24*.
[5] Tests including unit root test and weak exogeneity test, and estimation results of country-specific VARX* models are not shown here, but available upon request. Particularly, the weak exogeneity assumption can be considered to hold for the whole VARX* system.
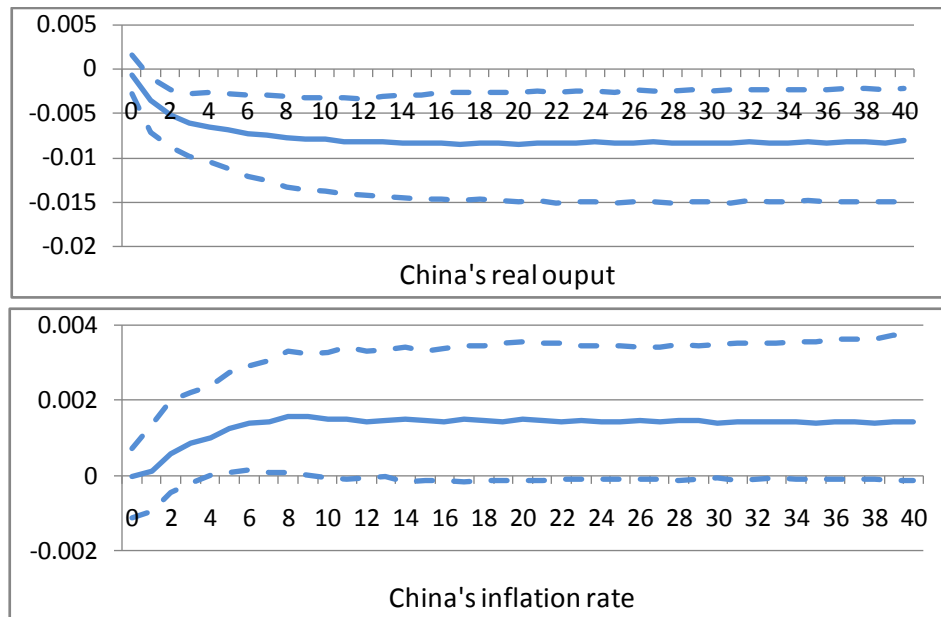
Figure 4. GIRFs of a positive one S.E. shock to US money supply

Overall, the real output o China has a significant decline, while its inflation rate is positively affected. We can provide an intuitive explanation as follows: when US money supply increases, US dollar is likely to depreciate, and then oil and many other commodities which are priced in US dollar are going to have higher prices. Since the exchange rate of RMB to US dollar is quite stable, the import prices of oil and other commodities for China will go up. Consequently, cost-push inflation is generated, and real output will decrease as well, according to the textbook AS-AD analysis.

3.5. The shortcomings of the empirical GVAR model

Although the above empirical GVAR model can give us some clue about how US money supply would affect China's economy, there are some patent shortcomings of this framework. First of all, as Dees *et al.* (2010) point out, it has proved difficult to use such reduced multi-country VARs to examine the effects of structural shocks with clear economic interpretation. Since the econometric model is not micro-founded, the transmission mechanism is not clear and not rationalized. The way the GAVR framework deals with the global linkages is also skeptical. Specifically, using trading weights to weight foreign financial variables such as interest rate is problematic, because international finance behaves in a quite different manner from that for international trade. Second, during the past decades the structure of global economy has changed dramatically, and a reduced form model with time-invariant coefficients can hardly capture this and is likely to tell biased stories.

Dees *et al.* (2010) try to incorporate the New Keynesian DSGE model into the GAVR framework. They criticize the existing multi-country DSGE literature that the open economy contributions have tended to use either models for two economies of comparable size, such as the Euro area and the US (as in de Walque *et al.*, 2005, for example), or small open economy models where the rest of the world is treated as

exogenous and there is no much interactions between them (as in Lubik and Schorfheide, 2007). So they build and estimate a relatively large multi-country New Keynesian DSGE-GVAR model, comprising 33 countries on quarterly data over the period 1979Q1-2006Q4. The country-specific models include a Phillips curve, an IS curve, a Taylor rule and a reduced-form real effective exchange rate equation. The main problem of the multi-country DSGE-GVAR model in Dees *et al.* (2010) is that the country-specific DSGE models are given arbitrarily, not strictly derived from the households' and firms' dynamic optimizations in a multi-country setting. For example, in the Phillips curve for an open economy, inflation rate depends not only on real marginal cost gap, but may also depend on some other variables such as terms of trade gap. They add real effective exchange rate and foreign output gap, which is also calculated as trade weighted average as in the traditional empirical GVAR models, into the IS curve. This is not strictly derived either. More importantly, with regard to our purpose in this paper, US dollar as a global currency cannot be straightforwardly incorporated into a simple four-equation country-specific DSGE model.

Therefore, in the following section we will develop a multi-country New Keynesian DSGE model in which we sufficiently take into account the interactions of different economies and US dollar is modeled as a global currency as well. Moreover, different institutional arrangements for different economies will also be considered.

4. BENCHMARK MODEL

Three economies are under consideration: China, US and ROW (rest of the world), among which China is viewed as the home country. US dollar serves as a global currency with two roles: there is dollar standard in international trade and US dollar is the only currency for foreign exchange reserve. The linkages through international trade and international finance will be endogenized. First of all, Table 3 below lists the institutional arrangements for each economy in our benchmark model.

Table 3. Institutional arrangements of the benchmark model

Economy	Exchange rate regime	Capital control	Exchange settlement and sales
China	Pegging dollar	Yes	Compulsory
US	Global currency	No	Not compulsory
ROW	Floating	No	Not compulsory

4.1. China's economy

4.1.1. Households

There is a continuum of infinitely-living households, and its measure is unity. A representative household seeks to maximize his life time utility:

$$U_0 = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[lnC_t - \phi_1 \cdot \frac{(L_t)^{1+\eta}}{1+\eta} + \phi_2 \cdot ln(M_t/P_t) \right] \tag{1}$$

where $\mathbb{E}$ is the expectation operator, β is the utility discount factor, ϕ_1 and ϕ_2

are the utility weights for labor supply L_t and real money balance M_t/P_t, P_t is the aggregate price level of final goods, and real consumption is C_t. For tractability, we assume additively separable utility here. And money is the Chinese currency: Renminbi.

The representative household can invest in two assets: real capital K_t which is used as a production factor with real rental rate r_t and domestic government bond B_t with nominal interest rate R_t. Since there are capital controls, Chinese households are not allowed to hold foreign assets such as the US government bonds in the benchmark model. Due to the monopolistic power of the intermediate-goods firms of the economy, nominal profit D_t is generated and then distributed to households. The government collects nominal lump-sum tax T_t from households. Therefore, the budget constraint for the representative household is:

$$P_t \cdot C_t + P_t \cdot K_{t+1} + B_{t+1} + T_t + M_t$$
$$\leq (1 - \delta + r_t) \cdot P_t \cdot K_t + W_t \cdot L_t + (1 + R_{t-1}) \cdot B_t + D_t + M_{t-1} \qquad (2)$$

where δ is the capital depreciation rate, and W_t is the nominal wage rate.

Then the household's problem is to choose the consumption level C_t, labor supply L_t, capital stock for the next period K_{t+1}, the quantity of government bond for the next period B_{t+1}, and the money demand M_t, in order to maximize his life time utility, equation (1), subject to the budget constraint of each period, equation (2), given the price level of final goods, the nominal wage rate, real capital rental rate and nominal bond interest rate. The first order conditions (FOCs) of the utility maximization problem can yield the following results:

$$\phi_1 \cdot C_t \cdot (L_t)^\eta = \frac{W_t}{P_t} \qquad (3)$$

$$\mathbb{E}_t \left\{ \beta \cdot \frac{C_t}{C_{t+1}} \cdot (1 - \delta + r_{t+1}) \right\} = 1 \qquad (4)$$

$$\mathbb{E}_t \left\{ \beta \cdot \frac{C_t}{C_{t+1}} \cdot \frac{P_t}{P_{t+1}} \cdot (1 + R_t) \right\} = 1 \qquad (5)$$

$$\frac{M_t}{P_t} = \frac{\phi_2 \cdot (1 + R_t)}{R_t} \cdot C_t \qquad (6)$$

4.1.2. Final good producers and price indices

Final good producers first produce home good $Y_{H,t}$ by combining a continuum of home-made intermediate goods $Y_{H,t}(i)$, and foreign good $Y_{F,t}$ by combining a continuum of imported foreign intermediate goods $Y_{j,t}(i)$ ($j = US$ or ROW); and then combine home good and foreign good to produce the final good Y_t, which can be used for households' consumption, capital investment and government's expenditure.

The final good producers are perfectly competitive and there is zero profit for these firms. The technologies of producing home and foreign good, and then final good are all CES technologies as follows:

$$Y_{H,t} = \left[\int_0^1 Y_{H,t}(i)^{\frac{\varepsilon-1}{\varepsilon}} di \right]^{\frac{\varepsilon}{\varepsilon-1}} \qquad (7)$$

$$Y_{F,t} = \left[(1-\rho_2)^{\frac{1}{\xi}} \cdot Y_{ROW,t}^{\frac{\xi-1}{\xi}} + \rho_2^{\frac{1}{\xi}} \cdot Y_{US,t}^{\frac{\xi-1}{\xi}} \right]^{\frac{\xi}{\xi-1}} \tag{8}$$

$$Y_{US,t} = \left[\int_0^1 Y_{US,t}(i)^{\frac{\varepsilon-1}{\varepsilon}} di \right]^{\frac{\varepsilon}{\varepsilon-1}} \tag{9}$$

$$Y_{ROW,t} = \left[\int_0^1 Y_{ROW,t}(i)^{\frac{\varepsilon-1}{\varepsilon}} di \right]^{\frac{\varepsilon}{\varepsilon-1}} \tag{10}$$

$$Y_t = \left[(1-\rho_1)^{\frac{1}{\omega}} \cdot Y_{H,t}^{\frac{\omega-1}{\omega}} + \rho_1^{\frac{1}{\omega}} \cdot Y_{F,t}^{\frac{\omega-1}{\omega}} \right]^{\frac{\omega}{\omega-1}} \tag{11}$$

where i represents the brand of intermediate goods, $j(=US \text{ or } ROW)$ is the country index, $Y_{j,t}$ is the foreign goods bundle from country j, ε denotes the elasticity of substitution between the differentiated intermediate goods within one single country, ξ measures the substitutability between goods produced in two foreign countries, ω represents the elasticity of substitution between domestic and foreign goods, ρ_1 refers to the share of domestic aggregate demand allocated to foreign goods and is thus a natural index of openness of the Chinese economy, and ρ_2 indicates the import share from US.

Table 4. Price system of the benchmark model

Economy	Domestically sold goods			Export goods		
	Intermediate goods	bundle	Invoicing currency	Intermediate goods	bundle	Invoicing currency
China	$P_{H,t}(i)$	$P_{H,t}$	Renminbi	$P_{H,t}^E(i)$	$P_{H,t}^E$	Dollar
US	$P_{US,t}^\$(i)$	$P_{US,t}^\$$	Dollar	$P_{US,t}^E(i)$	$P_{US,t}^E$	Dollar
ROW	$P_{ROW,t}^{Ro}(i)$	$P_{ROW,t}^{Ro}$	Ro	$P_{ROW,t}^E(i)$	$P_{ROW,t}^E$	Dollar

Then given the price levels of goods (described in Table 4), the cost minimization problem of the representative final good producer yields the following demand functions:

$$Y_{H,t}(i) = \left(\frac{P_{H,t}(i)}{P_{H,t}} \right)^{-\varepsilon} \cdot Y_{H,t} \tag{12}$$

$$Y_{US,t}(i) = \left(\frac{P_{US,t}^E(i)}{P_{US,t}^E} \right)^{-\varepsilon} \cdot Y_{US,t} \tag{13}$$

$$Y_{ROW,t}(i) = \left(\frac{P_{ROW,t}^E(i)}{P_{ROW,t}^E} \right)^{-\varepsilon} \cdot Y_{ROW,t} \tag{14}$$

$$Y_{US,t} = \rho_2 \cdot \left(\frac{P_{US,t}^E}{P_{F,t}^\$} \right)^{-\xi} \cdot Y_{F,t} \tag{15}$$

$$Y_{ROW,t} = (1-\rho_2) \cdot \left(\frac{P_{ROW,t}^E}{P_{F,t}^\$} \right)^{-\xi} \cdot Y_{F,t} \tag{16}$$

$$Y_{H,t} = (1 - \rho_1) \cdot \left(\frac{P_{H,t}}{P_t}\right)^{-\omega} \cdot Y_t \tag{17}$$

$$Y_{F,t} = \rho_1 \cdot \left(\frac{P_{F,t}^{\$} \cdot EX_t}{P_t}\right)^{-\omega} \cdot Y_t \tag{18}$$

where $P_{F,t}^{\$}$ is the aggregate price of foreign goods for China, denominated in US dollar; and EX_t is the exchange rate (US dollar to Renminbi).

Since the final good producers are perfectly competitive and there is no profit for them, we can easily derive the following price index formulas:

$$P_{H,t} = \left[\int_0^1 P_{H,t}(i)^{1-\varepsilon} di\right]^{\frac{1}{1-\varepsilon}} \tag{19}$$

$$P_{US,t}^E = \left[\int_0^1 P_{US,t}^E(i)^{1-\varepsilon} di\right]^{\frac{1}{1-\varepsilon}} \tag{20}$$

$$P_{ROW,t}^E = \left[\int_0^1 P_{ROW,t}^E(i)^{1-\varepsilon} di\right]^{\frac{1}{1-\varepsilon}} \tag{21}$$

$$P_{F,t}^{\$} = \left[(1 - \rho_2) \cdot P_{ROW,t}^E{}^{1-\xi} + \rho_2 \cdot P_{US,t}^E{}^{1-\xi}\right]^{\frac{1}{1-\xi}} \tag{22}$$

$$P_t = \left[(1 - \rho_1) \cdot P_{H,t}{}^{1-\omega} + \rho_1 \cdot (P_{F,t}^{\$} \cdot EX_t)^{1-\omega}\right]^{\frac{1}{1-\omega}} \tag{23}$$

In this paper we assume that three elasticities of substitution, ε, ξ, and ω, are the same across economies. Therefore, similarly we have the following expression:

$$P_{H,t}^E = \left[\int_0^1 P_{H,t}^E(i)^{1-\varepsilon} di\right]^{\frac{1}{1-\varepsilon}} \tag{24}$$

Then the terms of trade for China's economy can be defined as below:

$$TOT_t = P_{F,t}^{\$}/P_{H,t}^E \tag{25}$$

4.1.3. Intermediate-goods firms and prices setting

Intermediate goods market is monopolistically competitive. Firm i produces a differentiated intermediate good i with a Cobb-Douglas production function:

$$Y_t(i) = a_t \cdot K_t(i)^{1-\alpha} \cdot [L_t(i)]^{\alpha} \tag{26}$$

where a temporary productivity shock a_t follows the following stochastic process:

$$ln a_t = \rho_a \cdot ln a_{t-1} + v_t^a, v_t^a \sim N(0, \sigma_a^2) \tag{27}$$

The cost minimization problem is: given the prices of capital and labor, and the production function, equation (26),

$$\min_{\{K_t(i), L_t(i)\}} r_t \cdot K_t(i) + \frac{W_t}{P_t} \cdot L_t(i)$$

Then FOCs of the problem are as follows:

$$r_t = (1 - \alpha) \cdot a_t \cdot \left[\frac{K_t(i)}{L_t(i)}\right]^{-\alpha} \cdot mc_t(i) \tag{28}$$

$$\frac{W_t}{P_t} = \alpha \cdot a_t \cdot \left[\frac{K_t(i)}{L_t(i)}\right]^{1-\alpha} \cdot mc_t(i) \tag{29}$$

where $mc_t(i)$ is the real marginal cost. Equation (28) and (29) can imply:

$$\frac{W_t}{P_t \cdot r_t} = \frac{\alpha}{1-\alpha} \cdot \frac{K_t(i)}{L_t(i)} \tag{30}$$

$$mc_t(i) = \frac{1}{a_t} \cdot \frac{(1-\alpha)^{\alpha-1}}{\alpha^\alpha} \cdot \left(\frac{W_t}{P_t}\right)^\alpha \cdot (r_t)^{1-\alpha} \equiv mc_t \tag{31}$$

where the second part of equation (31) comes from the fact that the real marginal cost $mc_t(i)$ now does not depend on which kind of intermediate good it is, implying all the intermediate goods share the same real marginal cost.

Intermediate-goods firms need to set prices for both domestically sold and export goods; and the price of domestically sold goods is denominated in Renminbi, while the export price is set in US dollar. As the same logic for PCP explained in Corsetti *et al.* (2011), firms will optimally choose identical prices for both their ROW and US markets, since demand elasticities for intermediate goods are assumed to be constant and symmetric across countries in this paper, which is ε. This is why in our benchmark model the same exported good from one country to different destinations have only one price.

Following the staggered price setting of Calvo (1983), we assume each intermediate-goods firm may re-optimize its nominal prices, for both domestically sold and export, only with probability $1 - \theta$ in any given period. With probability θ, instead, the firm keeps its prices the same as in the previous period. Combining the fact that all firms resetting prices will choose an identical price combination $(P_{H,t}^S, P_{H,t}^{E,S})$ with equation (19), we can get:

$$P_{H,t} = \left[\theta \cdot (P_{H,t-1})^{1-\varepsilon} + (1-\theta) \cdot P_{H,t}^S{}^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}} \tag{32}$$

At the deterministic steady state, $P_{H,t}^S = P_{H,t}$. So log-linearization of equation (32) will yield the following:

$$\Pi_{H,t} = (1-\theta) \cdot \left(ln P_{H,t}^S - ln P_{H,t-1}\right) \tag{33}$$

The price-resetting firm sets prices $P_{H,t}^S$ and $P_{H,t}^{E,S}$ to maximize the current market value of the profits generated while that price remains effective, which means it solves the following optimization problem:

$$max_{\{P_{H,t}^S, P_{H,t}^{E,S}\}} \sum_{k=0}^\infty \theta^k \cdot \mathbb{E}_t \left\{ F_{t,t+k} \cdot \left[\begin{matrix} P_{H,t}^S \cdot Y_{t+k|t}^D + \\ P_{H,t}^{E,S} \cdot EX_{t+k|t} \cdot Y_{t+k|t}^F - \Phi_{t+k}(Y_{t+k|t}) \end{matrix} \right] \right\} \tag{34}$$

subject to the sequence of demand constraints:

$$\begin{cases} Y_{t+k|t} = Y_{t+k|t}^D + Y_{t+k|t}^F \\ Y_{t+k|t}^D = \left[\frac{P_{H,t}^S}{P_{H,t+k}}\right]^{-\varepsilon} \cdot Y_{t+k}^D \\ Y_{t+k|t}^F = \left[\frac{P_{H,t}^{E,S}}{P_{H,t+k}^E}\right]^{-\varepsilon} \cdot Y_{t+k}^F \end{cases} \tag{35}$$

where $F_{t,t+k}$ is the discount factor for nominal payoffs; Φ_{t+k} is the nominal cost function; $Y_{t+k|t}$ denotes output in period $t + k$ for a firm that last freely reset its price in period t, which equals domestic demand $Y_{t+k|t}^D$ plus foreign demand $Y_{t+k|t}^F$; and Y_{t+k}^D and Y_{t+k}^F are respectively the total domestic and foreign demand for made-in-China goods. FOCs of the above problem are given by:

$$\begin{cases} \sum_{k=0}^{\infty} \theta^k \cdot \mathbb{E}_t \{ F_{t,t+k} \cdot Y_{t+k|t}^D \cdot [P_{H,t}^S - \kappa \cdot \Phi'_{t+k|t}] \} = 0 \\ \sum_{k=0}^{\infty} \theta^k \cdot \mathbb{E}_t \{ F_{t,t+k} \cdot Y_{t+k|t}^F \cdot [P_{H,t}^{E,S} \cdot EX_{t+k|t} - \kappa \cdot \Phi'_{t+k|t}] \} = 0 \end{cases} \quad (36)$$

where $\Phi'_{t+k|t} = \Phi'_{t+k}(Y_{t+k|t})$ is the nominal marginal cost in period $t+k$ for a firm that last reset its price in period t and $\Phi'_{t+k|t} = P_{t+k} \cdot mc_{t+k|t}$, and $\kappa = \varepsilon/(\varepsilon - 1)$ which can be interpreted as the desired or frictionless markup. When there is no price rigidity ($\theta = 0$), the above FOCs collapse to the familiar optimal price setting under flexible prices:

$$\begin{cases} P_{H,t}^S = \kappa \cdot \Phi'_{t|t} \\ P_{H,t}^{E,S} = \kappa \cdot \Phi'_{t|t}/EX_t \end{cases}$$

The discount factor for nominal payoffs, $F_{t,t+k}$, can be defined as follows:

$$F_{t,t+1} \triangleq \frac{1}{1+R_t} = \mathbb{E}_t \left\{ \beta \cdot \frac{C_t}{C_{t+1}} \cdot \frac{P_t}{P_{t+1}} \right\} \quad (37)$$

$$F_{t,t+k} \triangleq \prod_{i=0}^{k-1} F_{t+i,t+i+1} = \prod_{i=0}^{k-1} \frac{1}{1+R_{t+i}} \quad (38)$$

where the second equality of equation (37) is derived from equation (5).

In the zero-growth and zero-inflation steady state, $EX_{t+k|t} = EX_t = EX$, $P_{H,t}^S = P_{H,t}$, $P_{H,t}^{E,S} = P_{H,t}^E$, and LOOP holds as well: $P_{H,t}^S = P_{H,t}^{E,S} \cdot EX_t$. We view the home good, $Y_{H,t}$, as the numeraire, and at the steady state the relative prices of foreign goods, $P_{US,t}^E \cdot EX_t/P_{H,t} \triangleq \tau_t^{US}$ and $P_{ROW,t}^E \cdot EX_t/P_{H,t} \triangleq \tau_t^{ROW}$, will be constant numbers, τ^{US} and τ^{ROW} respectively. Then the first-order Taylor expansion of FOCs, equation (36), will yield the following result:

$$\begin{cases} lnP_{H,t}^S - lnP_{H,t-1} = \beta \cdot \theta \cdot \mathbb{E}_t (lnP_{H,t+1}^S - lnP_{H,t}) + \\ \quad (1 - \beta \cdot \theta) \cdot (\widehat{mc}_t + lnP_t - lnP_{H,t}) + \Pi_{H,t} \\ lnP_{H,t}^{E,S} - lnP_{H,t-1}^E = \beta \cdot \theta \cdot \mathbb{E}_t (lnP_{H,t+1}^{E,S} - lnP_{H,t}^E) + \\ \quad (1 - \beta \cdot \theta) \cdot (\widehat{mc}_t + lnP_t - lnEX_t - lnP_{H,t}^E) + \Pi_{H,t}^E \end{cases} \quad (39)$$

where $\widehat{mc}_t = ln(mc_t) - ln(mc)$ is the log deviation of real marginal cost from its steady state value mc, and $mc = 1/\kappa = (\varepsilon - 1)/\varepsilon$; $\Pi_{H,t} \triangleq lnP_{H,t} - lnP_{H,t-1}$ and $\Pi_{H,t}^E \triangleq lnP_{H,t}^E - lnP_{H,t-1}^E$ are respectively the home-made goods' inflation rates for domestic price and export price.

At the steady state we have the following:

$$TOT_t = TOT \triangleq [(1 - \rho_2) \cdot (\tau^{ROW})^{1-\xi} + \rho_2 \cdot (\tau^{US})^{1-\xi}]^{\frac{1}{1-\xi}}$$

$$P_t/P_{H,t} = \tau \triangleq [(1 - \rho_1) + \rho_1 \cdot (TOT)^{1-\omega}]^{\frac{1}{1-\omega}}$$

And around the steady state, equations (23) and (25) together can imply that:[6]

$$lnP_t = lnP_{H,t} + \varphi \cdot (tot_t + x_t) \quad (40)$$

where $\varphi \triangleq 1 - \frac{1-\rho_1}{(1-\rho_1)+\rho_1 \cdot (TOT)^{1-\omega}}$; $tot_t \triangleq ln(TOT_t/TOT)$ and $x_t \triangleq ln(P_{H,t}^E \cdot EX_t/$

$P_{H,t})$ can be called terms of trade gap and LOOP gap respectively, which are the log deviations from their corresponding steady state values.

4.1.4. Dollar pricing, PCP, LCP and open-economy NKPC

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[6] In equation (40) and hereafter for any log-linearized equation, a constant term is omitted, since later on we will put the whole model into a cyclical representation where there is no constant term.

In a two-country model, dollar pricing is equivalent to the case that PCP is assumed for one country and LCP for the other. In our three-country model of this paper, the situation becomes more complicated. In fact, for US it is always PCP, for ROW it can be viewed as a partial LCP, and for China it is essentially PCP under the fixed exchange rate regime ad a partial LCP under the flexible exchange rate regime. To unify the analysis, we begin with the most general context.

Equation (40), together with equation (33) and (39), will give the following open-economy New-Keynesian Phillips curve (NKPC):

$$\Pi_{H,t} = \beta \cdot \mathbb{E}_t\big(\Pi_{H,t+1}\big) + \frac{(1-\theta)\cdot(1-\beta\cdot\theta)}{\theta} \cdot \{\widehat{mc}_t + \varphi \cdot (tot_t + x_t)\} \qquad (41)$$

Similarly, we can have another NKPC for export price:

$$\Pi_{H,t}^E = \beta \cdot \mathbb{E}_t\big(\Pi_{H,t+1}^E\big) + \frac{(1-\theta)\cdot(1-\beta\cdot\theta)}{\theta} \cdot \{\widehat{mc}_t - x_t + \varphi \cdot (tot_t + x_t)\} \qquad (42)$$

Here the inflation rates of home-made goods do not only depend on their future expectations and the real marginal cost, but also depend on the terms of trade and LOOP gap.

Particularly, for the benchmark setting with China's fixed exchange rate regime, the pricing mechanism of China's firms is in fact PCP, since the exchange rate of Renminbi EX_t is fixed as EX, and choosing $P_{H,t}^{E,S}$ is equivalent to choose $P_{H,t}^{E,S} \cdot EX$.

Under PCP, as explained in Corsetti *et al.* (2011), firms will optimally choose identical prices for both their domestic and export markets, and the LOOP will hold independently of barriers to markets integration. Therefore, $x_t \equiv 0$, and the open-economy NKPC with respect to the export goods' price, which is equation (42), will degrade to and should be replaced by the following LOOP condition:

$$P_{H,t}^E \cdot EX = P_{H,t}$$

When China adopts a flexible exchange rate regime, equation (42) applies.

4.1.5. Equilibrium and aggregation

Government debt B_t evolves according to:

$$B_{t+1} = (1 + R_{t-1}) \cdot B_t + G_t - T_t \qquad (43)$$

For labor market and capital market, we have the following market clearing conditions:

$$L_t = \int_0^1 L_t(i)\, di \qquad (44)$$

$$K_{t+1} = \int_0^1 K_{t+1}(i)\, di = (1-\delta) \cdot K_t + I_t \qquad (45)$$

We define the real GDP of China in the way below:

$$GDP_t \triangleq \left[\int_0^1 Y_t(i)^{\frac{\varepsilon-1}{\varepsilon}} di\right]^{\frac{\varepsilon}{\varepsilon-1}} \qquad (46)$$

And we also have the following aggregate demand equation:

$$Y_t = C_t + I_t + G_t/P_t \qquad (47)$$

The market clearing condition for each intermediate good is:

$$Y_t(i) = Y_{H,t}(i) + Y_{H,t}^{US}(i) + Y_{H,t}^{ROW}(i) \tag{48}$$

where $Y_{H,t}^j(i)$ is the demand of home-made intermediate good i from country j. According to equation (12)-(18) and their counterparts for US and ROW economies, equation (48) is equivalent to the following:

$$Y_t(i) = \left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{-\varepsilon} \cdot (1-\rho_1) \cdot \left(\frac{P_{H,t}}{P_t}\right)^{-\omega} \cdot Y_t$$

$$+ \left(\frac{P_{H,t}^E(i)}{P_{H,t}^E}\right)^{-\varepsilon} \cdot \rho_2^{US} \cdot \left(\frac{P_{H,t}^E}{P_{F,t}^{US}}\right)^{-\xi} \cdot \rho_1^{US} \cdot \left(\frac{P_{F,t}^{US}}{P_t^{US}}\right)^{-\omega} \cdot Y_t^{US}$$

$$+ \left(\frac{P_{H,t}^E(i)}{P_{H,t}^E}\right)^{-\varepsilon} \cdot \rho_2^{ROW} \cdot \left(\frac{P_{H,t}^E}{P_{F,t}^{ROW}}\right)^{-\xi} \cdot \rho_1^{ROW} \cdot \left(\frac{P_{F,t}^{ROW} \cdot EXR_t}{P_t^{ROW}}\right)^{-\omega} \cdot Y_t^{ROW} \tag{49}$$

where $P_{F,t}^j$, P_t^j, and Y_t^j are respectively foreign good price, aggregate price, and aggregate demand of country $j(= US \ or \ ROW)$; ρ_1^j and ρ_2^j are the country j's degree of openness parameters; and EXR_t is the exchange rate for the currency RO (US dollar to RO).

Log-linearizing of equation (46), (49), (22) and (23) around the steady state when $Y_t(i) = GDP_t$, together with equation (40) and the corresponding counterpart equations for the other two economies, we can have the following log-linearized market clearing condition for China's GDP:

$$lnGDP_t = \frac{(1-\rho_1) \cdot \tau^\omega \cdot Y}{GDP} \cdot [lnY_t + \omega \cdot \varphi \cdot (tot_t + x_t)]$$

$$+ \frac{\rho_2^{US} \cdot \rho_1^{US} \cdot \tau_1^\xi \cdot \tau_2^\omega \cdot Y^{US}}{GDP} \cdot \begin{bmatrix} lnY_t^{US} - \xi \cdot (1-\tau_5) \cdot \left(lnP_{H,t}^E - lnP_{ROW,t}^E\right) \\ -\omega \cdot (1-\varphi^{US}) \cdot (tot_t^{US} + x_t^{US}) \end{bmatrix}$$

$$+ \frac{\rho_2^{ROW} \cdot \rho_1^{ROW} \cdot \tau_3^\xi \cdot \tau_4^\omega \cdot Y^{ROW}}{GDP} \cdot \begin{bmatrix} lnY_t^{ROW} - \xi \cdot (1-\tau_6) \cdot \left(lnP_{H,t}^E - lnP_{US,t}^E\right) \\ -\omega \cdot (1-\varphi^{ROW}) \cdot (tot_t^{ROW} + x_t^{ROW}) \end{bmatrix} \tag{50}$$

where variables without subscript t mean steady state values; tot_t^j and x_t^j are respectively the terms of trade gap and LOOP gap for country $j(= US \ or \ ROW)$; φ^{US} and φ^{ROW} are defined similarly to φ; constants τ_1, τ_2, τ_3, τ_4, τ_5, and τ_6 are determined by steady state price ratios (τ^{US} and τ^{ROW}).

Certainly the following identity holds:

$$(1-\rho_1) \cdot \tau^\omega \cdot Y + \rho_2^{US} \cdot \rho_1^{US} \cdot \tau_1^\xi \cdot \tau_2^\omega \cdot Y^{US} + \rho_2^{ROW} \cdot \rho_1^{ROW} \cdot \tau_3^\xi \cdot \tau_4^\omega \cdot Y^{ROW} \equiv GDP$$

This identity in fact tells that in the steady state the domestic GDP of China consists of three parts: domestic demand, demand from US and demand from ROW. Constants τ, τ_1, τ_2, τ_3, and τ_4 represent the relative price effects. However, in normal times equation (50) indicates that China's GDP is also influenced by each economy's terms of trade gap and LOOP gap, and by export price differentials ($lnP_{H,t}^E - lnP_{ROW,t}^E$, and $lnP_{H,t}^E - lnP_{US,t}^E$) as well.

4.1.6. The external sector, current account and Central Bank's balance sheet

As China's capital account is closed, the private sector is not allowed to hold foreign assets. Instead, exporters swap their US dollar proceeds for domestic currency

(Renminbi), and importers swap Renminbi for US dollar, with the Central Bank (PBOC) at par market values. If there is a trade surplus, then Central Bank will increase the supply of Renminbi, and use the net inflow of US dollar to buy more US government bonds. Then for the US economy, money supply is not changed, while the demand for its government bond is increased. Similarly, if there is a trade deficit, the Central Bank will decrease both the supply of Renminbi and the demand of US government bonds.

Nominal net export of China, NNX_t, is denominated in US dollar and defined as:

$$NNX_t \triangleq P_{H,t}^E \cdot \left(Y_{H,t}^{US} + Y_{H,t}^{ROW} \right) - P_{F,t}^{\$} \cdot Y_{F,t} \tag{51}$$

Then GDP deflator, Def_t, can be defined as:

$$Def_t \triangleq (P_t \cdot Y_t + NNX_t \cdot EX_t)/GDP_t \tag{52}$$

Since the nominal profit comes from the monopolistic power of intermediate-goods firms, we have the following identity:

$$D_t = Def_t \cdot GDP_t - W_t \cdot L_t - P_t \cdot K_t \cdot r_t$$

Combining the above equation with the budget constraint of the representative household, equation (2), we can get the national account identity as follows:

$$Def_t \cdot GDP_t = P_t \cdot C_t + P_t \cdot I_t + G_t + (M_t - M_{t-1})$$

As we will see in equation (57), the term of money growth, $M_t - M_{t-1}$, is actually equal to the nominal net export denominated in Renminbi.

Given the relationships between aggregate demand of one economy and its components, nominal net export of China NNX_t then can be expressed as below:

$$NNX_t = P_{H,t}^E \cdot \begin{bmatrix} \rho_2^{US} \cdot \left(\dfrac{P_{H,t}^E}{P_{F,t}^{US}} \right)^{-\xi} \cdot \rho_1^{US} \cdot \left(\dfrac{P_{F,t}^{US}}{P_t^{US}} \right)^{-\omega} \cdot Y_t^{US} + \\ \rho_2^{ROW} \cdot \left(\dfrac{P_{H,t}^E}{P_{F,t}^{ROW}} \right)^{-\xi} \cdot \rho_1^{ROW} \cdot \left(\dfrac{P_{F,t}^{ROW} \cdot EXR_t}{P_t^{ROW}} \right)^{-\omega} \cdot Y_t^{ROW} \end{bmatrix}$$
$$- P_{F,t}^{\$} \cdot \rho_1 \cdot \left(\dfrac{P_{F,t}^{\$} \cdot EX_t}{P_t} \right)^{-\omega} \cdot Y_t \tag{53}$$

So the steady state value of nominal net export, NNX, is:

$$NNX = P_H^E \cdot \begin{bmatrix} \rho_2^{US} \cdot \rho_1^{US} \cdot \tau_1^{\xi} \cdot \tau_2^{\omega} \cdot Y^{US} + \\ \rho_2^{ROW} \cdot \rho_1^{ROW} \cdot \tau_3^{\xi} \cdot \tau_4^{\omega} \cdot Y^{ROW} - \rho_1 \cdot TOT^{1-\omega} \tau^{\omega} \cdot Y \end{bmatrix} \tag{54}$$

The (nominal) current account surplus (CA_t) equals the trade surplus plus the net interest income received from holdings of US government bonds. Since the amount of foreign capital inflows equals the current account surplus, and Central Bank buys up any net inflow of US dollar from the private sector using Renminbi (the so-called *non-sterilized* foreign-exchange reserve intervention) and then exchanges US dollar for US government bond; we have the following:

$$CA_t \triangleq NNX_t + R_{t-1}^{US} \cdot B_{H,t}^{US} \tag{55}$$

$$B_{H,t+1}^{US} = CA_t + B_{H,t}^{US} \tag{56}$$

$$M_t^S - M_{t-1}^S = EX_t \cdot \left[B_{HCB,t+1}^{US} - (1 + R_{t-1}^{US}) \cdot B_{HCB,t}^{US} \right] \tag{57}$$

where $B_{H,t}^{US}$ denotes China's foreign reserve, which here equals the Central Bank's

holdings of US government bond at the period t, $B_{HCB,t}^{US}$; R_{t-1}^{US} is the interest rate of US government bond; and M_t^S is the money supply of Renminbi. In the benchmark setting, the exchange rate for Renminbi, EX_t, is assumed to be fixed at its steady-state level: $EX_t = EX$.

4.2. The economies of US and rest of the world (ROW)

While many ingredients of the model economies of US and ROW are similar to China's above, there are some structural differences due to the differences in institutional arrangements. Except that three elasticities of substitution, ε, ξ, and ω, are assumed to be the same across economies, we allow for differences in other structural parameters such as the degree of openness, Calvo price stickiness and households preference parameters.

Particularly, for the open-economy NKPCs of country $j (= US\ or\ ROW)$, we have the following expressions, as the counterparts of equation (41) and (42):

$$\Pi_{j,t}^j = \beta^j \cdot \mathbb{E}_t\left(\Pi_{j,t+1}^j\right) + \frac{(1-\theta^j)\cdot(1-\beta^j\cdot\theta^j)}{\theta^j} \cdot \left\{\widehat{mc_t^j} + \varphi^j \cdot (tot_t^j + x_t^j)\right\} \qquad (58)$$

$$\Pi_{j,t}^E = \beta^j \cdot \mathbb{E}_t\left(\Pi_{j,t+1}^E\right) + \frac{(1-\theta^j)\cdot(1-\beta^j\cdot\theta^j)}{\theta^j} \cdot \left\{\widehat{mc_t^j} - x_t^j + \varphi^j \cdot (tot_t^j + x_t^j)\right\} \qquad (59)$$

where variables and parameters with superscript (or subscript) j denote the corresponding variables and parameters for country j which are defined in the similar way to those for China's economy. It is worth pointing out that for US equation (59) will degenerate to the LOOP condition: $P_{US,t}^E = P_{US,t}^\$$, since the logic of PCP holds here.

Similarly, as the counterparts of equation (50), aggregate demand equations for US and ROW can be expressed as follows:

$$lnGDP_t^{US} = \frac{(1-\rho_1^{US})\cdot(\frac{\tau_1\cdot\tau_2}{\tau^{US}})^\omega \cdot Y^{US}}{GDP^{US}} \cdot [lnY_t^{US} + \omega \cdot \varphi^{US} \cdot (tot_t^{US} + x_t^{US})]$$

$$+ \frac{\rho_2\cdot\rho_1\cdot(\frac{TOT}{\tau^{US}})^\xi\cdot(\frac{\tau}{TOT})^\omega \cdot Y}{GDP^{US}} \cdot \begin{bmatrix} lnY_t - \xi\cdot(1-\tau_7)\cdot\left(lnP_{US,t}^E - lnP_{ROW,t}^E\right) \\ -\omega\cdot(1-\varphi_1)\cdot(tot_t + x_t) \end{bmatrix}$$

$$+ \frac{(1-\rho_1^{ROW})\cdot\rho_1^{ROW}\cdot(\frac{\tau_3}{\tau^{US}})^\xi\cdot(\tau_4)^\omega \cdot Y^{ROW}}{GDP^{US}} \cdot \begin{bmatrix} lnY_t^{ROW} - \xi\cdot\tau_6\cdot\left(lnP_{US,t}^E - lnP_{H,t}^E\right) \\ -\omega\cdot(1-\varphi^{ROW})\cdot(tot_t^{ROW} + x_t^{ROW}) \end{bmatrix} \qquad (60)$$

$$lnGDP_t^{ROW} = \frac{(1-\rho_1^{ROW})\cdot(\frac{\tau_3\cdot\tau_4}{\tau^{ROW}})^\omega \cdot Y^{ROW}}{GDP^{ROW}} \cdot [lnY_t^{ROW} + \omega \cdot \varphi^{ROW} \cdot (tot_t^{ROW} + x_t^{ROW})]$$

$$+ \frac{(1-\rho_2)\cdot\rho_1\cdot(\frac{TOT}{\tau^{ROW}})^\xi\cdot(\frac{\tau}{TOT})^\omega \cdot Y}{GDP^{ROW}} \cdot \begin{bmatrix} lnY_t - \xi\cdot\tau_7\cdot\left(lnP_{ROW,t}^E - lnP_{US,t}^E\right) \\ -\omega\cdot(1-\varphi)\cdot(tot_t + x_t) \end{bmatrix}$$

$$+ \frac{(1-\rho_2^{US})\cdot\rho_1^{US}\cdot(\frac{\tau_1}{\tau^{ROW}})^\xi\cdot\tau_2^\omega \cdot Y^{US}}{GDP^{ROW}} \cdot \begin{bmatrix} lnY_t^{US} - \xi\cdot\tau_5\cdot\left(lnP_{ROW,t}^E - lnP_{H,t}^E\right) \\ -\omega\cdot(1-\varphi^{US})\cdot(tot_t^{US} + x_t^{US}) \end{bmatrix} \qquad (61)$$

Since we assume there is no capital control for US and ROW, the households of ROW are allowed to buy US bonds. To capture home bias in the household's portfolio choice, following Chang *et al.* (2013) we assume in this paper that domestic bonds

and US bonds are imperfect substitutes.[7] It is costly to adjust the share of domestic bonds in the household's portfolio away from the steady-state allocation, which is assumed to be the first best for the household. Therefore, the budget constraint for the representative household of ROW is as follows, as the counterpart of equation (2):

$$P_t^{ROW} \cdot C_t^{ROW} + P_t^{ROW} \cdot K_{t+1}^{ROW} + T_t^{ROW} + M_t^{ROW}$$

$$+\left(B_{t+1}^{ROW} + EXR_t \cdot B_{RP,t+1}^{US}\right)\left[1 + \frac{\Omega^{ROW}}{2}\left(\frac{B_{t+1}^{ROW}}{B_{t+1}^{ROW} + EXR_t \cdot B_{RP,t+1}^{US}} - \psi^{ROW}\right)^2\right]$$

$$\leq (1 - \delta^{ROW} + r_t^{ROW}) \cdot P_t^{ROW} \cdot K_t^{ROW} + W_t^{ROW} \cdot L_t^{ROW} + (1 + R_{t-1}^{ROW}) \cdot B_t^{ROW}$$
$$+(1 + R_{t-1}^{US}) \cdot EXR_t \cdot B_{RP,t}^{US} + D_t^{ROW} + M_{t-1}^{ROW} \qquad (62)$$

where variables and parameters with superscript ROW denote the corresponding variables and parameters for country ROW, which are defined in the similar way to those for China's economy; $B_{RP,t}^{US}$ is the private holdings of US government bonds for country ROW; Ω^{ROW} is a parameter measuring the size of the portfolio adjustment cost; the household's portfolio share of domestic bonds is denoted by $\psi_t^{ROW} \equiv B_{t+1}^{ROW}/(B_{t+1}^{ROW} + EXR_t \cdot B_{RP,t+1}^{US})$; and ψ^{ROW} is the steady-state portfolio share of domestic bonds held by ROW households. Then the first order conditions with respect to the optimal choices of B_{t+1}^{ROW} and $B_{RP,t+1}^{US}$ for the ROW representative household are given by:

$$1 + \frac{\Omega^{ROW}}{2}(\psi_t^{ROW} - \psi^{ROW})^2 + \Omega^{ROW}(\psi_t^{ROW} - \psi^{ROW})(1 - \psi_t^{ROW})$$

$$= (1 + R_t^{ROW})\mathbb{E}_t\left(\frac{\lambda_{t+1}}{\lambda_t}\right)$$

$$1 + \frac{\Omega^{ROW}}{2}(\psi_t^{ROW} - \psi^{ROW})^2 - \Omega^{ROW}(\psi_t^{ROW} - \psi^{ROW})\psi_t^{ROW}$$

$$= (1 + R_t^{US})\mathbb{E}_t\left(\frac{\lambda_{t+1} \cdot EXR_{t+1}}{\lambda_t \cdot EXR_t}\right)$$

where λ_t is the Lagrangian multiplier of the dynamic maximization problem (also can be interpreted as the marginal utility of nominal wealth), and it satisfies the following two FOCs as well:[8]

$$\mathbb{E}_t\left(\beta^{ROW} \cdot \frac{C_t^{ROW}}{C_{t+1}^{ROW}} \cdot \frac{P_t^{ROW}}{P_{t+1}^{ROW}}\right) = \mathbb{E}_t\left(\frac{\lambda_{t+1}}{\lambda_t}\right)$$

$$\frac{M_t^{ROW}}{P_t^{ROW} \cdot C_t^{ROW}}\left[1 - \mathbb{E}_t\left(\frac{\lambda_{t+1}}{\lambda_t}\right)\right] = \phi_2^{ROW}$$

Log-linearizing above FOCs around the steady state when $EXR_{t+1} = EXR_t$ and $R_t^{ROW} = R_t^{US}$ gives the following modified UIP condition:

$$R_t^{ROW} = R_t^{US} + \mathbb{E}_t(lnEXR_{t+1} - lnEXR_t) + \Omega^{ROW} \cdot \psi^{ROW} \cdot \widehat{\psi_t^{ROW}} \qquad (63)$$

where $\widehat{\psi_t^{ROW}}$ is the percent deviation of the portfolio share of domestic bonds from its steady-state level, and according to the definition of ψ_t^{ROW} the following equation

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holds:

$$\widehat{\psi_t^{ROW}} = (1 - \psi^{ROW})(\widehat{B_{t+1}^{ROW}} - \widehat{EXR_t}) - \psi^{ROW} \cdot \frac{Def^{ROW} \cdot GDP^{ROW}}{B^{ROW}} \cdot \widehat{B_{RP,t+1}^{US}}$$

where $\widehat{B_{RP,t+1}^{US}}$ is defined as the deviation of the following ratio from its steady-state value:

$$(EXR \cdot B_{RP,t+1}^{US})/(Def^{ROW} \cdot GDP^{ROW})$$

The modified UIP condition, equation (63), tells that the spread on ROW bonds versus US bonds depends not only on the expected depreciation of ROW currency, but also on the changes in the portfolio share. Since the adjustment of portfolio share is costly, the household should be compensated with a higher relative interest rate to be willing to hold more domestic bonds. Therefore, the interest rate differential $(R_t^{ROW} - R_t^{US})$ is positively related with portfolio share deviation. In fact, equation (63) can also represent a downward-sloping demand curve for domestic ROW bonds relative to foreign US bonds. When there is an increase in the interest rate differential $(R_t^{ROW} - R_t^{US})$, implying the price of domestic ROW bonds decreases, the demand for domestic ROW bonds relative to foreign US bonds will be raised, holding expected exchange rate movements unchanged.

For ROW the US bonds are held by both the central bank and the households, and the sum of private and public holdings of US bonds equal this economy's foreign reserves:

$$B_{ROW,t}^{US} = B_{RP,t}^{US} + B_{RCB,t}^{US} \tag{64}$$

where $B_{RCB,t}^{US}$ is the ROW central bank's holdings of US bonds. And the relationships among the foreign reserves, balance sheet of the central bank and net export for ROW are given by the following:

$$B_{ROW,t+1}^{US} = NNX_t^{ROW} + (1 + R_{t-1}^{US}) \cdot B_{ROW,t}^{US} \tag{65}$$

$$M_t^{ROW,S} - M_{t-1}^{ROW,S} = EXR_t \cdot \left[B_{RCB,t+1}^{US} - (1 + R_{t-1}^{US}) \cdot B_{RCB,t}^{US} \right] \tag{66}$$

where $M_t^{ROW,S}$ is the money supply of the economy ROW. If the ROW private holdings of US bonds are zero, the above relationships collapse to the same as China's case.

Because US dollar serves as the global reserve currency, we assume that for US households there is a complete home bias of government bonds and they will not buy the bonds from ROW. So the budget constraint for the representative household of US is similar to China's. We can see that even when the world trade is temporarily not balanced and for example there is a trade surplus for China and ROW, the US dollar flowing outside US will finally flow back into the US economy and the quantity of money supply of US dollar within the US economy keeps unchanged. However, the demand of US government bonds will be affected. When there is a trade deficit for US, the foreign demand of US bonds will increase: US consumes more than its production, while other economies save in the form of buying US bonds. So we have the following identity:

$$B_t^{US} = B_{H,t}^{US} + B_{ROW,t}^{US} + B_{US,t}^{US} \tag{67}$$

$$B_{US,t}^{US} = B_{UP,t}^{US} + B_{UCB,t}^{US} \qquad (68)$$

where B_t^{US} is the aggregate demand of US bonds, which consists of three parts: demand from China (here equals demand from China's central bank), from ROW (including private and public holdings) and US domestic demand ($B_{US,t}^{US}$, which equals US private demand $B_{UP,t}^{US}$ plus US central bank's demand $B_{UCB,t}^{US}$). So the balance sheet of US Federal Reserve expands in the following way:

$$M_t^{US,S} - M_{t-1}^{US,S} = B_{UCB,t+1}^{US} - (1 + R_{t-1}^{US}) \cdot B_{UCB,t}^{US} \qquad (69)$$

In the benchmark model, we assume the real money supply of US dollar is an AR(1) process and subject to a stochastic shock:

$$ln(M_t^{US,S}/P_t^{US}) = \rho_{MU} \cdot ln(M_{t-1}^{US,S}/P_{t-1}^{US}) +$$

$$(1 - \rho_{MU}) \cdot ln(M^{US}/P^{US}) + v_t^{MU}, v_t^{MU} \sim N(0, \sigma_{MU}^2) \qquad (70)$$

where M^{US} is the steady-state level of US money supply.

Given the budget constraints for all the three economies' representative households and the aggregate demand equation for US bonds, we can derive an identity linking three economies' nominal net exports:

$$NNX_t + NNX_t^{ROW} + NNX_t^{US} = 0 \qquad (71)$$

4.3. Fiscal policies

To make the benchmark model tractable and concentrate on monetary policy issues, we deal with fiscal policies of each economy in a simple way. Take China as an example. We define the debt-GDP ratio b_t, government expenditure-GDP ratio g_t, and fiscal revenue-GDP ratio as follows:

$$b_t = B_t/(Def_t \cdot GDP_t)$$
$$g_t = G_t/(Def_t \cdot GDP_t)$$
$$fr_t = T_t/(Def_t \cdot GDP_t)$$

Then g_t is assumed to follow an $AR(1)$ process:

$$ln(g_t) = (1 - \rho_G) \cdot ln(g) + \rho_G \cdot ln(g_{t-1}) + v_t^G, v_t^G \sim N(0, \sigma_G^2) \qquad (72)$$

And the tax rule of the government is exogenously given as well. The fiscal revenue reacts to, with one-period lag, the deviation of debt-GDP ratio from its target b:

$$\frac{fr_t}{fr} = \left(\frac{b_{t-1}}{b}\right)^{\varepsilon_T} \qquad (73)$$

where fr is the steady-state level of fiscal revenue-GDP ratio, and ε_T is the elasticity. Equation (43) can yield that: $fr = g + R \cdot b$.

4.4. Monetary policies, exchange rates determination and model stability

Monetary policies are related to both the determination of exchange rates and the saddle path stability of the global model in our framework. For an economy in a monetary DSGE model, normally either a Taylor-type interest rate rule or a rule for money supply is considered. The existence and uniqueness of a stable path of a dynamic model is a holistic phenomenon, depending on the interaction of all agents'

behaviors. In a closed economy, the Taylor principle (nominal interest rate set by the monetary authority should respond more than one-to-one to inflation) usually makes the model satisfy the Blanchard-Kahn conditions (one of these conditions is that the number of explosive eigenvalues of the dynamic system should be equal to the number of non-predetermined variables), which guarantee the stability and determinacy of the dynamic system. In an open economy, interest rate rule also plays a role in determining the exchange rate of currencies through a certain equilibrium condition such as uncovered interest rate parity. In some circumstance, a money supply rule can be an alternative to the interest rate rule, and money supply works as a policy instrument to determine nominal interest rate and exchange rate. Involved with money supply policy and exchange rate regime, the so called "impossible trinity" was widely discussed in old Keynesian literature, such as in the Mundell-Fleming framework. In the benchmark setting of this paper, three asymmetric economies with different monetary institutional arrangements and different degrees of openness are interacting. So the situation would be more complicated.

4.4.1. Monetary policies and exchange rates determination

For the three economies in the benchmark model, they are assumed to have different types of monetary policies, due to their different institutional arrangements and this paper's research interest. Then the exchange rate determination mechanisms for different currencies are not the same as well.

Since we have a special interest of US money supply shock's effect on China's economy, the monetary policy for US is a money supply rule, described by equation (70). The US monetary authority can influence the nominal interest rate of US bonds through the money supply of US dollar.

For China, fixed exchange rate regime is assumed for the benchmark setting. And the money supply of Renminbi passively expands or shrinks due to China's trade surplus or deficit, since there are capital controls and exchange settlement and sales are compulsory. Equations (55) to (57) depict this mechanism. Given the money supply of Renminbi, equation (6) determines the nominal interest rate for China, holding other variables unchanged. For example, when there is a trade surplus for China, the money supply will increase and nominal interest rate of China will decrease. This is a kind of monetary expansion policy, although it is "passive". And a lower interest rate will stimulate Chinese households to consume more and Chinese firms to invest more, which will consequently increase China's aggregate demand and import. Then net export of China will decrease and the trade has a tendency to be balanced.

In an upcoming part of this paper China's policy reforms will be explored, and a floating exchange rate regime or an opened capital account for China will be considered. If the capital account is opened and Chinese households are allowed to freely buy US bonds, a modified UIP condition like equation (63) will play a role in the determination of Renminbi's exchange rate. If China adopts a flexible exchange rate regime (while the capital control is maintained), the exchange rate of Renminbi

will be determined by the market clearing condition of China's GDP, equation (50); since the exchange rate of Renminbi reflects the relative price between Chinese goods and foreign goods, and it can influence the domestic demand of China's GDP. In this circumstance, when there is a trade surplus for China, the money supply will increase and simultaneously Renminbi will appreciate. Given the money demand function, equation (6), and a Taylor-type interest rate rule which is to replace the fixed exchange rate condition, an expanded money supply will push up the aggregate price level for China. So Renminbi will also "depreciate" relative to domestic goods. The appreciation of Renminbi relative to US dollar and its "depreciation" relative to domestic goods will unambiguously make China's import increase, which will then lead to the closure of China's trade gap.

For ROW which adopts a flexible exchange rate regime and whose households can get access to US bond market, a Taylor-type interest rate rule is assumed. In a stylized two-country NOEM model with perfect assets substitution, such as Corsetti *et al.* (2011), the exchange rate is determined by the equilibrium risk-sharing condition, or equivalently the normal UIP condition, given the monetary policies in the two countries. In our three-country model with imperfect assets substitution here the circumstance becomes more complicated. The modified UIP condition, equation (63), links the interest rate differential, exchange rate and the private holdings of foreign bonds. Therefore, given the monetary policies of all the countries, this modified UIP condition and market clearing conditions for US bonds determine the exchange rate of Ro and ROW private holdings of US bonds together.

4.4.2. Monetary policies and model stability

Monetary policies are related to the saddle path stability of our global model as well. Not as in a closed economy, the Taylor principle for the monetary policy is not necessarily a sufficient condition any more for the existence and uniqueness of a stable path for open-economy dynamic systems. For example, in a two-country model of Carton (2011), the dynamic system is unstable under certain circumstances, if the net foreign asset position is absent in monetary policy.

Given the fixed exchange rate regime and compulsory exchange settlement and sales for China and a money supply rule described by equation (70) for US in the benchmark model, a Taylor-type interest rate rule for ROW is assumed. And ROW monetary policy rule must be a forward looking rule (i.e. to react to the expectations of output gap and inflation gap of ROW) to make the global dynamic system achieve saddle-path stability for the calibrations to come in this paper. To be specific, the monetary policy for ROW is set as below:

$$R_t^{ROW} = R^{ROW} + \varphi_1^{ROW} \cdot \sum_{j=1}^4 \mathbb{E}_t\left(\widehat{\Pi_{t+j}^{ROW}}\right)/4$$

$$+\varphi_2^{ROW} \cdot \sum_{j=1}^4 \mathbb{E}_t(GAP_{t+j}^{ROW})/4 + v_{ROW,t}^R \tag{74}$$

where R^{ROW} is the steady-state level of nominal interest rate for ROW, and $\widehat{\Pi_t^{ROW}}$ and GAP_t^{ROW} are the inflation gap and real GDP gap of ROW respectively.

4.5. Steady state of the global economy

In this paper we assume neither real GDP growth nor positive inflation at the steady state. And it is also assumed that at the steady state the foreign asset (US bonds) holdings for China and ROW are zero, which implies complete asset home bias ($\psi^{ROW} = 1$) at the steady state and results in a balanced global trade at the steady state as well.

Since there is no real GDP growth at the steady state but in reality all the economies are growing (particularly, China is growing quite fast), great ratios such as the consumption-GDP ratio and investment-GDP ratio for all the three economies at the steady state cannot be calibrated to match the data. We assume the government spending-GDP ratio is 20% for all the economies at the steady state. Given the equilibrium conditions and the values of some parameters (such as the capital depreciation rate), the steady-state investment-GDP ratio for each economy and many other aggregate variables' steady-state values can be calculated.

Two relative prices at the steady state, τ^{ROW} and τ^{US}, are important, and they determine many coefficients of the log-linearized representation of the benchmark model. Given the steady-state values for any two economies' net nominal export, equation (54) and its analogue for ROW (or US) provide an equation group to solve τ^{ROW} and τ^{US}.

4.6. Mapping from the benchmark model to GVAR

Three economies of the world interact, and are linked through international trade and international financial market. And the global linkages are endogenized in our global DSGE framework, rather than exogenously given in traditional GVAR models. In the benchmark model, US dollar serves as a global currency, which is the only invoicing currency in the international trade and the only foreign exchange reserve currency. Log-linearizing the DSGE model for each economy will lead to a VARX* model for this economy, which takes the following form:

$$\mathbb{E}_t\left[\mathcal{F}_{\Theta(j)}^j\left(\widehat{X_{t+1}^j}, \widehat{X_t^j}, \widehat{X_{t-1}^j}, \widehat{X_{t+1}^{j1}}, \widehat{X_t^{j1}}, \widehat{X_{t-1}^{j1}}, \widehat{X_{t+1}^{j2}}, \widehat{X_t^{j2}}, \widehat{X_{t-1}^{j2}}, \Xi_t^j\right)\right] = 0$$

where X_t^j is a vector of all the endogenous variables for economy $j(= H, US\ or\ ROW)$, $\widehat{X_t^j}$ is its corresponding cyclical component vector, $\{j1, j2\} = \{H, US, ROW\} \setminus \{j\}$, $\Xi_t^j \sim iid(0, \Sigma_j)$ is a random vector of structural innovations for economy j, and $\mathcal{F}_{\Theta(j)}^j$ is a linear real function parameterized by a real vector $\Theta(j)$ gathering the deep parameters of the model for economy j. This VARX* model is stochastic, forward-looking and linear.

Piling up all the three VARX* models for three economies, we can get the following GVAR model:

$$\mathbb{E}_t\left[\mathcal{F}_{\Theta}\left(\widehat{X_{t+1}}, \widehat{X_t}, \widehat{X_{t-1}}, \Xi_t\right)\right] = 0$$

where $X_t = ((X_t^H)', (X_t^{US})', (X_t^{ROW})')'$ collects all the endogenous variables for the

whole global economy, and Ξ_t then gathers all the deep parameters in the global DSGE model. The solution of the above GVAR model is (or can be numerically approximated as) a VAR(1) process:

$$\widehat{X_t} = \mathcal{H}_\theta\left(\widehat{X_{t-1}}, \Xi_t\right)$$

5. CALIBRATION

The parameters of the cyclical global DSGE model fall into three categories: Category 1-basic structural parameters such as preference parameters, and some other parameters, which need be exogenously provided; Category 2-steady state values of aggregate variables, which are set to match the data (mainly the data of the year 2012 for the benchmark model); and Category 3-other parameters which are determined by the above two categories, given the steady state equilibrium conditions. Parameter values are specified on a quarterly model.

Category 1 parameters for the three economies are listed in Table 5 in the appendix. There are three elasticities assumed to be the same across economies: the elasticity of substitution between intermediate goods in one single economy ε, the elasticity of substitution between goods from different foreign economies ξ, and the elasticity of substitution between domestic and foreign goods ω. As in many New Keynesian DSGE models, ε is calibrated to be 11, leading to a 10% steady-state markup over marginal cost. For ξ, Collard and Dellas (2002) suggest a value between one and two, so we use 1.5. For ω, micro data typically indicates a value in the range of 5 to 10 (Funke *et al*., 2010); and Obstfeld and Rogoff (2000) have shown that such high elasticity can explain an observed large home bias in trade. So we set it to be 6 at the beginning. The inverse of Frisch elasticity of labor supply, η, is set to be 1.0 for all the three economies. In terms of labor share in production function, for China it is set to be 0.5, as in Chen *et al*. (2012) and indicating a relatively low output elasticity of labor in China[9]; and for US and ROW, we use a standard calibration, 0.67. The Calvo parameter is set to be 0.75 for China implying an average adjustment of prices every year and consistent with Chen *et al*. (2012), and to be 0.5 for US and ROW as normal. We set the depreciation rate of capital to a value of 5% for China[10] and 2.5% for the other two economies. The AR(1) persistence parameters are all set to be 0.7. The parameters of monetary policy rule for ROW are set to be 1.5 and 0.2, consistent with the literature. The government spending-GDP ratio at the steady state is 20% for all the economies. In terms of the elasticity in the tax rule, it is set to be 0.2 for each economy.

We set a baseline value for ρ_1 (degree of openness for China) of 0.3 and for ρ_2 of 0.247, which indicate that: when the prices of home goods and foreign goods are the same, import of China is about 30%[11] of its total demand (which means home

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[9] He *et al*. (2007) and Mehrotra *et al*. (2011) use an even smaller value, 0.4.

[10] This high depreciation rate is in line with the economic reality of China. As an example in the electronics sector, capital is sometimes assumed to depreciate fully in just three years. He *et al*. (2005) suggest a capital depreciation rate of 5% for China.

[11] According to the 2011 data from the National Bureau of Statistics of China, imported goods (service excluded)

bias exists); and when the prices of imported goods from US and ROW are the same, China's import share from these two economies is proportional to their GDP size (steady-state GDP levels for the three economies in the year 2012 are given by Table 6). For US and ROW, the specification is as follows: $\rho_1^{US} = 0.265$, $\rho_2^{US} = 0.147$; $\rho_1^{ROW} = 0.113$, $\rho_2^{ROW} = 0.344$. The rationality of this kind of specification is explained in Appendix A1.

Two parameters (ψ^{ROW} and Ω^{ROW}) in the modified UIP condition, equation (63), are calibrated as follows. The steady-state portfolio share of domestic bonds held by ROW households ψ^{ROW} is set to be 1.0, meaning that there are zero foreign asset holdings at the steady state, This guarantees a balanced global trade at the steady state for our model. The portfolio adjustment cost parameter Ω^{ROW} is set to be 0.22, in line with Chang *et al.* (2013) which estimate this parameter from a panel data set of 22 countries with a sample period from 2001 to 2011.[12]

Category 2 parameters for the three economies are listed in Table 6 in the appendix. The nominal GDP of China denominated in US dollar in 2012 is normalized to be unit. According to the IMF data, in 2012 the GDP of US and ROW are respectively 1.91 times and 5.81 times of China's. In terms of steady-state nominal interest rate, for all the three economies it is set to be 4% annually, and thus the quarterly rate is 1%. For government debt-GDP ratios, we refer to the IMF report *Fiscal Monitor* (IMF, 2013) and use the 2012 data. For US, it is 106.5%. For China, it is 22.8%, but sub-national debt is not included. So we use a higher value, 40%, for China. Then given the world average ratio 81.1% and world's GDP distribution, we can calculate that for ROW the debt-GDP ratio is about 79.8%. Since our model is a quarterly one, all these ratios are amplified by 4 times. The steady-state exchange rate of Renminbi is set to be 6.3, the average value for the year 2012. For ROW currency, Ro, its steady-state exchange rate is set to be 1 for simplicity, since exchange rate is just a relative price of currencies and its concrete steady-state value will not affect the whole model.

In Table 6 the ratio of money stock to nominal GDP in the steady state is set to match the M0-GDP ratio data in 2012. For China this ratio is 10.5%, for US it is 6.7%, and for ROW we take a value of 15%.[13] Finally we amplify these ratios by 4 times in accord with our quarterly model. Here we use M0 as the index of US money supply for three reasons: one is to make it consistent with our previous empirical GVAR analysis; the second reason is that: in our model there is capital accumulation and capital stock is owned by the households as saving, so in the model money as another kind of asset to the households is better to denote currency rather than more broadly defined moneys which include households' savings; and finally, in our model money is totally supplied by the central banks as their liabilities, so M0 rather than M1 or M2 is a better indicator.[14] In a coming section of sensitivity analysis, M1-GDP ratios will

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are about 24% of GDP (http://www.stats.gov.cn/tjsj/ndsj/2012/indexch.htm). The 2012 data for China is not available.

[12] We have also studied the benchmark model when Ω^{ROW} is set to be 0.15 or 0.25, and the results for the benchmark model in this paper do no change at all.

[13] The M0-GDP ratios for the Euro area, Japan, UK and India in 2012 are respectively 9.1%, 16.8%, 16.9% and 13.2%.

[14] In fact, only from the perspective of money supply, monetary base (M0 plus commercial banks' reserves that

be explored as well.

Category 3 parameters for the three economies are listed in Table 7 in the appendix. In the steady state, we can easily get that: $NNX = 0$, and $NNX^{ROW} + NNX^{US} = 0$. Given the assumption of complete steady-state asset home bias ($\psi^{ROW} = 1$), we can get that $NNX^{ROW} = 0$. Then equation (54) and its analogue for ROW (or US) provide an equation group to solve τ^{ROW} and τ^{US}, both of which are 1. This implies that balanced global trade leads to equal global prices.

6. IMPULSE RESPONSES AND WELFARE IMPLICATION

6.1. US money supply shock and China's economic fluctuation

Now we do the impulse response analysis to see how US money supply shock will affect China's macro economy through global linkages. Figure 5 depicts the reactions of China's aggregate variables to a one-percent US money supply shock. On impact China's inflation will increase by 0.003%, while China's GDP will increase as well, by about 0.002%. Both of these increases are very small. If we look at the time series of US money supply, which is examined in the empirical GVAR model of this paper, its HP-filter cycle has a standard error of about 10%. So even when there is a positive one standard-error (S.E.) shock to US money supply, on impact China's real GDP and inflation rate will still be slightly influenced. But one quarter later, both China's inflation rate and GDP level will be pulled down, and one year later inflation gap and output gap are respectively about -0.007% and -0.024%.
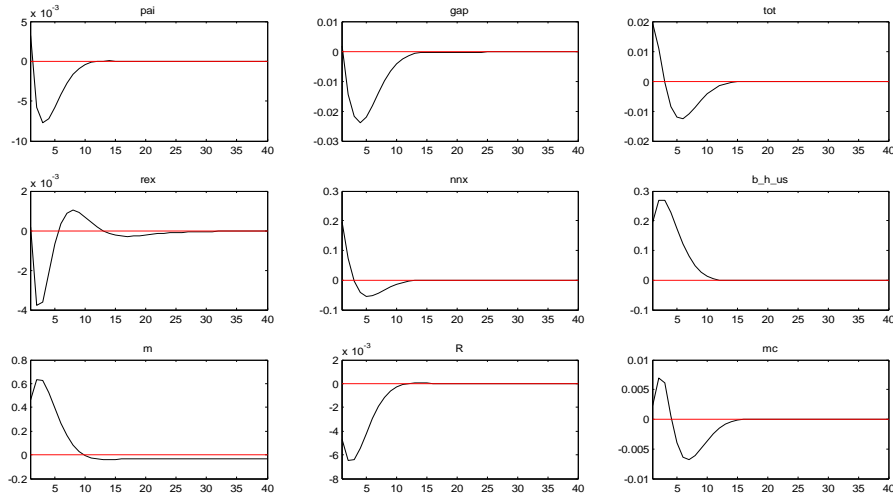
Figure 5. Impulse responses of China's aggregate variables (cycles) to a one-percent US money supply shock (in percent)

Generally speaking, US money supply shock has a tiny influence on China's

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are maintained in accounts with the central bank) is the most ideal indicator for our model here. But it is not a money supply concept and different from either M0 or M1. From the perspective of money demand, which is included in the household's utility function, monetary base is not suitable either.

inflation rate, but has a certain negative effect on China's real output in the medium term although the immediate effect is slightly positive. A positive one S.E. shock to US money supply results in that China's GDP will be 0.24% below its steady state level one year after the shock. These results are not that consistent with our previous empirical finding using a GVAR model, which is that: US money supply will lead to higher inflation and lower GDP level for China. The much more complex dynamic responses of China's inflation and output here indicate a more complicated transmission mechanism. The responses here seem not to be as persistent as in the previous empirical model either, and three years later both the inflation gap and output gap diminish to zero.

The transmission mechanism of the influence of US money supply shock on China's macro economy can be imagined to be quite complicated. US money supply shock will first affect US macro economy, and then affect the economies of China and ROW through international trade and global financial market. Note that this is just a first-round effect. Unlike many other open-economy models which take the rest of world as exogenous and passive and there is usually no feedback from home country to the rest of the world, in our interacting multi-country model there are infinite rounds' feedbacks among China, US and ROW. And the policy and transition functions as the solution of our cyclical DSGE model capture the accumulative effect of US money supply shock on China's macroeconomic variables such as output gap and inflation.

Figure 5 also shows the impulse responses of terms of trade, real exchange rate of Renminbi, nominal net export, real marginal cost and other variables of China to a one-percent US money supply shock. Figure 6 and 7 in the appendix show the aggregate variables' reactions to this US money supply for US and ROW.

To explain our empirical GVAR model result in section 3 of this paper, we employ the "cost-push inflation" explanation: a positive US money supply shock will depreciate US dollar and then oil and many other commodities' prices denominated in US dollar will increase, which will cause cost-push inflation for China and pull down China's GDP level as well since China adopts a dollar pegging exchange rate regime. Oil and other commodities can be viewed as part of the export goods of ROW, and their price increase can be partly represented by the increase of $P_{ROW,t}^{E}$.

Overall, for our benchmark model here the cost-push story almost holds at the very beginning when this US money supply shock hits the global economy. The real exchange rates for both Renminbi and Ro (in fact also for the nominal exchange rate of Ro) appreciate on impact, indicating the depreciation of US dollar. In fact, the export price of ROW goods will increase on impact, while the export goods' prices of China and US do not change much at the beginning. The increase of the export price of ROW goods can be largely understood as the price increase of oil and other international commodities. Since ROW is the biggest economy and also the biggest exporter in the world, the increase of its export price (denominated by US dollar) will generate cost-push pressure for both China and US, given that China adopts a fixed exchange rate regime and US dollar is US domestic currency. This partly explains why both the inflation rate and real marginal cost for both China and US will increase

at the very beginning when this US money supply shock hits the global economy.

Nevertheless, the cost-push story is not the full story here, because usually higher marginal cost generated by higher import price indicates lower GDP level, but for our model here China's GDP will increase slightly at the very beginning. Thus, at least we can and should tell another story: the story of relative price effect. US money supply shock can, through the price channel, influence China's GDP as well. Changes in relative prices of international trade will alter relative demands for China's products. Since the export price of ROW goods will increase much, while the export goods' prices of China and US do not change much at the beginning when US money supply shock hits the global economy, this will definitely lead to an increase of the terms of trade for both China and US, but lower down the terms of trade for ROW, which is shown by Figure 5, 6 and 7. Higher terms of trade together with the holding of LOOP for China imply that Chinese goods are becoming relatively cheaper in the global market, keeping other things equal. This kind of relative price effect will increase the world demand for China's GDP, which partly explains the immediately positive response of China's output gap to a positive US money supply shock. In our benchmark model here, this relative price effect on China's GDP seems to overwhelm the cost-push effect at the very beginning, but afterwards cost-push effect seems to dominate. Lowered GDP in the medium run also explains disinflation of China to a certain degree.

It is worth pointing out again that the transmission mechanism of the influence of US money supply shock on China's macro economy can be very complicated and the channels identified by us above are just part of it. There are many other possible channels. For example, the aggregate demands of all the economies will also be affected by US money supply shock, and this will then affect China's output gap as well.

Intuitively, as in a standard closed economy model, an increase of US money supply will lead to a lower level of US nominal interest rate, which is usually called *liquidity effect* and indeed holds in our global framework here. Partly due to the relatively cheaper price of Chinese goods (or higher terms of trade), the nominal net export for China (denominated in US dollar) increases at the beginning, which then leads to an increase of China's foreign asset (US bonds) holdings. Consequently, the money supply of China passively expands as well because of capital controls and the compulsory exchange settlement and sales in China. Then the nominal interest rate in China decreases as well due to the expansion of domestic money supply. Additionally, the expansion of China's money supply also contributes to a positive inflation for China in the short run. The nominal net export of US will also increase at the beginning, partly because that the US export goods become cheaper, relative to the ROW export goods. Since both US and China achieve trade surplus, naturally ROW will have a trade deficit, which then results in fewer holdings of its foreign assets (US bonds). In terms of the ROW private holdings of US bonds, the appreciation of Ro relative to US dollar has a positive effect on it due to a wealth effect in some sense, but a lower interest rate of US bonds has a negative effect. The model indicates a positive overall effect on the ROW private holdings of US bonds (not shown in Figure

7). Given fewer national holding of US bonds for ROW, the central bank of ROW will unambiguously hold fewer US bonds. This implies a shrinking money supply of ROW and then a possible higher nominal interest rate for ROW. The response of ROW nominal interest rate could also be explained by its Taylor rule, given the responses of ROW output gap and inflation gap shown in Figure 7. To conclude, at early stages after a positive US money supply shock hits the global economy, both China and US will have a trade surplus while for ROW there is a trade deficit; there is a domestic liquidity effect in US (lower nominal interest rate) and this liquidity effect spills over to China, but for ROW there is an opposite effect (higher domestic interest rate); the holdings of US bonds for China will increase, while for ROW they will decrease.

The above analysis mainly discusses the responses of global economy at the beginning periods after a positive US money supply shock hits the world economy. The responses of some variables in the medium term can be much more sophisticated than just converging to the steady state, since it is a large-scale model and different transmission channels are interacting with each other.

6.2. The persistence of US money supply shock

It is meaningful to examine the relationship between the persistence parameter of US money supply shock, ρ_{MU}, and the reactions of China's aggregate variables. This relationship can be revealed by Figure 8 in the appendix. Generally speaking, the more persistent US money supply shock is, the larger the responses of China's aggregate variables would be; while the qualitative results above remain unchanged.

6.3. The share of China's GDP in the world and US money supply shock

In the benchmark setting, China's GDP is about one half of US' and one sixth of ROW's. Will the response of China's economy to US money supply shock be smaller when the share of China's GDP in the global economy becomes larger and larger? The answer is no, shown by Figure 9 in the appendix.

When China's GDP at the steady state is doubled or quadrupled and the levels of US GDP and ROW GDP at the steady state keep unchanged,[15] a positive US money supply shock will result in slightly larger responses for China's aggregate variables. Considering the definition of cycles in this paper, the absolute response of China's economy is in fact larger than the benchmark setting. Therefore, the response of China's economy to US money supply shock will not become smaller when the share of China's GDP in the global economy becomes larger (even when it is double of US' GDP), as long as the US dollar remains as the world currency and there is no reform to China's institutional arrangements.

6.4.Sensitivity analysis

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[15] When the world's GDP distribution changes, some parameters (such as degree-of-openness parameters) should be re-calibrated according to the formula in Appendix A1.

In this section some sensitivity analysis will be implemented to see whether the results above about the response of China's economy to US money supply shock, for our benchmark model, are robust or not, especially for the responses of China's real output and inflation.

Five alternative re-calibrations are considered. For Case 1, we use M1 data rather than M0 to calibrate the steady-state money supply-GDP ratios. In 2012 M1-GDP ratio is 59.4% for China, and is 15.4% for US. For ROW we take a simple middle value of 37.4%. Again these ratios are amplified by 4 times in accord with a quarterly model.

In Case 2, the assumption of zero holdings of foreign assets at the steady state for ROW is relaxed, and thus the global trade at the steady state is unbalanced. Coeurdacier and Rey (2011) find that average bond home bias worldwide in 2008 is equal to 0.75. Earlier studies reported values for equity home bias around 0.80, such as in Aviat and Coeurdacier (2007). We take the value of 0.8 to re-calibrate the bond home bias for ROW: $\psi^{ROW} = 0.8$. Since at the steady state ROW still holds 20% of its total bonds in the form of US bonds and there is no accumulation of foreign assets at the steady state, ROW households will use the interest income from holding US bonds to buy goods from US. Thus at the steady state in this circumstance there is a permanent trade deficit for ROW but a permanent trade surplus for US. In this case, two key relative prices at the steady state τ^{ROW} and τ^{US}, are no longer 1, but are 0.9999 and 0.9977 respectively. This implies that unbalanced global trade leads to unequal global prices. Furthermore, all parameters determined by τ^{ROW} and τ^{US} in Table 7 and log-linearized FOCs involved with foreign asset holdings for ROW should change accordingly.

Case 3 is about the steady-state nominal interest rates for US and ROW. We reset the annual nominal interest rate to be 1% for US at the steady state, since in 2012 the short-term nominal interest rate of US government bonds is near zero. In the steady state nominal interest rates in US and ROW should be the same, so for ROW the annual steady-state interest rate is reset to be 1% as well. Because there are capital controls for China and Chinese households are not allowed to buy US bonds, the steady state nominal interest rates for China can be different from that of US. Therefore, it remains unchanged as a 4% annual rate. It is worth being noticed that the change of the steady-state nominal interest rates for US and ROW will change their steady-state investment-GDP ratios as well. The investment-GDP ratios for US and ROW in Table 7 should be replaced by a new number: 27.27%.

Case 4 considers a smaller Frisch elasticity of labor supply, 1/3, as in Galí and Monacelli (2005). So the parameter η is set to be 3. Another even bigger value $\eta = 10$, as in Chang *et al.* (2013), is examined as well, and the result (not shown in the paper) is nearly as the same as when $\eta = 3$. Case 5 changes the elasticity of substitution between domestic and foreign goods, ω, to be a rather smaller number, 1.5, in line with Chang *et al.* (2013) and others.

Figure 10 in the appendix shows, for Case 2, 3 and 4, the responses of China's aggregate variables to a positive US money supply shock. Qualitatively the results are the same as in the benchmark model. Quantitatively, only for Case 3 when the

steady-state nominal interest rates for US and ROW are set to be smaller, the overall response of China's economy is slightly larger than the benchmark case.

Figure 11 shows the results for Case 1 and 5, which exhibit some significant difference. For Case 1 when M1-GDP ratio rather than M0-GDP ratio is employed, the amplitude of China's response becomes much larger, compared to the benchmark. And the initial response of China's output gap is negative now, rather than slightly positive. However, as we explained before, M0-GDP ratio is better than M1-GDP ratio to match the money supply-GDP ratio for our benchmark model. For Case 5 when a smaller elasticity of substitution between domestic and foreign goods is assumed, the response of China's output gap is negative as well at the very beginning, rather than slightly positive in the benchmark model. This is reasonable, because a smaller elasticity of substitution between domestic and foreign goods indicates a smaller relative price effect, and then at the very beginning when US money supply shock hits the global economy the cost-push effect for China's real output is likely to dominate the relative price effect, not the other way around as in the benchmark setting. We prefer a higher elasticity of substitution between domestic and foreign goods, rather than a smaller one, because just as stated previously such high elasticity can explain an observed large home bias in trade, which is also an assumption in this paper.

Generally speaking, at least the following qualitative results are robust according to the sensitivity analysis: when a positive US money supply shock hits the global economy, the nominal interest rate of China will be lowered down (the spillover of liquidity effect); in the medium term both China's real output and its inflation rate are below the steady state levels; and both the terms of trade and nominal net export for China will be push up on impact, but be below the steady state levels in the medium term.

6.5. Welfare implication of the benchmark model

Now we calculate the welfare gain (or loss) of Chinese households in the benchmark model due to US money supply shock. First of all, we need to derive the welfare loss function of the representative household of China. In Chang *et al*. (2013), they use the following loss function:

$$W = -\frac{1}{2} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\lambda_\Pi \cdot \left(\widehat{\Pi_t} \right)^2 + \lambda_{GAP} \cdot (GAP_t)^2 + \lambda_R \cdot \left(\widehat{R_t} \right)^2 + \lambda_B \cdot \left(\widehat{B_{H,t}^{US}} \right)^2 \right]$$

They argue that "the quadratic terms involving inflation, output, and the nominal interest rate in the loss function are standard in the optimal monetary policy literature. They can be derived from second-order approximations to the representative household's utility function [e.g, Woodford (2003)]. The interest rate smoothing term appears in the policy objective in the presence of transaction frictions, such as money in the utility function." And they also add a quadratic term for foreign-asset holdings arbitrarily, which is not strictly derivable. In fact, their argument about the quadratic terms involving inflation, output and the nominal interest rate is problematic as well,

and not applicable for our model's welfare evaluation.

Edge (2003) extends the utility-based welfare criterion developed by Rotemberg and Woodford (1997) and Woodford (2003) to a model with endogenous capital accumulation, just as in our benchmark model. Edge (2003) proves that: although a criterion can be specified such that welfare losses depend solely on quadratic functions (including cross-product terms) of the model's variables (including capital stock and investment), an important difference from the traditional criterion is that the composition of output directly affects welfare in the endogenous-capital model. This endogenous-capital model is a closed-economy one and does not have real money balance in the utility function either. If we consider these two aspects which exist in our benchmark model, the welfare criterion would have a more complicated form and cannot be guaranteed to be a quadratic form.

Therefore, in this paper we do not seek to derive a quadratic form welfare criterion. Instead, we use a straightforward way to evaluate the welfare losses of Chinese households under US money supply shock. The welfare loss function is given below (see Appendix A2 for the derivation):

$$WL = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\widehat{C}_t - \phi_1 \cdot \widehat{L}_t + \phi_2 \cdot \left(\widehat{M}_t - \widehat{P}_t \right) \right]$$

When there is a shock to US money supply, we can get the impulse response functions for all the cyclical components of China's economy in the above equation: $\widehat{C}_t$, $\widehat{L}_t$, and $\left(\widehat{M}_t - \widehat{P}_t \right)$. Since in the end all these impulse responses will converge to zero, we take their values in the first 40 periods (10 years) to calculate an approximated welfare loss as follows:

$$WL \simeq \mathbb{E}_0 \sum_{t=0}^{40} \beta^t \left[\widehat{C}_t - \phi_1 \cdot \widehat{L}_t + \phi_2 \cdot \left(\widehat{M}_t - \widehat{P}_t \right) \right]$$

where the utility weights ϕ_1 and ϕ_2 are calibrated to be 1.56 and 0.01 respectively, in order to match the equilibrium conditions at the steady state and the benchmark calibration of the model.

Welfare calculation shows that: a positive 10% of US money supply shock will result in a positive 1.25% welfare gain (as a fraction of the steady state consumption) for China, a positive 0.06% welfare gain for US, but a 0.21% welfare loss for the rest of the world. This implies that a positive US money supply shock increases the welfare of US domestic households, although the welfare gain is not very big; and it generates a positive externality for Chinese households but a negative one for ROW. This positive 1.25% welfare gain for China can be decomposed into three parts: -0.15%, +1.08% and +0.32%, which are respectively the contributions from fluctuations of consumption, labor input and real money balance. Accompanied with a decline of China's GDP in the medium term after the shock, the consumption level of Chinese households is lowered down slightly as well. But the welfare loss from this part is very small, only -0.15% (as a fraction of the steady state consumption). The major contribution of the welfare gain for China comes from the decrease of labor input (or leisure increase). In other words, under US money supply shock, Chinese households work fewer hours without consumption being much affected, and thus

achieve some welfare gain.

6.6. Other shocks

Besides the money supply shock which we are most interested in, we can examine the effects of other foreign real or policy shocks on China's macro economy as well. We list in the appendix the figures for impulse responses of China's aggregate variables to TFP shocks (Figure 12), which can be assumed to be either uncorrelated or correlated across economies, and to foreign fiscal and monetary policy shocks as well (Figure 12).

In a typical small open economy model where the rest of world is exogenously given and passive, a positive foreign TFP shock normally results in a positive response of domestic real output. Nevertheless, in our globally interacting model, this does not necessarily hold. Fiscal policy shocks from US and ROW have the same qualitative effects on China's aggregates, but quantitatively the effects of US fiscal policy shock are slightly bigger even though the GDP share of US in the world is much smaller than that of ROW.

7. CHINA'S LIBERALIZATION REFORMS

Perfect capital mobility and flexible exchange rate usually can improve market efficiency and improve social welfare for an open economy, especially in the context with no big market failures. However, these also make the economy widely exposed to the international shocks. After the 2007-2008 global financial crisis, some economist and policy makers suggest to re-examine the financial liberalizing policies in developing countries. In this paper we mainly explore the impact of US money supply shock on China's economy, so we want to examine whether or not this kind of impact will be exaggerated when the Chinese economy were becoming more liberalized. Welfare analysis based on this may lead to constructive policy suggestions for China's liberalizing reform.

So in this section we evaluate the dynamics of China's economic responses to the same US money supply shock when some kind of liberalization of China's economy has taken place. We consider three alternative liberalization reforms for China: (1) a partial lifting of capital controls with maintenance of the exchange rate peg, (2) allowing the exchange rate of Renminbi to float while keeping the capital account closed, and (3) the full reform which is the combination of a partial opening of capital controls and allowing a floating exchange rate.

7.1. Opening the capital account

We begin with a partial liberalization of China's capital account while maintaining a fixed exchange rate for Renminbi. In this circumstance, the Chinese households are assumed to be allowed to hold US government bonds as an imperfect substitute for domestic bonds, like the households of ROW; while the households of US and ROW

would not buy any Chinese bonds. The benchmark-model budget constraint of the Chinese representative household, equation (2), is now replaced by the following:

$$P_t \cdot C_t + P_t \cdot K_{t+1} + T_t + M_t +$$

$$(B_{t+1} + EX_t \cdot B_{HP,t+1}^{US}) \left[1 + \frac{\Omega}{2} \left(\frac{B_{t+1}}{B_{t+1} + EX_t \cdot B_{HP,t+1}^{US}} - \psi \right)^2 \right] \leq (1 - \delta + r_t) \cdot P_t \cdot K_t$$

$$+ W_t \cdot L_t + (1 + R_{t-1}) \cdot B_t + (1 + R_{t-1}^{US}) \cdot EX_t \cdot B_{HP,t}^{US} + D_t + M_{t-1}$$

where ψ is the steady-state portfolio share of domestic bonds and is calibrated to be 1.0 (the same as the setting for ROW), in order to indicate a zero steady-state holdings of US bonds for China and thus a balanced global trade at the steady state.

Then we can get a modified UIP condition between China and US as follows:

$$R_t = R_t^{US} + \mathbb{E}_t(lnEX_{t+1} - lnEX_t) + \Omega \cdot \psi \cdot \widehat{\psi_t}$$
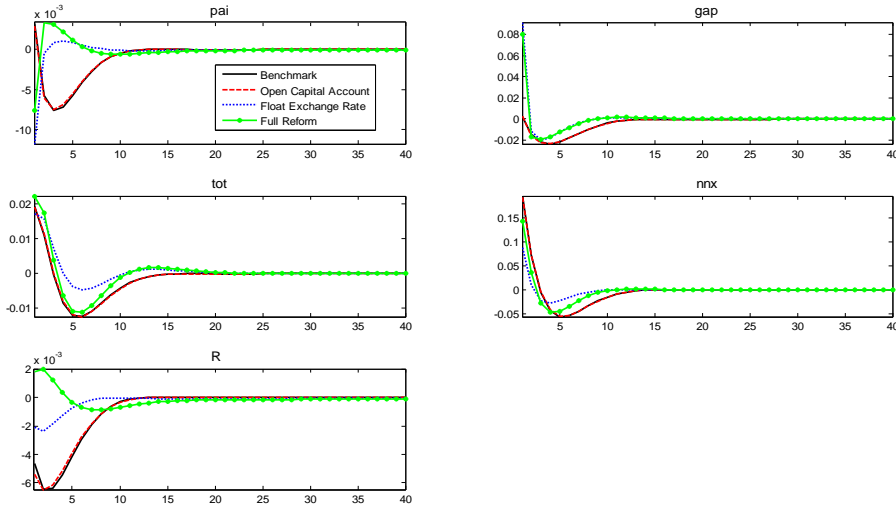
$$\widehat{\psi_t} = (1 - \psi)(\widehat{B_{t+1}} - \widehat{EX_t}) - \psi \cdot \frac{Def.GDP}{B} \cdot \widehat{B_{HP,t+1}^{US}}$$

Since the fixed exchange rate regime is maintained as $EX_t \equiv EX$, the modified UIP condition is reduced to:

$$R_t = R_t^{US} - \Omega \cdot \frac{Def.GDP}{B} \cdot \widehat{B_{HP,t+1}^{US}}$$

And we also have another equilibrium condition for the Chinese economy as below:

$$B_{H,t}^{US} = B_{HP,t}^{US} + B_{HCB,t}^{US}$$

Figure 14. Impulse responses of China's aggregate variables (cycles) to a one-percent US money supply shock under alternative regimes for China (in percent)

Figure 14 depicts the impulse responses of China's major aggregate variables to US money supply shock in this circumstance. Compared to the benchmark case, the response of China's economy is nearly the same. This is reasonable because of the strong home-bond bias and the existence of portfolio adjustment cost. By opening its capital accounts and allowing its households to freely hold US bonds, rather than letting the central bank be the only player to deal with US dollar inflows and outflows

and accumulate foreign exchange reserves, China will surely have more flexibility to some degree. However, since there is some cost for portfolio adjustment, Chinese households have no big incentive to deviate much from the steady-state zero holdings of foreign assets, especially when the interest rate differential between US and China is not large and the exchange rate of Renminbi is fixed.

Nevertheless, by opening the capital account, China can achieve some flexibility and then some welfare gains under US money supply shock, although the welfare gain is quite small. Table 8 in the appendix provides the welfare gain (or loss) (as a fraction of the steady-state consumption) of Chinese households when a one-percent US money supply shock hits the global economy, under the benchmark and all alternative counterfactual settings. The counterfactual analysis is implanted in two ways: one is to reform China's monetary institutional arrangements, which is analyzed in this section; and the other way is to weaken the global roles of US dollar, which is the task of Section 8 of this paper. Table 9 and 10 show the welfare results for US and ROW respectively.

7.2. Floating the exchange rate of Renminbi

We turn to an alternative policy reform for China when the exchange rate peg is removed but capital controls are maintained. Compared to the benchmark case, the exchange rate of Renminbi now is allowed to float freely rather than being fixed at its steady-state level. The monetary policy to stabilize China's economy now is a Taylor-type interest rate rule as follows:[16]

$$R_t = R + \varphi_1 \cdot \widehat{\Pi_t} + \varphi_2 \cdot GAP_t + v_t^R$$

In this circumstance, the price setting for Chinese firms is no longer equivalent to PCP, and the LOOP condition does not hold any more. Instead, the open-economy NKPC with respect to the Chinese export goods' price, which is equation (42), now applies.

For China, the GMM estimation of Mehrotra $et\ al.$ (2011) suggests 1.34 and 0 for the two Taylor rule parameters. The value 1.34 indicates that monetary policy in China fulfils the Taylor principle, which is in line with the empirical observation that China's inflation rate has been remarkably low since the mid-1990s. But the value 0 seems to underestimate the interest rate response to the output gap for China. We set φ_2 to be a little larger value, 0.15.

Figure 14 also gives the impulse responses of China's inflation and output to US money supply shock in this counterfactual situation. Compared to the benchmark regime, the effect on the inflation rate is totally opposite: negative responses in the short run but positive responses in the medium run; the response of China's real GDP is similar but the immediate effect is quite large. Since the exchange rate of Renmibi is flexible, on impact Renminbi appreciates (not shown in Figure 14), like the response of Ro. The larger positive response of real GDP on impact can be explained as follows: an appreciating Renminbi will attenuate the cost-push effect which will lower down China's real GDP, so the overall effect would be larger given that at the beginning the relative price effect dominates the cost-push effect. The appreciation of

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[16] Persistence can be added into the Taylor rule, but the results remain nearly the same.

Renminbi has a wealth effect as well: the international goods priced by US dollar is now becoming relatively cheaper, so the import of China will relatively increase, resulting in a smaller trade surplus in the beginning compared to the benchmark model. The negative responses of inflation in the short run could be partly explained by the price stickiness and the failure of LOOP here due to a floating Renminbi: given the price stickiness, the LOOP gap $x_t \triangleq ln(P_{H,t}^E \cdot EX_t/P_{H,t})$ will be negative because of the appreciation of Renminbi, so in the short run the inflation rate gap for the home-made goods price will be negative (given not very big values for marginal cost gap and terms of trade gap), explained by equation (41); and because nearly 70% of the final goods are made of home-made goods, the aggregate-price inflation is likely to be negative as well.

By floating the exchange rate of Renminbi while maintaining capital controls, China will have some welfare losses under US money supply shock now, rather than getting some welfare gains as in the benchmark model. Table 8 in the appendix shows that: a 10% US money supply shock will result in 0.5% welfare loss for Chinese households. The welfare loss mainly comes from the disutility generated by the net increase of labor supply, while in fact the welfare effect from consumption is slightly positive.

7.3. Liberalizing the capital account and floating the exchange rate

Finally, a full reform is considered, when both the capital account is opened and the exchange rate of Renminbi is allowed to float. The impulse responses of China's aggregate variables are similar to the situation when only the exchange rate of Renminbi is floating. This is not surprising since opening the capital account has no big influence, as explained before. The only big difference is that the short-run response of nominal interest rate of China is slightly positive now, rather than negative. This can be illustrated straightforwardly by the Taylor interest rate rule, given the short-run responses of China's output gap and inflation gap. The welfare result for Chinese households is still negative, but improved a little compared to the case with floating exchange rate of Renminbi but capital controls.

8.   A WEAKENED US DALLAR IN THE GLOBAL ECONOMY

In the benchmark model, US dollar serves as the unique global currency with two key roles: it is the only invoicing currency in the international trade and the only foreign reserve currency. Due to the rise of Euro and rapid economic growth and stronger global influence of emerging countries such as China and India during the past decades, dollar standard in the international trade and international finance is being challenged, although US dollar is still the only currency that can be viewed as a global currency if we suppose there is one.

In this section we evaluate the dynamics of China's economic responses to the same US money supply shock when some of the US dollar's global roles have been weakened. Three counterfactual cases are considered: (1) there is no dollar standard in

the international trade and the dollar pricing is replaced by PCP, (2) US dollar is no longer the global reserve currency, and (3) US dollar serves as neither the only invoicing currency in the international trade nor the global reserve currency, and it is only the domestic currency for US. Would US money supply shock have smaller impacts on China's economy or not, given a weakened US dollar in the world economy? The counterfactual analysis in this section can also help us understand better about what happens in reality, because the assumption of US dollar's global roles in this paper deviates from the reality in some sense, and the real response of China's economy to US money supply shock should lie somewhere between the results from the benchmark model and the following counterfactual analysis.
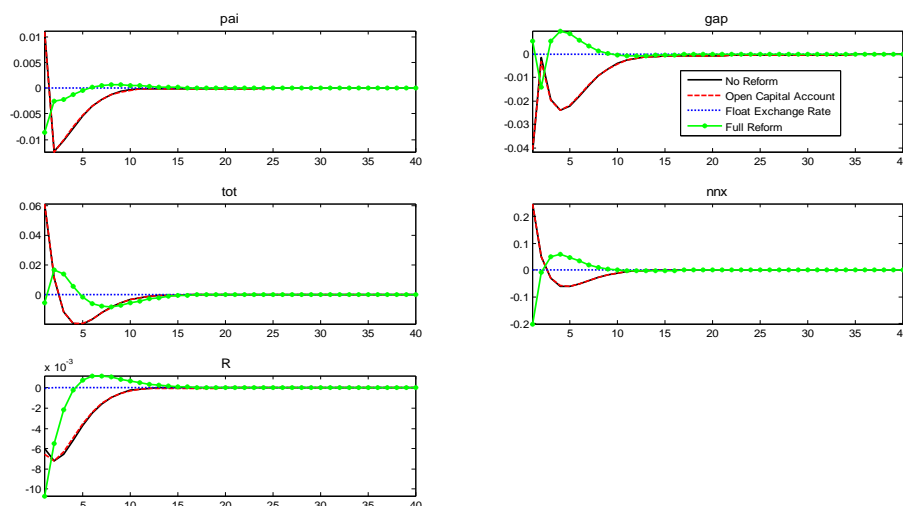
8.1. Removing dollar pricing in international trade

First we remove the dollar standard in international trade, and consider an alternative pricing mechanism: producer currency pricing (PCP). Under PCP the LOOP condition holds for all the three economies:

$$P_{H,t}^E \cdot EX_t = P_{H,t}$$
$$P_{Row,t}^E \cdot EXR_t = P_{ROW,t}^{RO}$$
$$P_{US,t}^E = P_{US,t}^{\$}$$

In this circumstance there is another exchange rate of the ROW currency in price of Renminbi, $EXRR_t$, and the non-arbitrage condition is assumed to be satisfied: $EXRR_t = EX_t/EXR_t$. So for notational convenience we can still denote all the export prices by US dollar prices, and this will not affect the model result.

Under PCP we also consider four alternative monetary regimes for China: the benchmark one when the capital accounts are closed and the exchange rate of Renminbi is fixed, opening the capital account only, floating the exchange rate only and the full liberalizing reform.

Figure 15. Impulse responses of China's aggregate variables (cycles) to a one-percent US money supply shock under different regimes for China when the dollar pricing in the international trade is replaced by PCP (in percent).

Figure 15 provides the impulse responses of China's aggregate variables to the same US money supply shock under these four settings. Generally, we can have three points as follows. First of all, compared to the benchmark model result under the dollar pricing, the response of China's economy with no reform or only opening the capital account under PCP is nearly the same, except that the initial response of the real GDP is negative now rather than slightly positive. Secondly, under PCP, a reform with a floating Renminbi but closed capital account will make China's economy almost unaffected by US money supply shock. Finally, under PCP, the response of China's economy with a full liberalizing reform is quite different from that with no reform, especially for nominal net export, terms of trade and real GDP.

Welfare comparison shows that: under PCP the welfare of Chinese households will be always improved compared to the dollar pricing setting, no matter what kind of regime China adopts; and still the regime with no capital controls but fixed exchange rate is best for China, while the regime with capital controls but floating exchange rate is worst, under US money supply shock. Under PCP, there is welfare loss for US households when there is no reform for China. However, a floating Renminbi can always make US households achieve some welfare gains.

8.2. Eliminating the role of US dollar as the global reserve currency

In this part the dollar standard in the international trade is maintained and US dollar is still the only invoicing currency, but it is assumed that US dollar is no longer the global reserve currency. For this counterfactual circumstance, we consider two alternative settings: (1) there is a kind of international bond with zero net supply, but this bond is still denominated in US dollar, (2) there is a kind of international bond with zero net supply, and this bond is denominated in a supranational reserve currency, which is a combination of three currencies (US dollar, Renminbi and Ro), weighted by the corresponding country's GDP share in the world.

8.2.1. An international bond denominated in US dollar

In this case a kind of international bond denominated in US dollar, B_t^{Int}, is the only internationally traded asset, to replace US government bond in the benchmark model. Its nominal interest rate is R_t^{Int} and its net supply is zero in every period. When there are capital controls for China, but not for US and ROW, both the households and the central bank of US or ROW can buy this kind of international bond. So the market clearing conditions for this international bond change to:

$$B_{H,t}^{Int} + B_{ROW,t}^{Int} + B_{US,t}^{Int} = 0$$
$$B_{US,t}^{Int} = B_{UP,t}^{Int} + B_{UCB,t}^{Int}$$
$$B_{ROW,t}^{Int} = B_{ROW,t}^{Int} + B_{ROW,t}^{Int}$$

The foreign asset accumulation equations for the three economies are now:

$$B_{H,t+1}^{Int} = NNX_t + (1 + R_{t-1}^{Int}) \cdot B_{H,t}^{Int}$$

$$B_{US,t+1}^{Int} = NNX_t^{US} + (1 + R_{t-1}^{Int}) \cdot B_{US,t}^{Int}$$

$$B_{ROW,t+1}^{Int} = NNX_t^{ROW} + (1 + R_{t-1}^{Int}) \cdot B_{ROW,t}^{Int}$$

These three equations together with the zero net supply condition for the international bond yield the following identity for the international trade:

$$NNX_t + NNX_t^{ROW} + NNX_t^{US} = 0$$

In this situation not only for China and ROW but also for US the expansion of money supply is backed by the increase of the international bond holdings. Therefore, the following equations hold as well:

$$M_t^S - M_{t-1}^S = EX_t \cdot \left[B_{HCB,t+1}^{Int} - (1 + R_{t-1}^{Int}) \cdot B_{HCB,t}^{Int} \right]$$

$$M_t^{ROW,S} - M_{t-1}^{ROW,S} = EXR_t \cdot \left[B_{RCB,t+1}^{Int} - (1 + R_{t-1}^{Int}) \cdot B_{RCB,t}^{Int} \right]$$

$$M_t^{US,S} - M_{t-1}^{US,S} = B_{UCB,t+1}^{Int} - (1 + R_{t-1}^{Int}) \cdot B_{UCB,t}^{Int}$$

The nominal interest rate of the international bond is determined by the global financial market, and the following two modified UIP conditions link this rate with the nominal interest rates of US and ROW:

$$R_t^{ROW} = R_t^{Int} + \mathbb{E}_t(lnEXR_{t+1} - lnEXR_t) + \Omega^{ROW} \cdot \psi^{ROW} \cdot \widehat{\psi_t^{ROW}}$$

$$R_t^{US} = R_t^{Int} + \Omega^{US} \cdot \psi^{US} \cdot \widehat{\psi_t^{US}}$$

where ψ_t^{ROW} and ψ_t^{US} are the households' portfolio share of domestic bonds for ROW and US, and are now defined respectively as: $\psi_t^{ROW} \equiv B_{t+1}^{ROW}/(B_{t+1}^{ROW} + EXR_t \cdot B_{RP,t+1}^{Int})$ and $\psi_t^{ROW} \equiv B_{t+1}^{US}/(B_{t+1}^{US} + B_{UP,t+1}^{Int})$. $\widehat{\psi_t^{ROW}}$ and $\widehat{\psi_t^{US}}$ are the percent deviations of ψ_t^{ROW} and ψ_t^{US} from their steady-state values. Here for the modified UIP condition linking the nominal interest rates of US bond and the international bond, there is no term for exchange rate, because the international bond is still denominated in US dollar here, which is the same for US bond.

Under this counterfactual setting we consider four alternative monetary regimes for China as well: the regime when the capital accounts are closed and the exchange rate of Renminbi is fixed (no reform), opening the capital account only, floating the exchange rate only and the full liberalizing reform.
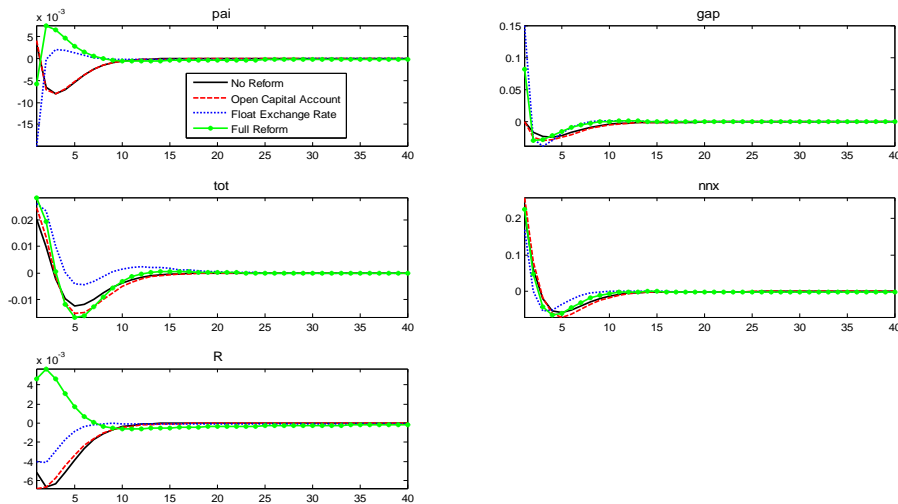
Figure 16. Impulse responses of China's aggregate variables (cycles) to a one-percent US money supply shock under different regimes for China when an international bond denominated in US

dollar replaces US bond as the global foreign exchange reserves (in percent).

Figure 16 shows the results in this circumstance. If we compare Figure 16 with Figure 14, we can find that they are almost the same. So if there is an international bond to replace US government bond, as the global reserve asset, but the international bond is still denominated in US dollar, the response of China's economy to US money supply shock will be similar to the case as if the US bond were still the only global reserve asset. The welfare implication for China is also nearly the same, as shown in Table 8. The reason is maybe that for the benchmark setting when the US bond is the only global reserve asset, its net supply and other countries' holdings of it at the steady state are all zero, which is close to the assumption here that the net supply of this international bond is zero. However, as we will see, when this international bond is denominated not in US dollar but in a supranational reserve currency, the result would be quite different.

8.2.2. An international bond denominated in a supranational reserve currency

In this case, to eliminate US bond's role in the international financial market as in the benchmark model, still there is a kind of international bond, B_t^{Int}, which is the only internationally traded asset and has zero net supply. The difference from the above case is that this bond is denominated in a supranational reserve currency, which is created as a combination of three currencies (US dollar, Renminbi and Ro), weighted by the corresponding country's GDP share in the world. Simply it can be expressed as below:

$$Int = \omega_1 \cdot RMB + \omega_2 \cdot Ro + (1 - \omega_1 - \omega_2) \cdot USD$$

where Int denotes this supranational reserve currency, and RMB, USD and Ro denote respectively Renminbi, US dollar and the ROW currency, Ro. The weights, ω_1 and ω_2, are respectively the GDP shares of China and ROW in the world at the steady state.

Therefore, the supranational currency Int now does not only have its own nominal interest rate, but also has its exchange rates relative to US dollar, Renminbi and Ro. Suppose the exchange rates of Int to Renminbi, Ro and US dollar, under the indirect quotation, are $IntEX_t$, $IntEXR_t$ and $IntEXU_t$ respectively. Then these three exchange rates can be in fact explained by two exchange rates of US dollar (under the indirect quotation as well), EX_t and EXR_t, as below:

$$IntEX_t = \omega_1 + \omega_2 \cdot \frac{EX_t}{EXR_t} + (1 - \omega_1 - \omega_2) \cdot EX_t$$

$$IntEXR_t = \omega_1 \cdot \frac{EXR_t}{EX_t} + \omega_2 + (1 - \omega_1 - \omega_2) \cdot EXR_t$$

$$IntEXU_t = \omega_1 \cdot \frac{1}{EX_t} + \omega_2 \cdot \frac{1}{EXR_t} + (1 - \omega_1 - \omega_2)$$

Then if we assume the dollar pricing still exists, the foreign asset accumulation equations for the three economies are now:

$$\left[B_{H,t+1}^{Int} - (1 + R_{t-1}^{Int}) \cdot B_{H,t}^{Int}\right] \cdot IntEX_t = NNX_t \cdot EX_t$$

$$\left[B_{US,t+1}^{Int} - (1 + R_{t-1}^{Int}) \cdot B_{US,t}^{Int}\right] \cdot IntEXU_t = NNX_t^{US}$$

$$\left[B_{ROW,t+1}^{Int} - (1 + R_{t-1}^{Int}) \cdot B_{ROW,t}^{Int}\right] \cdot IntEXR_t = NNX_t^{ROW} \cdot EXR_t$$

These three equations together with the zero net supply condition for the international bond can still yield the following identity for the international trade with US dollar as the invoicing currency:

$$NNX_t + NNX_t^{ROW} + NNX_t^{US} = 0$$

The equations for money supply expansions and modified UIP conditions should be changed accordingly as follows:

$$M_t^S - M_{t-1}^S = IntEX_t \cdot \left[B_{HCB,t+1}^{Int} - (1 + R_{t-1}^{Int}) \cdot B_{HCB,t}^{Int}\right]$$

$$M_t^{ROW,S} - M_{t-1}^{ROW,S} = IntEXR_t \cdot \left[B_{RCB,t+1}^{Int} - (1 + R_{t-1}^{Int}) \cdot B_{RCB,t}^{Int}\right]$$

$$M_t^{US,S} - M_{t-1}^{US,S} = IntEXU_t \cdot \left[B_{UCB,t+1}^{Int} - (1 + R_{t-1}^{Int}) \cdot B_{UCB,t}^{Int}\right]$$

$$R_t^{ROW} = R_t^{Int} + \mathbb{E}_t(ln(IntEXR_{t+1}) - ln(IntEXR_t)) + \Omega^{ROW} \cdot \psi^{ROW} \cdot \widehat{\psi_t^{ROW}}$$

$$R_t^{US} = R_t^{Int} + \mathbb{E}_t(ln(IntEXU_{t+1}) - ln(IntEXU_t)) + \Omega^{US} \cdot \psi^{US} \cdot \widehat{\psi_t^{US}}$$

In this circumstance the modified UIP condition linking the nominal interest rates of US bond and the international bond has terms for exchange rate, because the international bond is now denominated in the supranational currency Int, rather than US dollar.
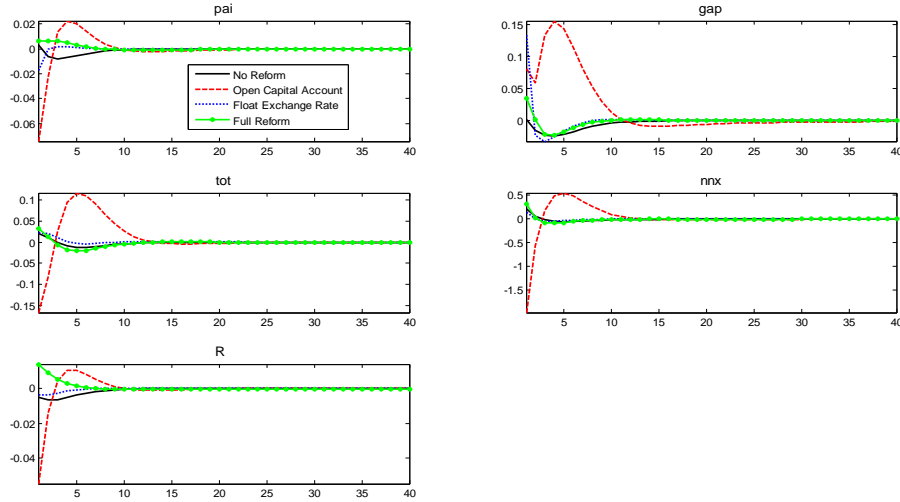
Figure 17. Impulse responses of China's aggregate variables (cycles) to a one-percent US money supply shock under different regimes for China when an international bond denominated in a supranational reserve currency replaces US bond as the global foreign exchange reserves (in percent).

Under this counterfactual setting we again consider four alternative monetary regimes for China: the regime when the capital accounts are closed and the exchange rate of Renminbi is fixed (no reform), opening the capital account only, floating the exchange rate only and the full reform. As shown in Figure 17, except for the regime opening the capital account only, for all other three regimes, the response of China's

economy to US money supply shock is similar to the case as if the US bond were still the only global reserve asset. But for the regime opening the capital account only, the responses of China's aggregate variables are totally opposite to the regime with no reform and the magnitude becomes much larger. This kind of larger fluctuation generates a big welfare loss for China: a 10% US money supply shock will result in 3.85% welfare loss for Chinese households. And in this scenario no reform is the best reform for China, under US money supply shock.

8.3. When US dollar serves as the US domestic currency only

In this part the dollar standard in the international trade is removed and replaced by PCP, and US dollar is no longer the global reserve currency. In other words, US dollar now does not serve as the world currency, but serves as the US domestic currency only. We focus on the situation when there is an international bond denominated in a supranational reserve currency. For the case when the international bond is denominated in US dollar, we still provide the relevant results in the appendix of this paper.

Figure 18 shows the impulse responses of China's aggregate variables to the same US money supply shock under four alternative regimes for China. Generally, we have three points to make, under this circumstance when US dollar is no longer the world currency. First of all, with no reform China's economy would have similar response to the situation when US dollar is the world currency, and this makes the best welfare gain for Chinese households. Secondly, with the regime opening the capital account only but keeping the exchange rate of Renminbi pegging the US dollar, China's economy would be much more fluctuating, and thus Chinese households would have quite a big welfare loss, as shown in Table 8. Third, to let the exchange rate of Renminbi to float, China's economy will nearly not be influenced by US money supply shock at all, no matter whether capital controls are lifted or not.
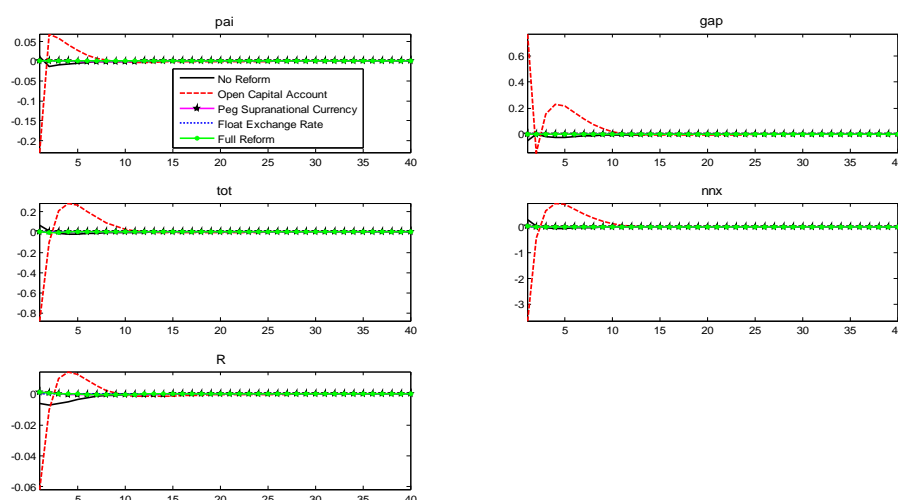
Figure 18. Impulse responses of China's aggregate variables (cycles) to a one-percent US money supply shock under different regimes for China when the dollar pricing in international trade is

replaced by PCP and an international bond denominated in a supranational reserve currency replaces US bond as the global foreign exchange reserves (in percent). (Note: the case "Peg Supranational Currency" means that the capital account of China is opened but the exchange rate of Renminbi to this supranational reserve currency, rather than to US dollar, is fixed)

One question arises here: since US dollar now is no longer the world currency, why should Renminbi peg US dollar? We also examine the circumstance that the capital account of China is opened but Renminbi pegs the supranational reserve currency, rather than US dollar. The corresponding result is shown in Figure 18 as well. Now with the regime opening the capital account only, China's economy would not fluctuate largely any more. Therefore, when US dollar serves only as the US domestic currency, pegging US dollar but opening capital account would generate a large welfare loss for China due to big economic fluctuation; but when pegging the supranational reserve currency rather than US dollar, China's economy would nearly not be affected by US money supply shock any more.

9.   CONCLUDING REMARKS

In this paper, we model US dollar as a world currency in a New Keynesian global DSGE framework within which three asymmetric economies are interacting with each other and the so called "rest of the world" is not exogenously or passively given; and focus on the effects of US money supply shock upon China's macro economy.

Due to the special roles of US dollar (dollar pricing in the international trade and global reserve currency) and special institutional arrangements of China (nominal exchange rate targeting and capital controls), some negative effect of US money supply shock on China's GDP can be imagined. A preliminary empirical global VAR (GVAR) model shows that when there is a positive shock to US money supply, China will have higher inflation rate and lower GDP level.

Our global DGSE model finds the following results: when a positive US money supply shock hits the global economy, the nominal interest rate of China will be lowered down (the spillover of liquidity effect); in the medium term both China's real output and its inflation rate are below the steady state levels; and both the terms of trade and nominal net export for China will be push up on impact, but be below their steady state levels in the medium term. Several kinds of sensitivity analysis are implemented, and the above results are quite robust. Cost-push effect and relative price effect are employed to discuss the transmission mechanism.

Welfare calculation for the benchmark model shows that a positive 10% of US money supply shock will result in a positive 1.25% welfare gain (as a fraction of the steady state consumption) for Chinese households, a positive 0.06% welfare gain for US, but a 0.21% welfare loss for the rest of the world.

We also examine the relationship between the persistence of US money supply shock and its influence on China's economy. The more persistent US money supply shock is, the larger the responses of China's aggregate variables would be. It is also found that: the response of China's economy to US money supply shock will not

become smaller when the share of China's GDP in the global economy becomes larger (even when it is double of US' GDP), as long as the US dollar remains as the world currency and there is no reform to China's institutional arrangements.

Counterfactual analyses are implemented in two ways: to reform China's institutional arrangements and to weaken the global roles of US dollar. For China's liberalization reform, three cases are considered: a partial lifting of capital controls with maintenance of the exchange rate peg, allowing the exchange rate of Renminbi to float while keeping the capital account closed, and the combination of allowing a floating exchange rate and a partial opening of capital controls. For weakening the US dollar's global roles, we assume dollar pricing in international trade is replaced by PCP, or assume there is another international bond to replace US bond as the global reserve asset. This international bond can be denominated in either US dollar or a supranational currency, and both of these two cases are examined. Given that US dollar's hegemony is not weakened, the regime with liberalized capital accounts but fixed exchange rate for China is best for the Chinese households under US money supply shock, while the regime with floating exchange rate and capital controls is the worst. However, this conclusion does not always hold when US dollar's global roles are removed. When US dollar is no longer the global reserve currency but instead a supranational reserve currency replaces it, then for China the regime with liberalized capital accounts and exchange rate pegging US dollar now is the worst kind of reform, no matter whether or not the dollar standard in the international trade is maintained. For China, to maintain the status quo (nominal exchange rate targeting and capital controls) cannot always achieve the first best, but can guarantee a second best under US money supply shock. When US dollar serves only as the domestic currency for US, then for China a floating exchange rate regime or pegging the supranational currency can make China's economy nearly unaffected by US money supply shock, no matter whether or not its capital account is opened.

We do not intend to push our numerical results too aggressively. However, qualitatively our conclusions from the benchmark model and the counterfactual analysis can help us better understand US dollar as a world currency and the effect of US money supply shock on China's economy, and then can provide some meaningful information for China's policy makers. Considering only US money supply shock, a fully liberalizing reform with capital controls removed and the exchange rate of Renminbi floating is not the best reform for China. This result is different from Chang *et al*. (2013) who consider only the US interest rate shock in a small-open economy framework. Besides US money supply shock and US interest rate shock, many other external shocks and risks that are influential to China's economy, should be considered as well to evaluate the potential reforms to China's institutional arrangements. We leave this for future studies.

Our framework and analysis could be extended by several means. First of all, the so called "sterilization activity" could be introduced by allowing the central bank of China to hold a certain amount of domestic bonds. Then the purchases of foreign assets can be financed by selling domestic bonds, which does not result in an expansion but instead leads to a structural reallocation of the central bank's balance

sheet. Secondly, it would be a challenge to try to incorporate stochastic GDP and price trends into the model, so as to make it more realistic and have a chance to make best of data as well. We have in the model three economies, which in reality have different GDP growth rates and whose relative sizes are changing over time. Third, one can introduce the zero lower bond of nominal interest rate for US, and examine the spillover effects of US money supply shock when there is a liquidity trap in US. Fourth, a natural extension can be achieved by incorporating financial frictions into the model and making it more complex and realistic. Last but not least, optimal monetary policy making and possible policy coordination between US and China could be considered.

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APPENDICES

Appendix A: supplementary algebra

Appendix A1: specification of degree-of-openness parameters for US and ROW

China's GDP can be normalized to be unit. Assume the GDP of US and ROW are respectively x and y. Then the economy of US and ROW can be viewed as consisting of x and y unit economies like China, and the global economy has $(1 + x + y)$ unit economies. Consider the situation when the prices of all kinds of goods are the same. Assume the import of each unit economy is ρ_1 times its aggregate demand (which is equal to its GDP, since the trade is balanced here), and it equally comes from the rest $(x + y)$ unit economies. So the import of any unit economy from another different unit economy is $\rho_1/(x + y)$. Ignoring the intra-national trade of US and ROW, we can get the following table for each economy's import components:

Import from	China	US	ROW
China	0	$\rho_1 \cdot x/(x + y)$	$\rho_1 \cdot y/(x + y)$
US	$\rho_1 \cdot x/(x + y)$	0	$\rho_1 \cdot x \cdot y/(x + y)$
ROW	$\rho_1 \cdot y/(x + y)$	$\rho_1 \cdot x \cdot y/(x + y)$	0

Using this table, we can calculate ρ_2 and the parameters (ρ_1^j and ρ_2^j) for US and ROW easily:

$$\rho_2 = x/(x + y)$$
$$\rho_1^{US} = \rho_1 \cdot (1 + y)/(x + y), \rho_2^{US} = 1/(1 + y)$$
$$\rho_1^{ROW} = \rho_1 \cdot (1 + x)/(x + y), \rho_2^{ROW} = 1/(1 + x)$$

In fact, the international trade here is a simple gravity model.

Appendix A2: derivation of the welfare loss function

This appendix derives a second-order approximation to the China's representative household's utility when the economy remains in a neighborhood of the steady state.

The following second-order approximation of relative deviations in terms of log deviations is frequently used:

$$\frac{Z_t - Z}{Z} \simeq \hat{Z}_t + \frac{1}{2}\left(\hat{Z}_t\right)^2$$

where $\hat{Z}_t = log(Z_t) - log(Z)$ is the log deviation from steady state for a generic variable Z_t. The period t utility of the China's representative household, u_t, is given below:

$$u_t = lnC_t - \phi_1 \cdot \frac{(L_t)^{1+\eta}}{1+\eta} + \phi_2 \cdot ln(M_t/P_t)$$

The Second-order Taylor expansion of u_t around a steady state (C, L, M, P) yields:

$$u_t - u \simeq \frac{C_t - C}{C} - \phi_1 \frac{L_t - L}{L} + \phi_2 \cdot \left(\frac{M_t - M}{M} - \frac{P_t - P}{P}\right)$$

$$+ \frac{1}{2}\left\{ -\left(\frac{C_t - C}{C}\right)^2 + \phi_1 \cdot \left(\frac{L_t - L}{L}\right)^2 - \phi_2 \cdot \left(\frac{M_t - M}{M}\right)^2 + \phi_2 \cdot \left(\frac{P_t - P}{P}\right)^2 \right\}$$

In terms of log deviations,

$$u_t - u \simeq \widehat{C_t} - \phi_1 \cdot \widehat{L_t} + \phi_2 \cdot \left(\widehat{M_t} - \widehat{P_t}\right)$$

Then a second-order approximation to the consumer's welfare losses can be written and expressed as a fraction of the steady state consumption as:

$$WL \triangleq \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{u_t - u}{u_C \cdot C}\right) = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t (u_t - u)$$

$$= \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\widehat{C_t} - \phi_1 \cdot \widehat{L_t} + \phi_2 \cdot \left(\widehat{M_t} - \widehat{P_t}\right)\right]$$

Appendix B: supplementary tables

Table 5. Parameter calibration: Category 1

China		ROW		US	
parameter	value	parameter	value	parameter	value
α	0.5	α^{ROW}	0.67	α^{US}	0.67
θ	0.75	θ^{ROW}	0.5	θ^{US}	0.5
δ	5.0%	δ^{ROW}	2.5%	δ^{US}	2.5%
ρ_1	0.3	ρ_1^{ROW}	0.113	ρ_1^{US}	0.265
ρ_2	0.247	ρ_2^{ROW}	0.344	ρ_2^{US}	0.147
η	1	η^{ROW}	1	η^{US}	1
ε	11	ε	11	ε	11
ξ	1.5	ξ	1.5	ξ	1.5
ω	6	ω	6	ω	6
ψ^{ROW}	1.0	Ω^{ROW}	0.22		
φ_1	1.34	φ_1^{ROW}	1.5		
φ_2	0.15	φ_2^{ROW}	0.2		
$G/(Def \cdot GDP)$	20%	$G^{ROW}/(Def^{ROW} \cdot GDP^{ROW})$	20%	$G^{US}/(Def^{US} \cdot GDP^{US})$	20%
ε_T	0.2	ε_T^{ROW}	0.2	ε_T^{US}	0.2
ρ_a	0.7	ρ_a^{ROW}	0.7	ρ_a^{US}	0.7
ρ_R	0.7	ρ_R^{ROW}	0.7	ρ_R^{US}	0.7
ρ_G	0.7	ρ_G^{ROW}	0.7	ρ_G^{US}	0.7
				ρ_{MU}	0.7

Table 6. Parameter calibration: Category 2

China		ROW		US	
parameter	value	parameter	value	parameter	value
$Def \cdot GDP/EX$	1	$Def^{ROW} \cdot GDP^{ROW}/EXR$	5.81	$Def^{US} \cdot GDP^{US}$	1.91
R	0.01	R^{ROW}	0.01	R^{US}	0.01
$M/(Def.GDP)$	10.5%*4	$M^{ROW}/(Def^{ROW} \cdot GDP^{ROW})$	15%*4	$M^{US}/(Def^{US} \cdot GDP^{US})$	6.7%*4
$B/(Def.GDP)$	40%*4	$B^{ROW}/(Def^{ROW} \cdot GDP^{ROW})$	79.8%*4	$B^{US}/(Def^{US} \cdot GDP^{US})$	106.5%*4
EX	6.3	EXR	1		

Table 7. Parameter calibration: Category 3

China		ROW		US	
parameter	value	parameter	value	parameter	value
β	0.99	β^{ROW}	0.99	β^{US}	0.99
r	0.06	r^{ROW}	0.035	r^{US}	0.035
NNX	0	NNX^{ROW}	0	NNX^{US}	0
		τ^{ROW}	1	τ^{US}	1
TOT	1	TOT^{ROW}	1	TOT^{US}	1
φ	0.3	φ^{ROW}	0.1131	φ^{US}	0.2646
P	1	P^{ROW}	0.1587	P^{US}	0.1585
τ_7	0.2474	τ_3	1	τ_1	1
		τ_4	1	τ_2	1
		τ_6	0.3436	τ_5	0.1468
$P \cdot I/(Def \cdot GDP)$	37.88%	$P^{ROW} \cdot I^{ROW}/(Def^{ROW} \cdot GDP^{ROW})$	21.43%	$P^{US} \cdot I^{US}/(Def^{US} \cdot GDP^{US})$	21.43%
Y	6.3	Y^{ROW}	36.603	Y^{US}	12.033
B_H^{US}	0	B_{ROW}^{US}	0	B_{UCB}^{US}	0
		B_{RCB}^{US}	0		

Table 8. Welfare gain (or loss) for China under alternative counterfactual settings

| Regime of China's economy	US dollar's global roles (R1 & R2)					
	Benchmark (R1 + R2)	No R1	No R2		No R1 and No R2	
			Case 1	Case 2	Case 1	Case 2
Benchmark	+ 0.125	+ 0.146	+ 0.126	+ 0.125	+ 0.149	+ 0.147
Capital controls lifted	+ 0.126	+ 0.147	+ 0.145	- 0.385	+ 0.180	- 0.893
Exchange rate peg removed	- 0.049	0.000	- 0.086	- 0.076	0.000	0.000
Full reform	- 0.042	+ 0.026	- 0.037	- 0.022	- 0.004	- 0.003

Notes: 1. Welfare gain (or loss) is measured as a fraction of the steady-state consumption under a one-percent US money supply shock; 2. All numbers are in percent; 3. *R1* and *R2* respectively denote the two roles of US dollar as the world currency, the only invoicing currency in the international trade and the only global reserve currency; 4. *Case 1* and *Case 2* denote two alternative situations that the international bond is denominated either in US dollar or in a supranational reserve currency.

**Table 9**. Welfare gain (or loss) for US under alternative counterfactual settings

Regime of China's economy	US dollar's global roles (R1 & R2)					
	Benchmark (R1 + R2)	No R1	No R2		No R1 and No R2	
			Case 1	Case 2	Case 1	Case 2
Benchmark	+ 0.006	- 0.009	+ 0.006	+ 0.005	- 0.010	- 0.010
Capital controls lifted	+ 0.006	- 0.008	+ 0.004	+ 0.098	- 0.018	+ 0.369
Exchange rate peg removed	+ 0.003	+ 0.015	- 0.002	- 0.002	+ 0.016	+ 0.016
Full reform	+ 0.000	+ 0.096	- 0.003	- 0.007	+ 0.001	+ 0.003

Notes: 1. Welfare gain (or loss) is measured as a fraction of the steady-state consumption under a one-percent US money supply shock; 2. All numbers are in percent; 3. *R1* and *R2* respectively denote the two roles of US dollar as the world currency, the only invoicing currency in the international trade and the only global reserve currency; 4. *Case 1* and *Case 2* denote two alternative situations that the international bond is denominated either in US dollar or in a supranational reserve currency.

Table 10. Welfare gain (or loss) for ROW under alternative counterfactual settings

Regime of China's economy	US dollar's global roles (R1 & R2)					
	Benchmark (R1 + R2)	No R1	No R2		No R1 and No R2	
			Case 1	Case 2	Case 1	Case 2
Benchmark	- 0.021	- 0.017	-0.030	- 0.034	- 0.027	- 0.031
Capital controls lifted	- 0.020	- 0.017	-0.038	+ 0.459	- 0.040	+ 0.625
Exchange rate peg removed	- 0.035	+ 0.001	-0.111	- 0.110	+ 0.013	+ 0.013
Full reform	- 0.041	+ 0.058	-0.088	- 0.101	- 0.010	- 0.008

Notes: 1. Welfare gain (or loss) is measured as a fraction of the steady-state consumption under a one-percent US money supply shock; 2. All numbers are in percent; 3. *R1* and *R2* respectively denote the two roles of US dollar as the world currency, the only invoicing currency in the international trade and the only global reserve currency; 4. *Case 1* and *Case 2* denote two alternative situations that the international bond is denominated either in US dollar or in a supranational reserve currency.
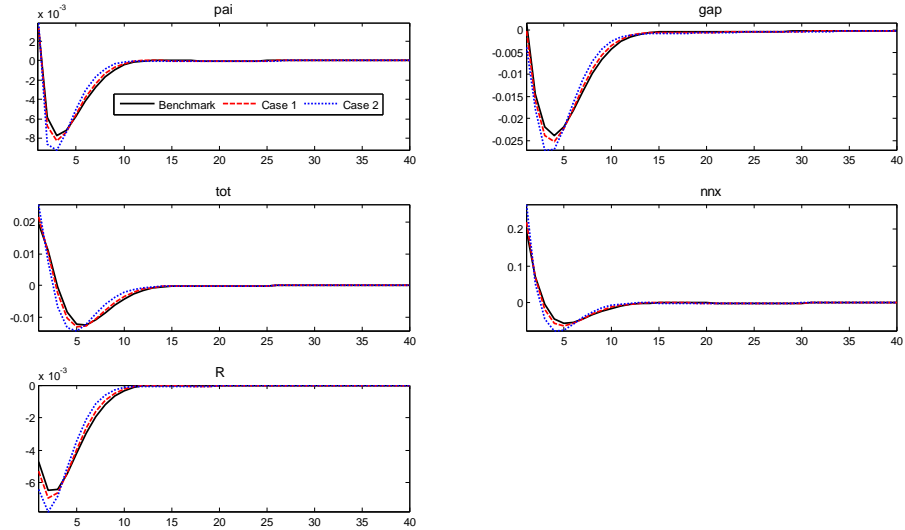
Appendix C: supplementary figures
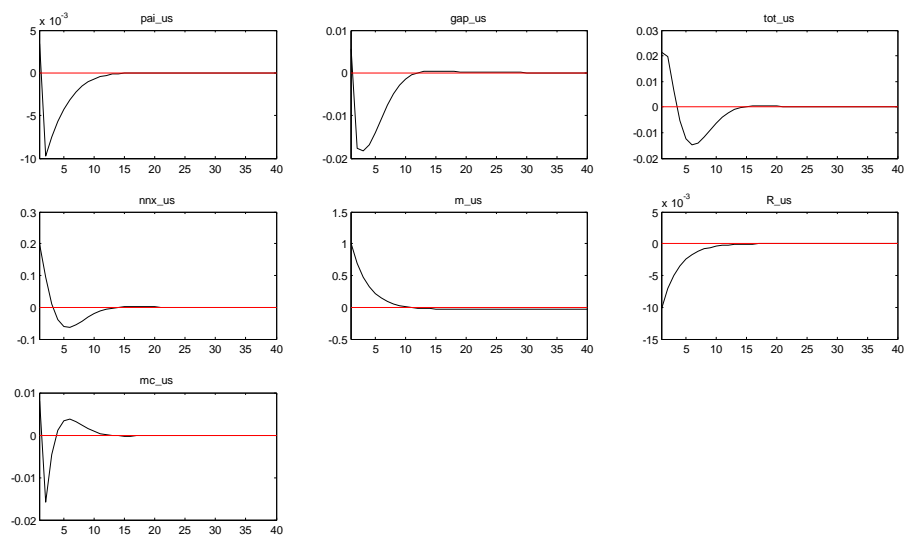
Figure 6. Impulse responses of US aggregate variables (cycles) to a one-percent US money supply shock (in percent).
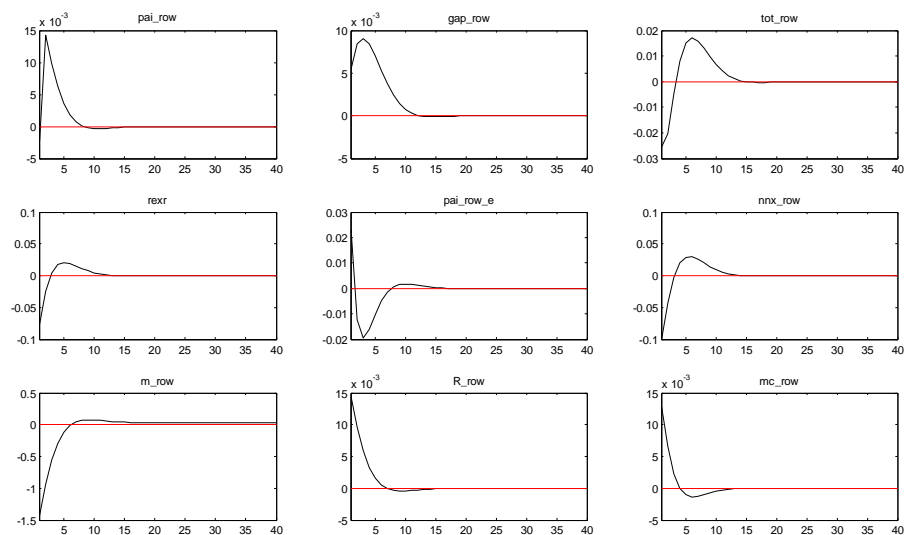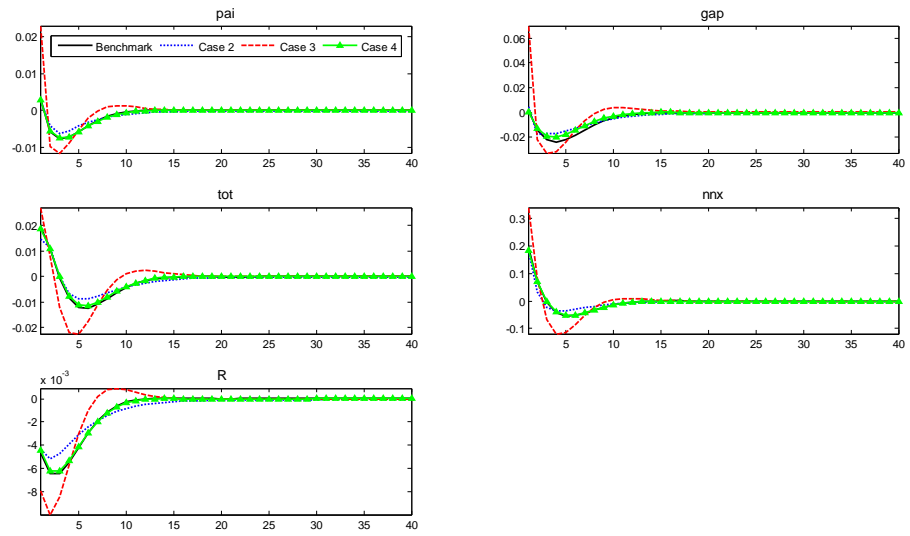

Figure 7. Impulse responses of ROW aggregate variables (cycles) to a one-percent US money supply shock (in percent)
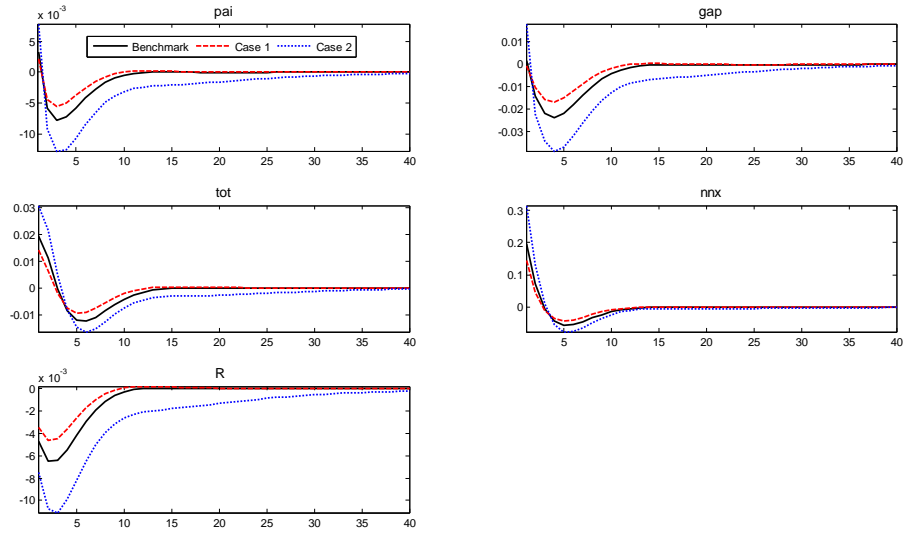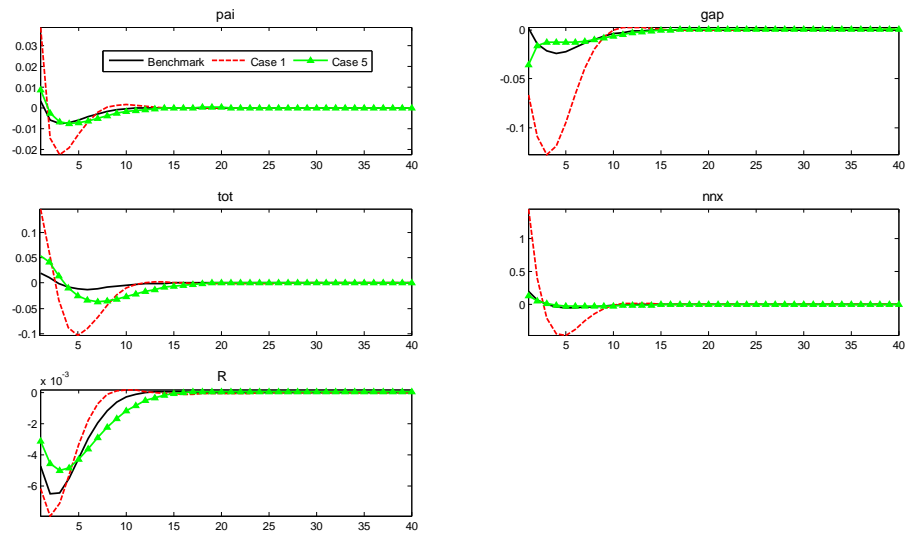
Figure 8. Impulse responses of China's aggregate variables (cycles) to a one-percent US money supply shock under different settings for the persistence parameter of the shock: Benchmark $\rho_{MU} = 0.7$, Case 1 $\rho_{MU} = 0.5$, and Case 2 $\rho_{MU} = 0.9$ (in percent).
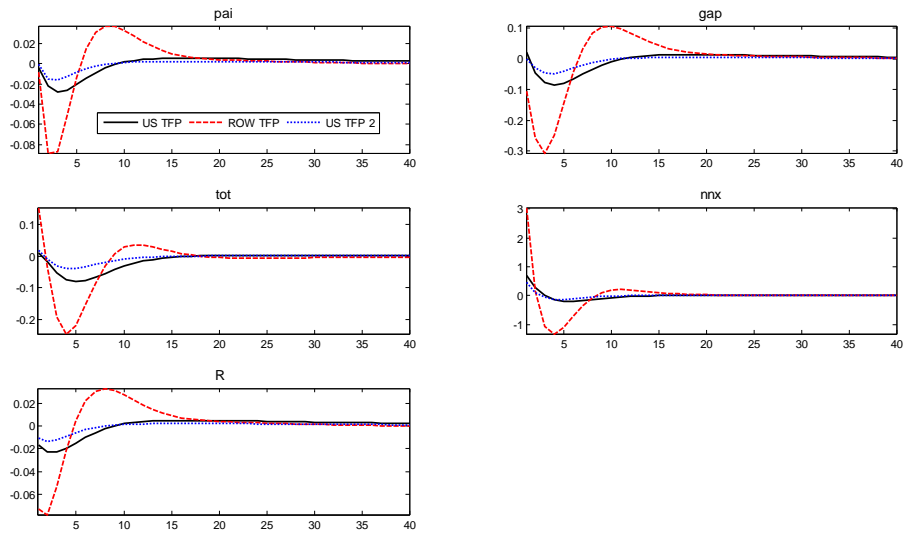

Figure 9. Impulse responses of China's aggregate variables (cycles) to a one-percent US money supply shock under different settings for the size of China's economy in the world at the steady state: for Case 1 China's real GDP is doubled, while US GDP and ROW GDP keep the same as in the benchmark model setting; and for Case 2 China's real GD is quadrupled (in percent).

Figure 10. Sensitivity analysis A: impulse responses of China's aggregate variables (cycles) under different model settings: benchmark and Case 2, 3, 4 of the sensitivity analysis (in percent).


Figure 11. Sensitivity analysis B: impulse responses of China's aggregate variables (cycles) under different model settings: benchmark and Case 1, 5 of the sensitivity analysis (in percent).

Figure 12. Impulse responses of China's aggregate variables (cycles) to a one-percent US TPF shock, to a one-percent ROW TPF shock, and to a one-percent US TPF shock when TFP shocks are correlated (indicated by "US TFP 2" in the figure) (the correlation coefficient is 0.5 between US TFP shock and China's, and is 0.7 between US's and ROW's) (in percent)..
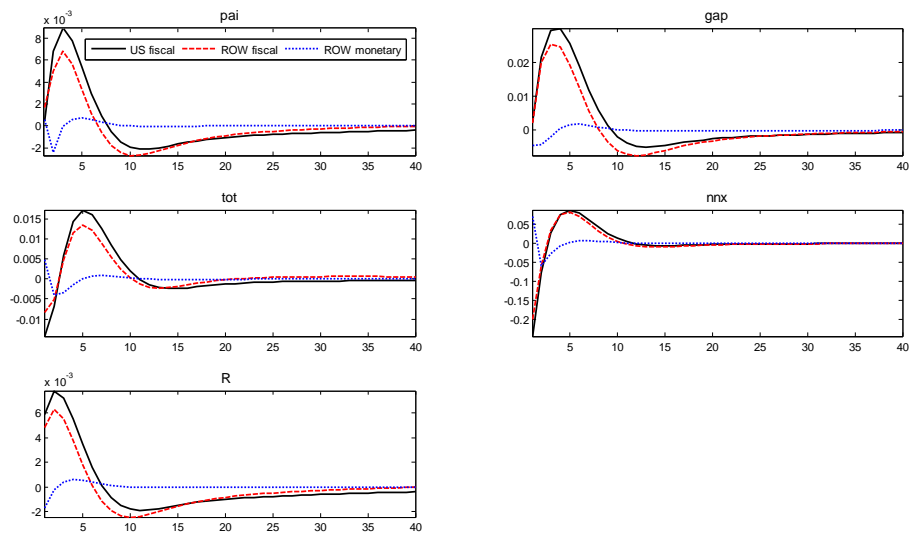
Figure 13. Impulse responses of China's aggregate variables (cycles) to foreign policy shocks: fiscal policy shock (a one-percent government spending shock) and monetary policy shock (a basis-point nominal interest rate shock) (in percent).
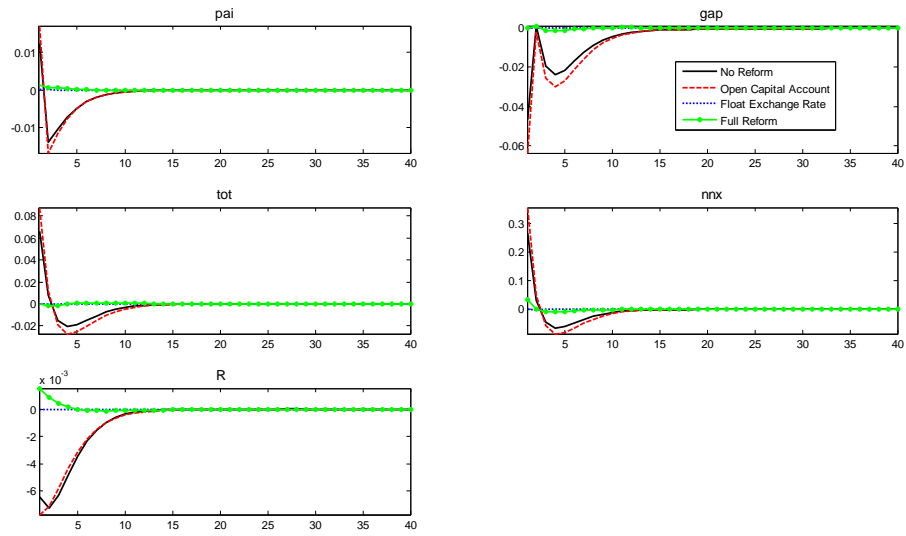
Figure 19. Impulse responses of China's aggregate variables (cycles) to a one-percent US money supply shock under different regimes for China when dollar pricing in international trade is replaced by PCP and an international bond denominated in US dollar replaces US bond as the global foreign exchange reserves (in percent).