Forward Guidance and Financial Stability in a Model of Optimal Central Bank Swap Lines

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The main goal of this study is to develop a dynamic equilibrium model of central bank swap lines that helps understand the recent observed behaviors of foreign reserves and to analyze the potential effect of the Federal Reserves' foreign exchange swap lines on the determination of international reserves and exchange rates. The model focuses on the issue of moral hazard that can arise with the liquidity provision of the Federal Reserve through its swap lines with other central banks. This study argues that a standard debt contract under asymmetric information between lenders and borrowers may not work to model actual swap lines between the Federal Reserve and foreign central banks because lenders tend to accept credit risks in debt contract models. This study shows that debt contracts between the Federal Reserve and foreign central banks are inferior to swap contracts in the presence of the informational advantage of foreign central banks for local financial institutions in their jurisdictions. Although the proposed model is primarily intended to understand the contractual relation between the Federal Reserve and foreign central banks, it can also serve as a determination model for the nominal exchange rate. A policy implication of this model is that short-run and long-run channels are available through which the expectation formation of agents is affected by the behavior of international reserves and the credible long-term stance of the monetary policy.

Keywords: International Reserves, Exchange Rate, Central Bank Liquidity Swap Lines

JEL Classification: E31, F31, F32

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[**Seoul Journal of Economics** 2015, Vol. 28, No. 2]

I. Introduction

The recent two decades have witnessed a relatively long trend of reserve accumulation prior to the global financial crisis and its substantial declines during the crisis in the group of emerging-market countries. Before the crisis, the academia and practical policy makers remarked that that their hoarding of international reserves might be excessive in light of the so-called "Guidotti-Greenspan" prescription for reserve adequacy. This situation held especially for reserve stocks that were more than enough to cover potential disruptions in the international settlements of imports and even in the roll-over of their short-term external debts. During the crisis, the Federal Reserve provided foreign exchange swap lines with other central banks that include the European Central Bank, the Swiss National Bank, the Bank of Japan, and the Bank of Korea.

The main goal of this study is to develop a dynamic model that helps understand the observed behaviors of foreign reserves summarized above and to analyze the potential effect of the foreign exchange swap lines of the Federal Reserves on the determination of international reserves and exchange rates. In the proposed model, foreign central banks engage in the financial intermediation between the Federal Reserve and non-U.S. financial institutions. Specifically, foreign central banks distribute U.S. dollars to local financial institutions with "variable rate" auctions while making currency swap contracts with the Federal Reserve.

A notable feature of the foreign exchange swap lines from the Federal Reserve is that different lending rates are set for different central banks, whereas the Federal Reserve does not accept credit risks that may arise from lending to local financial institutions. Given this actual working of foreign exchange swap lines, assuming that the Fed delegates its lending capacity to foreign central banks to save intermediation costs that may arise with the asymmetric information about balance sheet conditions of local financial institutions that benefited from foreign exchange swap lines may not be unreasonable. In fact, the moral hazard that can arise with the liquidity provision of the Federal Reserve through its swap lines has been considered in the academia and practical policy circles. However, a standard debt contract under asymmetric information between lenders and borrowers may not work to model actual swap lines between the Federal Reserve and foreign central banks because lenders tend to accept credit risks in debt contract models.

This study shows that debt contracts between the Federal Reserve and foreign central banks are inferior to swap contracts between them

in the presence of the informational advantage of foreign central banks for local financial institutions in their jurisdictions. In the presence of a moral hazard issue, central bank swap lines may not enable a country to attain an arbitrarily large level of short-term financial debt. Therefore, seeking a prescription for an adequate financial capacity of international reserves would be desirable when the financial capacity of international reserves is defined as the sum of its international reserves and the borrowing from central bank swap lines. In this regard, if the short-term international debt is deposited in regional banks and the central bank defends the stability of regional financial markets, then the financial capacity of an international country will have the tendency to move in tandem with its broad monetary aggregates on average.

In particular, this prescription is in accordance with the view of Obstfeld, Shambaugh, and Taylor (2009 and 2010) that a central bank holds reserves as protection against "double-drain" crisis scenarios, in which banking and currency problems interact in ways that are likely to cause a sharp and disruptive external currency depreciation. The key point of their "financial stability model" is that considering the ratio of M_2 to GDP as an independent explanatory variable in their regression equation leads to a good understanding of the observed "excessive" levels of international reserves. The model presented in this study (up to the first-order approximation) leads to roughly the same specification as that used in the empirical model of international reserves reported in Obstfeld, Shambaugh, and Taylor (2009) under the assumption that the maximum internal drain of a country during crises is an increasing function of both M_2 and GDP.

One may also wonder if the introduction of foreign exchange swap lines can alter the way through which the exchange rate is determined in the foreign exchange market. Although the proposed model is primarily intended to understand the contractual relation between the Federal Reserve and foreign central banks, this model also describes how the nominal exchange rate is determined. In particular, the behavior of international reserves and the credible long-term stance of the monetary policy affect the expectation formation of agents through short-run and long-run channels.

The key mechanism behind this implication reflects the model feature in which a modified covered interest parity condition (up to the first-order approximation) can be derived from the equilibrium equation for international reserves. The implications of this modified covered interest parity condition for the determination of exchange rate can be summar-

ized as follows: A currency of a country is appreciated with the amount of its current and future international reserves but depreciated with its monetary aggregates when the debt capacity of international reserves is binding. This occurrence may hold even in the absence of foreign exchange swap lines.

The rest of this paper is organized as follows. The next section describes a model of central bank swap lines to mitigate U.S. dollar liquidity shocks. In Section III, I analyze the effect of central bank swap lines on the determination of nominal exchange rates and the issue of financial stability. Section IV concludes the paper.

II. A Model of Central Bank Swap Lines

In this section, I present a model of central bank foreign exchange swap lines. This model has four players: the Federal Reserve, foreign central banks, local wholesale financial institutions, and retail private banks. These players are all risk-neutral. Moreover, individual households are not allowed to have access to wholesale loan markets, as discussed below.

The foreign central bank holds a total stock of its international reserves I_t^* at the beginning of period t. The foreign central bank withdraws an amount of international reserves F_t^* from its total balance of reserves at the time when it enters into the foreign exchange swap contract with the the Federal Reserve. Using this contract, the foreign central bank adds $(A_t^* - F_t^*)$ to its own holding of reserves to generate a total stock of A_t^* available at period t. In return for its borrowing, the foreign central bank pays $(1+z_t)(A_t^* - F_t^*)$ to the Federal Reserve, where z_t is the contractual interest rate. Note that allowing both swap reserves and non-swap reserves helps explain how the reference nominal exchange rate (denoted by e_t) is determined through the interactions of different wholesale banks.

The important feature of central bank swap lines is that the Federal Reserve does not bear any credit risk associated with the distribution of U.S. dollars drawn from central bank swap lines to local banks. The Federal Reserve is not a counterparty to the loan extended by the foreign central bank to the local depository institutions. Therefore, the foreign central bank bears the credit risk associated with the loans it makes to institutions in its jurisdiction.

Another important feature of central bank swap lines is the repurchased agreement between the Federal Reserve and foreign central banks.

At the beginning of their transaction, the foreign central bank sells its domestic currency M_t to the Federal Reserve in exchange for dollars $(A_t^* - F_t^*)$ at a spot nominal exchange rate e_t, so that $M_t = e_t(A_t^* - F_t^*)$ should hold. The Federal Reserve and the foreign central bank also enter into an agreement that requires the foreign central bank to buy back its currency at the same exchange rate e_t. The use of the same exchange rate for the repurchase agreement described above implies that changes in the market exchange rate do not affect the recorded value of the foreign exchange currency amount, and that the Federal Reserve bears no exchange rate risk.

The foreign central bank uses "variable-rate auctions" when providing loans with financial institutions in its jurisdiction. That is, U.S. dollar loans are allotted at the rate submitted by each successful bidder whose bid is greater than the minimum rate set by the central bank. To rationalize this assumption, the European Central Bank, the Swiss National Bank, and the Bank of England all conducted overnight variable-rate auctions for U.S. dollars during the second and third phases of foreign swap lines between the Federal Reserve and the central banks. The rate bids for dollars in these auctions tend to reflect the pressures in overseas U.S. dollar funding markets over this period.[1]

To rationalize the establishment of central bank swap lines, U.S. dollar liquidity shocks in local financial markets are assumed. The magnitude of U.S. dollar liquidity shocks is measured using the excess demand of U.S. dollars in each local market. A continuum of local financial markets exists where retail banks operate to help the exchange among different currencies. Each local market is differentiated ex-post depending on the realized values of U.S. dollar liquidity shocks that are idiosyncratic across different local markets. As mentioned in the introduction, addressing the issue of moral hazard in the provision of U.S. dollars through central bank swap lines is essential. The potential possibility of moral hazard problems may exist because of the asymmetric information between the Federal Reserve and local institutions. Specifically, the Federal Reserve alone does not observe these shocks unless it pays physical resources,

[1] The variable-rate tender is defined as a tender procedure in which counterparties bid both the amount of money they want to transact with the central bank and the interest rate at which they want to enter into the transaction in the glossary of the European Central Bank. By contrast, a fixed rate tender is defined as a tender procedure in which the interest rate is specified in advance by the central bank and participating counterparties bid the amount of money they want to transact at that interest rate.

as will be elaborated later.

I now discuss the formal description of liquidity shocks for U.S. dollars in local markets. Suppose that retail banks who operate in the local market i have their total demands for U.S. dollars of D_t^i in local currencies. The amount of U.S. dollars available from the supplies of wholesale banks in local market i is A_t^*, and the spot exchange rate at period t in the wholesale market is e_t. Therefore, the market-clearing condition in local market i is $D_t^i = \omega_t^i e_t A_t^*$ where ω_t^i is the shortage of U.S. dollars in local market i given a supply level of A_t^*. The random variable ω is independently and identically distributed across time and across local markets with a continuous and once-differentiable cumulative probability distribution function, $\gamma(\omega)$, over a non-negative support. This expected value is equal to one, $E[\omega]=1$.

Local banks are also assumed to enter into forward exchange rate contracts to hedge exchange risks. The forward rate at period t for the spot nominal exchange rate at period $t+1$ is denoted by f_t. The absence of arbitrage in local market i is then given by $1+i_t^{*,i}=(1+i_t)\omega_t^i e_t/f_t$, where $i_t^{*,i}$ is the interest rate for U.S. dollar-denominated loans in local market i. As a result, a wholesale bank that enters local market i has an ex-post gross return from its loan portfolio of $\omega_t^i\{(1+i_t)e_t/f_t\}$, where $\{1+i_t)e_t/f_t\}$ can be interpreted as the ex-post aggregate average return on domestic loan portfolios. In this case, the aggregate market clearing condition should be $D_t = e_t A_t^*$, where $D_t = \int_0^\infty D_t^i(\omega)d\gamma(\omega)$. As a result, the aggregate average gross return of U.S. dollar loans from wholesale banks is $e_t(1+i_t)A_t^*/f_t$. However, note that only a fraction of wholesale banks has U.S. dollar loans from the central bank's auctions. The banks that are not successful or do not participate in the auctions of the central bank do not need to make any repayments to the central bank.

Definition 2.1 (News Shocks for True Liquidity Shocks) The market-clearing condition in local market i is $D_t^i = \omega_t^i e_t A_t^*$, where ω_t^i is the shortage of U.S. dollars in local market i given a supply level of A_t^*. The random variable ω is independently and identically distributed across time and local markets with a continuous and once-differentiable cumulative probability distribution function, $\gamma(\omega)$, over a non-negative support. This expected value is also equal to one, $E[\omega]=1$. The realized values of these market-specific liquidity shocks have "new shocks" before their true realization. The information content of "news shocks" indicates the capability of the foreign central bank to gather information about the correct liquidity conditions of the local financial markets in its jurisdiction.

The information structure of the model is described as follows. Determining whether the foreign central bank has certain information about the realization of U.S. dollar liquidity shocks is important when this bank enters into a contract with the Federal Reserve. This task is essential because the contractual interest rates of swap lines become the stop-out rates of auctions used to distribute U.S. dollars. Moreover, the swap agreements among central banks should be determined before auctions. In fact, if the central bank's drawings from its swap lines are not its normal routine work, then the central bank should be able to determine in each period whether to use its swap line or not.

For this reason, "news shocks" about the realized values of market-specific idiosyncratic liquidity shocks are assumed to exist. These "news shocks" have the same cumulative probability distribution as those of idiosyncratic shocks. The foreign central bank knows when it enters in the swap contract with the Federal Reserve and also believes that its knowledge about "news shocks" will hold true. Therefore, the foreign central bank believes that it has the full information about the realization of each local market's risk denoted by ω. Therefore, as mentioned earlier, the information content of "news shocks" reflects the capability of the foreign central bank to gather information about accurate liquidity conditions of the local financial markets in its jurisdiction. However, the Federal Reserve does not observe the realization of "news shocks" but knows their probability distributions denoted by $\gamma(\omega)$.

Definition 2.2 (Variable-Rate Auction) The foreign central bank announces a "variable-rate auction" to distribute an amount of U.S. dollars $(1-\gamma(\bar{\omega}_t))A_t^*$. Each wholesale bank, the market liquidity shock of which is ω, bids $\omega\{(1+i_t)e_t/f_t\}$ for A_t^* in the variable-rate auction provided by the foreign central bank. The stop-out rate for the auction is set by satisfying the following condition:

$$\bar{\omega}_t\{(1+i_t)e_t/f_t\}A_t^* = (1+z_t)(A_t^* - F_t^*),$$

where z_t is the interest rate at period t for the foreign exchange swap line with the Federal Reserve. If a wholesale bank (the shock ω of which is greater than $\bar{\omega}_t$) has a successful bid in the auction, then it repays $\omega\{(1+i_t)e_t/f_t\}A_t^*$ to the foreign central bank.

A wholesale bank with a market idiosyncratic shock of ω sets its bid rate as $\omega\{(1+i_t)e_t/f_t\}$. The foreign central bank then sets the lowest successful bid rate (denoted by $\bar{\omega}_t$) by satisfying the following equation:

$$\bar{\omega}_t\{(1+i_t)e_t/f_t\}A_t^* = (1+z_t)(A_t^* - F_t^*).$$

Therefore, the profit of the central bank that can be obtained from the variable-rate auction is given by

$$G(\bar{\omega}_t)\{(1+i_t)e_t/f_t\}A_t^*; \quad \Phi(\bar{\omega}) = \int_{\bar{\omega}}^{\infty}(\omega - \bar{\omega})d\Upsilon(\omega).$$

Only a fraction of wholesale banks has U.S. dollar loans from the central bank's auctions. The banks that are unsuccessful or do not participate in the central bank's auctions do not need to make any repayments to the central bank. Therefore, the total amount of U.S. dollars distributed through this auction is $(1-\gamma(\bar{\omega}_t))A_t^*$, and the other fraction $\gamma(\bar{\omega}_t)A_t^*$ is sold at retail foreign exchange markets.

Considering other ways to set the minimum rate in auctions may be possible. For example, although considering a rule to set the minimum rate that makes a zero cash flow of the central bank may be possible, this rule may not be useful to make a well-defined contract problem for central bank swap lines that address the issue of moral hazard. Therefore, I choose the rule of the minimum rate discussed earlier.

I now discuss the condition under which private debt contracts among private agents cannot replicate the foreign exchange swap lines discussed earlier if private international investors cannot verify the realized values of idiosyncratic shocks in the portfolios of private financial institutions. Considering this condition is necessary, as the debt contract developed in Bernanke, Gertler, and Gilchrist (1999) can create the same expected profit of the foreign central bank as that of a private agent who participates in the contract with its net worth F_t^*.

To show this result, the debt contract between the foreign central bank and a private international investor is regarded to lead to a non-default loan rate z_t and a threshold value of the idiosyncratic shock $\bar{\omega}_t$, such as that for the values of the idiosyncratic shock greater than or equal to $\bar{\omega}_t$. Under the debt contract, the whole realized values of the idiosyncratic shock is partitioned into default and non-default regions. In addition, the private international investors can borrow in the international financial market at a rate of i_t^*.

If the idiosyncratic shock belongs to the non-default region ($\omega \geq \bar{\omega}_t$), then the foreign central bank transfers $(1+z_t)(A_t^*-F_t^*)$ to its counterparty and keeps $\omega\{(1+i_t)e_t/f_t\}A_t^*-(1+z_t)(A_t^*-F_t^*)$. In the default region of $\omega < \bar{\omega}_t$, the foreign central bank cannot pay the contractual return and thus

declares default. The private investor pays the auditing cost and keeps what it gains. The default cost is proportional to the realized revenue: $\mu\omega\{(1+i_t)e_t/f_t\}A_t^*$, where a positive constant μ is less than one. In the default region, this constant receives $(1-\mu)\omega\{(1+i_t)e_t/f_t\}A_t^*$. As a result, if a private international investor borrows in the international financial market to invest in the debt contract with the foreign central bank, then its expected cash flow under the debt contract can be written as follows:

$$\Pi(\bar{\omega}_t, A_t^*; F_t^*) = \Psi(\bar{\omega}_t)\{(1+i_t)e_t/f_t\}A_t^* - (1+i_t^*)(A_t^* - F_t^*);$$
$$\Psi(\bar{\omega}) = (1-\Upsilon(\bar{\omega}))\bar{\omega} + (1-\mu)\int_0^{\bar{\omega}} \omega d\Upsilon(\omega)$$

where $\Pi(\bar{\omega}_t, A_t^*; F_t^*)$ is the expected cash flow of the private international investor under the debt contract with the foreign central bank. As a result, the optimal debt contract between a private international investor and the foreign central bank can be summarized as follows:

Definition 2.3 (Debt Contract) Suppose that private international investors can borrow in the international financial market at a rate of i_t^*. Under a debt contract with a private international investor, the foreign central bank solves the following optimization problem:

$$\max_{\bar{\omega}_t, A_t^*} G(\bar{\omega}_t)\{(1+i_t)e_t/f_t\}A_t^* \quad s.t. \quad \Pi(\bar{\omega}_t, A_t^*; F_t^*) \geq 0,$$

taking as given $\{(1+i_t)e_t/f_t\}$ and F_t^*. The equality of the constraint holds with free entries of private investors for debt contracts.

In particular, the debt contract defined earlier is the one that will be available when the Federal Reserve and local wholesale banks make debt contracts without any intermediation of the foreign central bank. In this case, swap lines can proceed without any explicit role of the foreign central bank. Having debt contracts between the foreign central bank and local wholesale banks is also possible, while the foreign central bank transfers a contractual interest to the Federal Reserve. However, any of the debt contracts defined earlier cannot realize the role of variable-rate auctions in central bank swap lines. Therefore, the swap contracts discussed in this paper are differentiated from debt contracts even with the fact that the two types of contracts have an identical form of optimization problem.

In this part, I characterize the central bank liquidity swap contracts. A formal definition of a central bank currency swap contract should

naturally include the following features to reflect central bank liquidity swap lines observed during the global financial crisis of 2008 to 2009:

1. Repurchase agreement at the same exchange rate
2. Variable-rate auction between the foreign central bank and wholesale banks
3. Payment of contractual interest by the foreign central bank for its borrowing in swap lines
4. Absence of the liquidity provider's bearing of credit risk

Given this characterization of central bank swap lines, a solution to the following optimization problem can be used to satisfy the requirement for characterizing central bank swap lines.

Definition 2.4 (Central Bank Swap Contract) Assume that i_t^* represents the Federal Reserve's opportunity cost for its lending to the foreign central bank. Under a central bank currency swap contract, the foreign central bank solves the following optimization problem:

$$\max_{\bar{\omega}_t, A_t^*} G(\bar{\omega}_t)\{(1+i_t)e_t/f_t\}A_t^* \quad s.t. \quad \underline{\Pi}_t \le \Pi(\bar{\omega}_t, A_t^*; F_t^*) \le 0 \;\; and \;\; z_t > i_t^*$$

taking as given $\{(1+i_t)e_t/f_t\}$, F_t^*, and a finite negative value $\underline{\Pi}_t$.

I now discuss the reasons why such constraints should be included to define a swap problem. The requirement of $z_t > i_t^*$ can be regarded as the Federal Reserves' participation constraint in the central bank swap contract given a level of the foreign central bank's borrowing. This condition means that the Federal Reserve's revenue under a debt contract with free entries of private investors for the liquidity provision is dominated by that under the swap contract defined earlier. The condition of $\Pi(\bar{\omega}_t, A_t^*; F_t^*) \le 0$ (along with $z_t > i_t^*$ in the case of equality) can be interpreted as the condition that eliminates the possibility of the private provision of liquidity under a debt contact with the same conditions that can be attained under a central bank currency swap contract. This condition also serves as a necessary condition for the Federal Reserve to choose a swap contract rather than a debt contract.

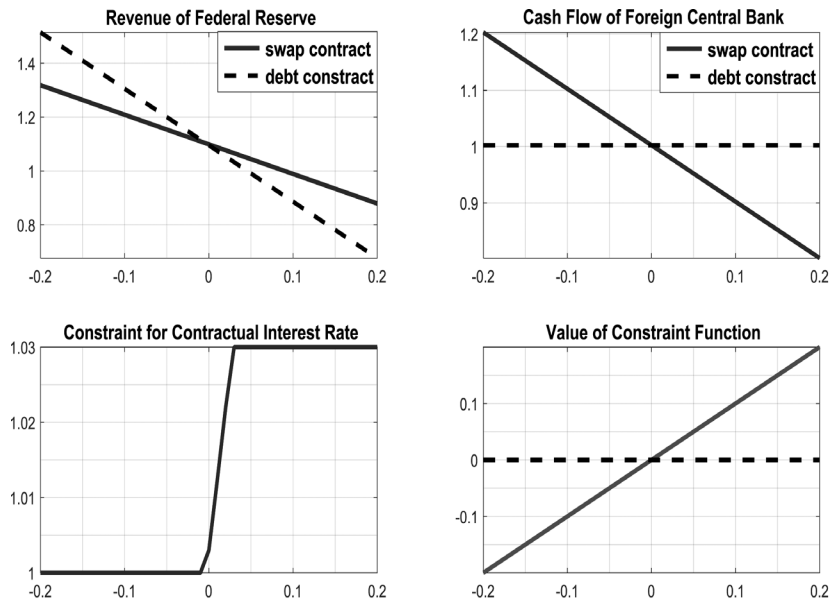
In particular, the constraint of $\Pi(\bar{\omega}_t, A_t^*; F_t^*) \le 0$ guarantees that the Federal Reserve does not participate in a debt contract (with free entries of private lenders) with the same form of objective function as that of the swap contract. This consideration is legitimate because of the asym-

metric information between the Federal Reserve and the foreign central banks. In addition, given that a lower value of the constraint function leads to a higher value of the objective function but a lower value of the Federal Reserve's revenue, assuming that a lower bound exists for the constant function that makes the Federal Reserve participate in the contract, denoted by $\underline{\Pi}_t$ in the definition of a central bank swap contract is reasonable. Therefore, I have rationalized the reason behind the importance of including the constraints for the central bank swap contract problem shown earlier.

Example 2.1 (Numerical Example) After describing the optimization problems of debt and swap contracts, I provide a numerical example for the model that may help to understand the important features of the model. The distribution of market-specific liquidity shocks follows a log-normal distribution: $\log \omega$: $N(-0.5\sigma^2, \sigma^2)$, where $\sigma=0.28$. In addition, the size of auditing costs that will occur with the bankruptcies of retail banks is set to be proportional to the realized value of their portfolios, the proportionality constant of which is set to be $\mu=0.12$, following the calibration of Bernanke, Gertler, and Gilchrist (1999). The spread of the covered interest parity is simply set to 5% in this example. Figure 1 shows the comparison of cash flows of central banks under swap and debt contracts. The upper panels of this figure show the cash flows of the Federal Reserve and foreign central banks under debt and swap contracts as the value of participation constraint varies from -0.2 to 0.2. The lower left panel shows that the contractual interest rate under the swap contract is lower than the opportunity cost for the Federal Reserve. The upper right panel indicates that the cash flow of the foreign central bank is higher under the swap contract than under the debt contract when $\varepsilon<0$. The lower left panel also shows that the constraint of $z_t>i_t^*$ is binding at around $\varepsilon=-0.01$, and the value of z_t increases when the value of ε increases. In particular, $z_t>i_t^*$ at $\varepsilon=0$. As a result, the lower left panel implies that the Federal Reserve will choose the swap contract when $\varepsilon=0$, even when a debt contract is available.

I now discuss the characterization of the optimal swap contract using its definition expressed earlier. Drawing the following assumption is crucial to guarantee the existence of solutions to both debt and swap contracts defined earlier.

Assumption 2.1 A unique solution to the debt contract problem with



Note: The upper panels of this figure displays the cash flows of the Federal Reserve and foreign central banks under debt and swap contracts as the value of participation constraint varies from -0.2 to 0.2. The lower left panel shows that the contractual interest rate under the swap contract is lower than the opportunity cost for the Federal Reserve.

FIGURE 1

CASH FLOWS OF CENTRAL BANKS UNDER SWAP AND DEBT CONTRACTS

free entries of private liquidity providers is expressed as $\Pi(\bar{\omega}_t, A_t^*; F_t^*)=0$. In this case, the contractual interest denoted by z_t is greater than the opportunity cost of liquidity providers (including the Federal Reserve) denoted by i_t^*: $z_t > i_t^*$.

A detailed discussion of the set of sufficient conditions confirming this assumption is provided in the Appendix.

Assumption 2.2 The value of the constraint function is denoted by $\varepsilon_t = \Pi(\bar{\omega}_t, A_t^*; F_t^*)$. The contractual interest at t denoted by z_t is continuously differentiable with respect to ε_t. In this case, $\partial z_t / \partial \varepsilon_t < 0$.

If this assumption is true, then the contractual interest under a swap contract decreases with the value of the constraint function $\Pi(\bar{\omega}_t, A_t^*; F_t^*)$.

TABLE 3
EXPECTED PAYOFFS OF CENTRAL BANKS IN DEBT AND SWAP CONTRACTS

	Federal Reserve	Foreign Central Banks	Participation Constraints
Central Bank			$\underline{\Pi}_t \leq \Pi(\bar{\omega}_t, A_t^*; F_t^*) \leq 0$
Swap Contract	$(1+z_t)B_t^*$	$(1-\Gamma(\bar{\omega}_t))(1+i_t)e_t f_t^{-1} A_t^*$	$z_t > i_t^*$
	Bear No Credit Risk		
Debt Contract	$(1+i_t^*)B_t^*$	$(1-\Gamma(\bar{\omega}_t))(1+i_t)e_t f_t^{-1} A_t^*$	$\Pi(\bar{\omega}_t, A_t^*; F_t^*) = 0$
	Bear Credit Risk		

Note: In the central bank swap contract, the constraint of $\Pi(\bar{\omega}_t, A_t^*; F_t^* \leq 0)$ in this table guarantees that the debt contract (with free entries of private lenders) is inferior to the swap contract for the Federal Reserve.

A detailed discussion of the set of sufficient conditions confirming Assumption 2.2 is provided in the Appendix. The immediate implication of this assumption is that the highest level of the contractual interest rate can be attained with $\Pi(\bar{\omega}_t, A_t^*; F_t^*)=0$. In this case, Assumption 2.1 guarantees that the contractual interest is greater than the opportunity cost of liquidity providers: $z_t > i_t^*$. The discussions presented are summarized in the following proposition.

Proposition 2.1 Suppose that assumptions 2.1 and 2.2 are satisfied. Then, the following statements are true:

1. Suppose that $\Pi(\bar{\omega}_t, A_t^*; F_t^*)=0$ is true. In this case, the Federal Reserve prefers a swap contract to a debt contract.
2. The maximum value of z_t is attained with $\Pi(\bar{\omega}_t, A_t^*; F_t^*)=0$ (with $z_t > i_t^*$).
3. In the case of $\Pi(\bar{\omega}_t, A_t^*; F_t^*)=0$, the total amount of foreign exchange reserves available at period t under a swap contract can be written as follows:

$$A_t^* = \phi\left(\frac{(1+i_t)e_t}{(1+i_t^*)f_t}\right)F_t^*,$$

where function $\phi(x)$ is an increasing function of x.

A detailed discussion of formal evidence is provided in the Appendix. This proposition significantly implies that both debt and swap contracts can be characterized by the same optimization problem, whereas objective and constraint have different meanings. In particular, the reason why the optimal swap contract can guarantee a risk-less contractual interest whereas the corresponding debt contract cannot may be unknown. This result indicates that wholesale banks transfer their realized gross returns (above the contractual payment to the Federal Reserve) to the central bank under the swap contract, whereas the debt contract requires them to transfer only contractual gross returns that are below their realized ones. Note that the absence of the information asymmetry between the foreign central bank and wholesale banks can make variable-rate auctions available, while information asymmetry exists between the Federal Reserve and the foreign central bank.

Discussing the role of the spread of "covered interest parity" in this financial contract, $\{(1+i_t)e_t/(1+i_t^*)f_t\}$, is necessary. Notably, this equilibrium condition is essentially the same as that of Bernanke, Gertler, and Gilchrist (1999). In their model with asymmetric information, this condition is the case in which raising funds from lenders is virtually always more expensive than internal finance. The reason behind this positive external finance premium is that outside lenders consider some costs of evaluating borrowers' prospects and monitoring their actions. Howeover, I should emphasize that, in this model, the Federal Reserve as the lender does not bear any credit costs. Instead, the foreign central bank bears the credit risk associated with the lending of U.S. dollars to local financial institutions. However, the external finance premium paid by a borrower in this model should depend inversely on the strength of the borrower's financial position measured by the size of international reserves, and the spread of "covered interest parity" can be interpreted as the external finance premium for those institutions through the intermediation of their central banks.[2]

I now discuss the government's budget constraint to determine how international reserves are accumulated. The government holds its dollar-denominated foreign assets (denoted by I_t^*) at the beginning of each

[2] In models with carry trades, this spread of "covered interest parity" can be interpreted as the carry trade margin earned by a currency trader who borrows U.S. dollars from the international financial market and converts them to a local currency to invest in the certificates of deposit in that country. When the spread of "covered interest parity" is high, the return to the carry trade (long position in the local currency and short in dollars) yields a high return.

period $t=0, 1, \ldots$. Assume that the government does not have any interest earnings from holding international reserves. Then, the government's one-period flow budget constraint can be written as follows:

$$(1+i_t)^{-1}B^G_{t+1} - e_t I^*_{t+1} + P_t T_t = B^G_t - I^*_t e_t + P_t G_t + G(\bar{\omega}_t)\{(1+i_t)e_t/f_t\}A^*_t,$$

where B^G_{t+1} is the domestic currency value of outstanding government debt at the end of period t, P_t is the price level at period t, T_t is the real value of the government tax, and G_t is the real government expenditures. The final term on the right-hand side of this equation denotes the central bank's earnings from its variable-rate auctions. As discussed earlier, the central bank holds a total stock of its international reserves I^*_t at the beginning of period t. The central bank withdraws an amount of international reserves F^*_t from its total balance of reserves at the time when it enters into the foreign exchange swap contract with the Federal Reserve.

The financial capacity of international reserves emerges in the framework discussed earlier. Specifically, international reserves act as collateral for the drawings of swap lines. Therefore, a country's own international reserves can create a multiplier effect for the amount of U.S. dollars available to maintain the stability of domestic financial markets and the foreign exchange market. This multiplier effect is regarded as the stabilizing power of international reserves that can arise with the efficient use of central bank swap lines. The third bullet point of **Proposition 2.1** is directly related to the magnitude of the international capacity of international reserves. In summary, given a level of international reserves I_t in period t, this proposition shows that a country's maximum capacity of U.S. dollars denoted by A^*_t can be written as follows:

$$A^*_t = \phi\left(\frac{(1+i_t)e_t}{(1+i^*_t)f_t}\right)I^*_t.$$

The most important role of central bank swap lines is to create the financial capacity of international reserves and thus help attain the stability of financial markets and the foreign exchange market. The use of central bank swap lines has a stabilizing impact on the spot nominal exchange rate at the time when it is likely to have sharp depreciations in the presence of the U.S. dollar shortage. The exchange rate effect of central bank swap lines can be summarized in the following proposition.

Proposition 2.2 Under the optimal central bank swap contract described earlier, the maximum appreciation of the spot nominal exchange rate that occurs with the introduction of central bank swap lines is determined by the leverage ratio of central bank swap lines:

$$\frac{e^a - e^p}{e^a} = (1 + (\frac{B^*}{I^*})^{-1})^{-1},$$

where e^a is the nominal exchange rate in the absence of central bank swap lines, e^p is the the nominal exchange rate in the presence of central bank swap lines, and B^* is the borrowing from central bank swap lines.

The right-hand side of this equation $(=(e^a - e^p)/e^a)$ measures the appreciation rate of the nominal exchange rate that can arise with the introduction of central bank swap lines, given that $e_a > e_p$. In particular, this proposition implies that the appreciation rate increases as the borrowing from central bank swap lines increases. The aggregate market-clearing condition of the foreign exchange market discussed earlier can be written as $D = e^a/*$ in the absence of central bank swap lines and as $D = e^p \phi(\frac{(1+i)e^p}{(1+i^*)f})I^*$ in the presence of central bank swap lines. By comparing these two equations, the exchange rate effect of central bank swap lines summarized in Proposition 2.2 can be derived.

The question surrounding what to do with this financial capacity of international reserves may emerge. Therefore, determining the set of desirable target variables of the financial capacity of international reserves is important.

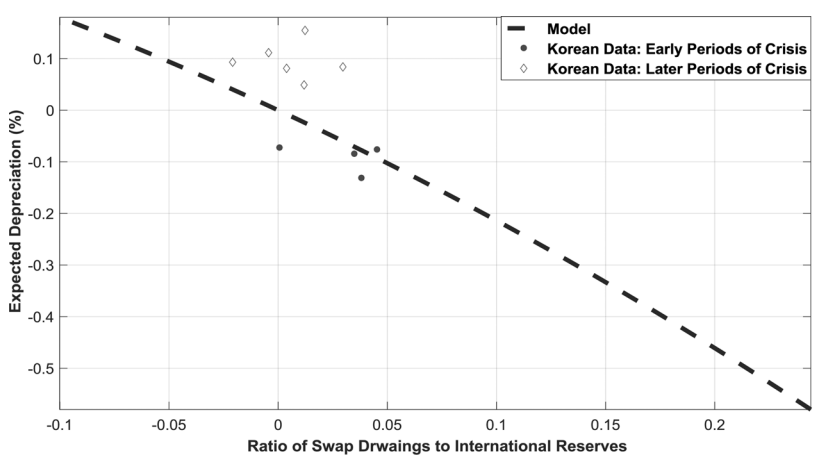
III. International Reserves and Exchange Rate

The main goal of this section is to use the proposed model to analyze the potential impact of central bank swap lines on the determination of nominal exchange rates and the issue of financial stability. The immediate short-run effect of drawing the central bank swap line can be found in the forward exchange rate denoted by f_t. The model implies that the ratio of the central bank's drawing from the swap line to its own holding of international reserves can help stabilize the forward exchange rate, given the current interest rates and spot exchange rate. To obtain this result, the ratio of the central bank's drawing from the swap line to its own holding of international reserves is denoted by $b_t^* = B_t^*/F_t^*$, where B_t^*

$=A_t^* - F_t^*$. The equilibrium condition for central bank swap lines shown in the previous section can be rewritten as follows:

$$f_t / e_t = \left(\frac{1+i_t}{1+i_t^*}\right)\phi^{-1}(1+b_t^*)^{-1}.$$

In this equation, the expected appreciation rate measured by $\log(f_t/e_t)$ depends on the logarithmic difference between domestic and foreign interest rates and the ratio of the central bank's borrowing from the Federal Reserve to its own holding of international reserves. In particular, the expected appreciation rate increases with the central bank's borrowing relative to its own holding of international reserves.[3] The implication of the model for the expected depreciation of the domestic currency discussed earlier is summarized in the following proposition:



Note: This figure shows the prediciton of the model on the effect of central bank swap lines on the expected changes in the nominal exchange rate. The x-axis represents the logarithmic deviation of the ratio of the foreign central bank's swap borrowing to its own holdings of international reserves. The y-axis represents the expected depreciation rate defined as the logarithmic deviation of the ratio of the forward rate to the spot exchange rate.

FIGURE 2

CENTRAL BANK SWAP LINES AND THE EXPECTED DEPRECIATION

[3] In this model, the forward rate is assumed to be determined by a "non-deliverable" forward contract. The "non-deliverable" forward contract is similar to a regular forward foreign exchange contract, except that this contract does not require the physical delivery of currencies at its maturity and is typically settled in an international financial center in U.S. dollars.

Proposition 3.1 Under the optimal central bank swap contract described earlier, the expected depreciation rate is decomposed into the logarithmic difference between interest rates and the part that is affected by the ratio of the foreign central bank's borrowing to its own international reserves:

$$\Delta e_t = \Delta i_t - \log \phi^{-1}(1 + b_t^*),$$

where $\Delta e_t = \log(f_t/e_t)$, $\Delta i_t = \log(1+i_t)/(1+i_t^*)$, and $\phi^{-1}(x)$ is the inverse function of $\phi(x)$.

Figure 2 shows the prediction of the model on the effect of central bank swap lines on the expected change in the nominal exchange rate. The x-axis of this figure represents the logarithmic deviation of the ratio of the foreign central bank's swap borrowing to its own holding of international reserves. The y-axis represents the expected depreciation rate defined as the logarithmic deviation of the ratio of forward rate to the spot exchange rate. Figure 2 shows that the magnitude of the expected appreciation increases as the ratio of drawings of swap lines to international reserves increases. Specifically, to the extent that $\phi^{-1}(x)$ is increasing in x, the expected depreciation rate decreases as the ratio of drawings of swap lines to international reserves increases.

A policy implication of this equilibrium condition is the presence of an expectation management channel through which swap lines may have an impact on the expectation formation of participants in the forward foreign exchange market. The equilibrium equation shown earlier implies that if the expected depreciation rates (or appreciation rates) are targeted, attaining this rate through appropriate changes in the use of swap lines, to the extent that they are not excessive, will be possible. Moreover, this equation opens the possibility that the ratio of drawings of swap lines to international reserves can affect the nominal exchange rate if a channel exists through which the current forward exchange rate affects the spot exchange rate in the next period. To show the reason why this argument may be legitimate to the extent that $f_t = E_t[e_{t+1}]$ is true in each period, the successive forward iteration of this equation with some terminal conditions leads to

$$e_t = \sum_{k=0}^{\infty} E_t[\log \phi^{-1}(1 + b_{t+k}^*)] - \sum_{k=0}^{\infty} E_t[\Delta i_{t+k}],$$

where $\lim_{k\to\infty} E_t[e_{t+k}]=0$. Aside from the expected path of interest rate differentials between home and foreign countries, the expected path of the ratio of drawings of swap lines to international reserves affects the level of the current nominal exchange rate. In summary, the relative size of swap lines and international reserves can be used as a policy tool to stabilize movements of the nominal exchange rate.

Note that distinguishing between short-run and long-run implications of the equilibrium condition of the model discussed earlier is necessary. The long-run implication of the model is that the current level of the nominal exchange rate is affected by the expectation on the long-term behavior of the ratio of drawings of swap lines to international reserves to the extent that the unbiasedness hypothesis of the forward exchange rate ($f_t=E_t[e_{t+1}]$) is true. The short-run implication of this model is that, without the assumption of this unbiasedness hypothesis, short-run increases in the ratio of drawings of swap lines to international reserves tend to move down the expected depreciation rate given the short-term interest differential.

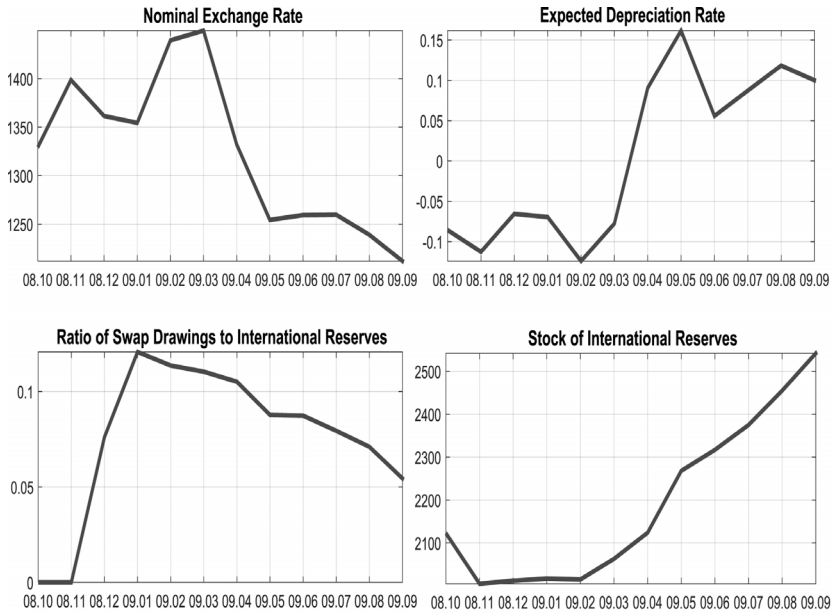
However, several factors should be considered to investigate whether this policy implication is true in actual cases. The effectiveness of central bank swap lines in the stability of foreign exchange markets may vary across different countries, especially their effectiveness in the stability of the exchange rate. The reason may be that drawings from central bank swap lines differ across different countries. Moreover, the size of the swap lines available varies across countries. For major industrialized countries, the capacity of central bank swap lines eventually became unlimited. The swaps used were clearly large in magnitude for many advanced countries. For every advanced country except Japan, the size of the swap has exceeded 50% of actual reserves held. In addition, in the cases of the United Kingdom, Australia, and the European Central Bank, the swap was larger than the existing reserves. For countries such as Denmark, Sweden, and New Zealand, the swap line was nearly as large as the existing reserves. The swaps to emerging countries were never larger than 50% of their actual reserves.

Moreover, the number of time periods of swap lines varies across different countries. The Federal Reserve's liquidity swap lines took several stages before they were made available to emerging-market countries. Initially, large swap lines were offered to major industrial country central banks (European Central Bank, Bank of Japan, Bank of England, and Swiss National Bank) in 2007. In the fall of 2008, the Federal Reserve extended its swap lines to almost all advanced economies in the run-up

of the global financial crisis. In the third phase of central bank liquidity swap lines starting on October 29, 2008, the Federal Reserve extended its swap lines to four emerging market countries, namely, Brazil, Korea, Mexico, and Singapore.

After identifying several factors that help create different levels of effectiveness of central bank swap lines across different countries, focusing on a particular example in which the use of central bank swap lines can be an effective tool to attain the stability of the nominal exchange rate is reasonable. One issue that emerges is whether the use of swap lines is intended to mitigate the liquidity shortage alone or to reduce the potential possibility of sharp depreciations of the nominal exchange rate. The tenors of central bank swap drawings differ across countries and also across various time periods. The European Central Bank and the Swiss National Bank chose short tenors of drawings especially when their liquidity shortage was extremely severe, and their main concern was to secure ample liquidity in interbank markets, for example, one day or within a month. I consider that the effectiveness of swap lines as a tool to affect the movements of the nominal exchange rate may require a relatively long tenor, at least enough to have a persistent impact on the expectation formation of participants in the forward foreign exchange market. The Bank of Korea's tenors remained uniform at 84 days for drawings from its swap lines with the Federal Reserves. Therefore, regardless of the Bank of Korea's primary purpose for the use of the its swap lines, its drawing is a good actual example to investigate.

Figure 3 demonstrates that the won-dollar exchange rate went up at the end of 2008. Although the swap line between the Bank of Korea and the Federal Reserve was set up in October 2008, the Bank of Korea's initial drawing from its swap line with the Federal Reserve started in December 2008. For the initial two months when the Bank of Korea began to use its swap line, the Korean won depreciated as the ratio of central bank swap drawings to its own international reserves increased to its peak. After its peak, the ratio of central bank swap drawings to its own international reserves declined as the Bank of Korea began to curtail the use of its swap lines. The appreciation of the Korean won after February 2009 is more closely associated with the increases in the Bank of Korea's own holding of international reserves, as shown in the lower left panel. Therefore, as the time span when the Bank of Korea relied on the swap line with the Federal Reserve was relatively short, its effect on the stability of foreign exchange market was also short. In summary, the plots in Figure 1 provide certain scenarios that at least open



Note: The expected depreciation rate is negative in the late 2008 and early 2009, when increases in the Bank of Korea's total drawings from its central bank swap line were evident. The nominal exchange rate is defined as the Korean won price of one dollar at the spot foreign exchange market. The expected depreciation rate is defined as the logarithm of the ratio of "non-deliverable forward rate" to the spot exchange rate in each month.

FIGURE 3

IMPACT OF CENTRAL BANK CURRENCY SWAP LINES ON KOREA

the potential possibility of the effectiveness of the Federal Reserve's swap linein the stability of the Korean Foreign exchange market, although they are not decisive. In particular, the empirical relation between the expected depreciation rates of the Korean won (relative to the U.S. dollar) and the ratio of the Bank of Korea's drawings to its own reserves derived in the upper right and lower left panels of Figure 3 is consistent with that of Proposition 3.1 and Figure 2.

Assumption 3.1 (Size of Capital Flights) Let D_t be the nominal amount of deposits in the domestic banking section (in the denomination of domestic currency) at period t that can be used in the possible event of a domestic capital flight. Assume that this amount of domestic financial

assets is an increasing function of both M_2 and GDP:

$$\frac{D_t}{P_t} = V_t(\frac{M_{2t}}{P_t})^{\alpha} Y_t^{1-\alpha},$$

where α is a positive constant less than one, V_t denotes the random disturbances in this function, M_{2t} is the stock at period t of M_2, and Y_t is the level at period t of the real gross domestic product (GDP).

I now discuss the implication of this equilibrium condition for financial stability. I follow the view of Obstfeld, Shambaugh, and Taylor (2010) that the main reason for a central bank to hold foreign reserves is to protect its domestic banking sector (generally the domestic credit markets) without having limited external currency depreciation only. In particular, their "double drain" crisis scenario implies that the main concern of the central bank's reserve management should be given to the domestic financial stability because the domestic capital flight could come with withdrawals of domestic bank deposits.

Assume that the target of the total stock of international reserves is D_t, which is defined as the nominal amount of deposits in the domestic banking section (in the denomination of domestic currency) at period t that can be used in the possible event of a domestic capital flight. Given this choice of the target variable, the equilibrium condition in the model of central bank swap lines is written as follows:

$$\frac{F_t^*}{Y_t^*} = V_t(\frac{M_{2t}}{P_t Y_t})^{\alpha} \phi(\frac{(1+i_t)e_t}{(1+i_t^*)f_t})^{-1},$$

where Y_t^* is the nominal GDP measured in U.S. dollars. I now make a log-linear approximation of this equation around its steady state:

$$\hat{F}_t^* - \hat{Y}_t^* = \hat{V}_t + \alpha(\hat{m}_{2t} - \hat{Y}_t) + \varepsilon_{\phi}(\hat{i}_t^* - \hat{i}_t + E_t[\hat{e}_{t+1}] - \hat{e}_t),$$

where ε_{ϕ} is the elasticity of ϕ with respect to its argument, m_{2t} is the real balance of M_2, and a variable x with a hat (denoted by $\hat{x}$) represents its logarithmic deviation from the steady state value. In this log-linear approximation, I assume that the expected value of the exchange rate in the next period is equal to the forward exchange rate, and thus the unbiased forward rate hypothesis is true up to the first-order ap-

proximation.

The log-linearized equation implies that the ratio of international reserves to the GDP increases with the ratio of M_2 to the GDP and the expected depreciation. In particular, the higher the expected return from holding foreign assets relative to those of domestic assets, the higher is the ratio of international reserves to the GDP. This relation is in accordance with the view that international reserves are held by central banks as protection against the "double drain" crisis scenario, as domestic capital flights are more likely to occur with a higher expected return from holding foreign assets.

The most important feature of this rule is that the ratio of international reserves to the GDP should be proportional to the ratio of M_2 to the GDP. This feature is important because the dependence of international reserves on the stock of M_2 helps explain the excessive holdings of international reserves held by emerging-market countries. Similarly, Obstfeld, Shambaugh, and Taylor (2009) showed that an empirical model of "financial stability" helps explain the excessive holdings of international reserves held by emerging-market countries. A representative specification of their models can be written as follows:

$$\ln\left(\frac{Res}{GDP}\right) = 6.514 + 0.604 \ln\left(\frac{M2}{GDP}\right),$$

where "control" represents the estimated effects of other variables:

$$control = 1.047 FinOpen + 0.224 Peg + 0.187 SoftPeg - 1.098 AD + 1.498 Sin.$$

As mentioned earlier, this estimation result indicates a substantial dependence of international reserves on the stock of M_2. This feature helps explain the excessive holdings of international reserves held by emerging-market countries. The justification is that these countries hold international reserves as protection against the "double drain" crisis scenario.

I now discuss the nominal exchange rate implied by the model. The equilibrium condition is a forward-looking difference equation for the nominal exchange rate. Its forward-looking solution can be written as follows:

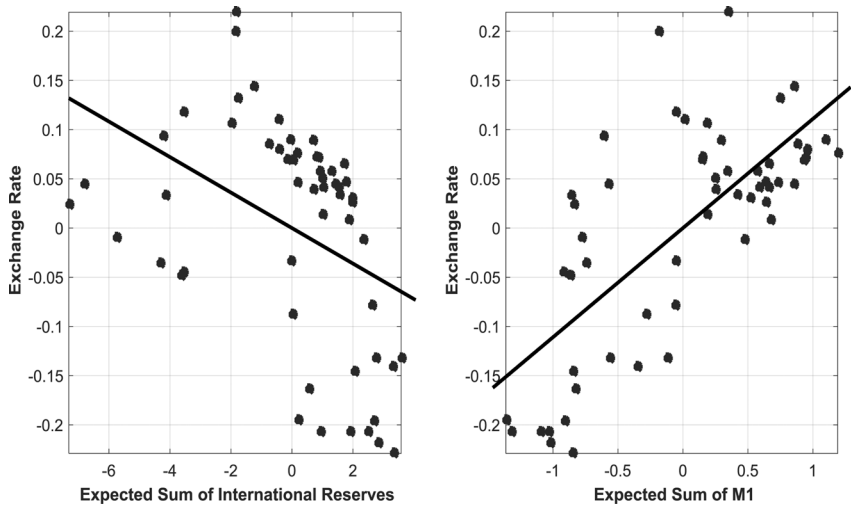
$$e_t = \sum_{k=0}^{\infty} E_t[\hat{i}^*_{t+k} - \hat{i}_{t+k}] + \frac{\alpha}{\varepsilon_\phi} \sum_{k=0}^{\infty} E_t[\hat{m}_{2t+k} - \hat{Y}_{t+k}] - \frac{1}{\varepsilon_\phi} \sum_{k=0}^{\infty} E_t[\hat{F}^*_{t+k} - \hat{Y}^*_{t+k}]$$
$$+ \frac{1}{\varepsilon_\phi} \sum_{k=0}^{\infty} E_t[\hat{V}_{t+k}],$$

where $\lim_{k\to\infty} E_t[e_{t+k}]=0$. The first implication of this equilibrium determination of the nominal exchange rate is that changes in the short-term policy interest rate induce changes in the exchange rate to the extent that they generate long-term interest differentials between foreign and home countries. In particular, the first term on the right-hand side of this equation is the difference between the expected sums of foreign and home current and the future short-term interest rates, which can be interpreted as long-term interest differentials between foreign and home countries. The nominal exchange rate falls (appreciates) as the long-term interest rate of home country increases relative to that of the foreign country. Therefore, the conventional wisdom about the exchange rate effects of the changes in the short-term policy interest rate is still effective.

Note that this model can be used to analyze the exchange rate effects of unconventional monetary policy measures implemented over the past several years, such as quantitative easing and forward guidance. The implied relationship between the long-term interest rates and the exchange rates of the model is identical to that implied by the conventional specification of the "uncovered interest parity" condition. Based on the recent empirical works of Chinn (2013) and Kiley (2103), the proposed model also suggests that a country's monetary policy actions to lower long-term interest rates can contribute to a lower exchange value of its home currency.

Moreover, suppose that when the central bank expands its balance sheet, this situation leads to persistent increases in the stock of M_2 relative to a measure of a real economic activity, such as the nominal GDP. In this case, the proposed model implies that the expansion of the central bank's balance sheet lowers its currency's exchange value (depreciation) unless it increases the ratio of international reserves to the GDP more than the ratio of M_2 to the GDP. Therefore, even when the short-term nominal policy rate is fixed at its lower bound, the unconventional monetary policy that comes along with the central bank's balance sheet will lead to the depreciation of the exchange value of its home currency.

The second implication is that the current nominal exchange rate is affected by the expected path of international reserves. In particular, the third term on the right-hand side of this equation shows that an increase in the expected path of the ratio of international reserves to the GDP increases the exchange value of the home currency. This result is caused by the spread of "covered interest parity" falling with the



Note: The left panel shows the scatter plot of the relation between the expected sum of the ratio of international reserves to the *GDP* and the nominal exchange rate. The right panel shows the relation between the expected sum of the ratio of M_1 to the *GDP* and the nominal exchange rate.

FIGURE 4

INTERNATIONAL RESERVES AND EXCHANGE RATE IN THE KOREAN DATA FROM 1999 TO 2013

stock of international reserves. In particular, an increase in the stock of international reserves acts as an increase in the collateral for the borrowing from central bank swap lines. The resulting increase in the total amount of U.S. dollars available may have stabilizing effects on movements of the nominal exchange rate even during financial and currency crises.

I use the Korean quarterly data that cover 1999:3 to 2013:2 to investigate how the ratio of international reserves to the GDP or the ratio of M_2 to the GDP affects the Korean won-dollar exchange rate. In Figure 4, the left panel shows that the expected sum of the ratio of international reserves to the *GDP* tends to decrease the nominal exchange rate (appreciation). The right panel shows that the expected sum of the ratio of M_1 to the *GDP* tends to increase the nominal exchange rate (depreciation). In summary, the scatter plots in Figure 4 are consistent with the theoretic predictions implied by the log-linear approximation of the equilibrium equation.

IV. Conclusion

In this study, I examine the implications of a dynamic equilibrium model of central bank swap lines to determine the nominal exchange rate and the role of international reserves in financial stability. The proposed model focuses on the issue of moral hazard that can arise with the liquidity provision of the Federal Reserve through its swap lines with other central banks.

This model is not only primarily intended to understand the contractual relation between the Federal Reserve and foreign central banks, but it also serves as a descriptive model to explain how the nominal exchange rate is determined. In particular, short-run and long-run channels exist through which the expectation formation of agents is affected by the behavior of international reserves and the credible long-term stance of the monetary policy.

I present a couple of issues that may be worthy of future research. First, the main concern of the model is bilateral contracts. Therefore, extending the current model to the analysis of multilateral contracts would be interesting. Second, the absence of information asymmetry between the foreign central bank and the wholesale banks in its jurisdiction makes using "variable-rate auctions" possible. In this auction, different loan rates are submitted by different wholesale banks. However, once the information problem emerges, making debt contracts between the foreign central bank and the wholesale banks is more desirable. Even with debt contracts between the foreign central bank and the wholesale banks, delivering a risk-less contractual interest payment to the Federal Reserve is still possible. Therefore, analyzing the optimal mechanism design for central bank swap lines is interesting for future research.

(Received 2 July 2014; Revised 22 April 2015; Accepted 23 April 2015)

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