The Effects of Unconventional Monetary Policy in an Open Economy

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Abstract

A macroeconomic effect of term premiums is a controversial issue both theoretically and quantitatively. In this paper, we explore the possibility that term premiums influence inflation rates and real economy via exchange rate dynamics. For this purpose, we construct a small-open economy model with limited participation of asset markets, focusing particularly on the empirical fact that the uncovered interest parity (UIP) tends to hold for longer term interest rate differentials. In a quantitative exercise, we estimate parameters using Japanese and U.S. data and show that changes in term premiums have sizable effects on inflation rates via exchange rates. This quantitative result implies that the long-term bond purchases by central banks have somewhat supported inflation rates via exchange rate depreciation.

Keywords: Exchange Rate; Term Premium; Monetary Poilcy

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1 Introduction

Recently, a number of central banks have adopted a massive purchasing program of long-term bonds in the face of the zero lower bound of nominal interest rates. Such purchasing programs are supposed to work as lowering long-term interest rates particularly through reducing term premiums, and such policy effects on long-term interest rates have been established by some empirical studies (e.g., D'Amico, English, Lopez-Salido, and Nelson (2012) and BankofJapan (2015)). In terms of the transmission mechanism, however, there is little theoretical background on the relationship between term premiums and economic activity as pointed out by, for example, Stein (2012) and Faust (2015).[1] In that sense, the policy effects of lowering term premiums are still controversial both theoretically and quantitatively in the literature.

This paper contributes to the literature by constructing a small-open economy model with long-term bonds and exploring the possibility that term premiums have effects on inflation rates and real economy via exchange rate dynamics. While some commentators mention the exchange rate channel of unconventional monetary policy, our aim here is to show what assumptions are necessary for making term premiums relevant to the economy and to quantify the policy effect of term premiums via the exchange rate channel consistently with data. By doing so, we try to deepen our understanding of the relationship between term premiums, exchange rates, and inflation rates theoretically and quantitatively.

Our motivation for exploring the exchange rate channel comes from an empirical fact on the relationship between long-term interest rate differentials and exchange rate dynamics. Figure 1 plots the interest rate differentials of n-year bonds ($n = 0, 2, 5,$ and 10) between Japan and the U.S. with changes in yen-dollar exchange rates from t to $t + n$. The figure points out that a theoretical prediction of the uncovered interest parity (UIP) condition (i.e., the positive relationship between interest rate differentials

[1] Stein (2012) takes a simple corporate finance example to examine the effect of term premiums on corporate investment and concludes *"...investment spending is decoupled from the term premium and is determined instead by the expected future path of short rates"*.

and future exchange rate changes) holds only for long-term interest rates: While the yen-dollar exchange rate dynamics are almost uncorrelated with interest rate differentials of policy rates as well as 2-year and 5-year government bonds, they are positively correlated for 10-year government bonds.[2] This empirical fact suggests the possibility that changes in term premiums influence the exchange rate, thus having effects on inflation rates and real economy.

In order for the model to behave consistently with this empirical fact, the following two limited participation assumptions are incorporated into the model. First, households cannot access foreign bonds and save only by domestic short-term and long-term bonds. This assumption can be interpreted as a kind of "home bias" in the household's investment behavior. The second assumption is that a risk-neutral international arbitrager trades only long-term domestic and foreign bonds and does not trade short-term domestic and foreign bonds. This second assumption might be justified by the fact that most institutional investors tend to trade long-term bonds rather than short-term bonds. As a result of the two limited participation assumptions, the exchange rate in the model is determined by the UIP condition associated with long-term interest rates rather than short-term interest rates as observed in data.

A noteworthy consequence of those limited participation assumptions is that those assumptions work as necessary conditions for term premiums to influence inflation rates via exchange rate dynamics in the model. As Chen, Curdia, and Ferrero (2012) point out, changes in term premiums do not have any effect on the economy unless there is an agent who only has access to long-term bonds and whose actions are relevant to the economy. In our model, the international arbitrager who trades only domestic and foreign long-term bonds takes this role. The arbitrager's actions are relevant to the economy because the limited participation assumption for the households implies that only the arbitrager's actions determine exchange rates in the model. In other words, if the households can access foreign bonds, and consequently the UIP condition holds not

[2] The phenomenon that the UIP condition is satisfied only for longer-term interest rates is observed not only for the yen-dollar exchange rate but also for the exchange rate of other currencies with the U.S. dollar.

only for long-term interest rates but also for short-term interest rates, changes in term premiums would not have any effects on inflation rates and real economy in our model.

In a quantitative analysis, we estimate the model parameters using the yen-dollar exchange rate data as well as Japanese and U.S. data, and quantitatively investigate the effects of term premiums on exchange rates and inflation rates in Japan. The impulse response analysis suggests that there are significant policy effects of term premiums via exchange rate dynamics: A one percent decline in term premiums (i) increases inflation rates by around one percent, and (ii) entails a depreciation of exchange rates by around 60 percent. Thus, the quantitative result implies that the decline in term premiums through the massive purchases of long-term bonds conducted by the central bank in Japan has somewhat contributed to the increase in inflation rates through exchange rate depreciation.

In terms of literature, the most related studies are Andres, Lopez-Salido, and Nelson (2004) and subsequent studies which try to investigate the policy effects of term premiums. In particular, Chen, Curdia, and Ferrero (2012) construct a DSGE model where a part of households access only to long-term bonds and consequently their consumption behavior is influenced by term premiums. Our paper extends their model to a small-open economy model and proposes a different (but compatible) mechanism for the policy effects of term premiums. In the literature subsequent to Chen, Curdia, and Ferrero (2012), Wesolowski (2015) investigates the effects of term premiums in the context of small-open economy model like our paper and estimate it by Poland's data. Alpanda and Kabaca (2015) examine the effect of term premiums in a two-country DSGE model and point out that the U.S. unconventional monetary policy had a strong international spillover effect. Another strand of literature related to our paper is the literature on the relationship between interest rate differentials and exchange rates, which is recently surveyed by Engel (2014). In particular, Kano and Wada (2015) focus the relationship between long-term interest rate differentials and the yen-dollar exchange rates as our paper, and conclude that most exchange rate dynamics after introducing Abenomics are accounted for by the U.S. long-term interest rates.

The paper proceeds as follows. In Section 2, we construct a small-open new Keynesian model with limited participation of asset markets and explain the relationship between long-term interest rate differentials and exchange rates in the model. Section 3 estimates the model parameters and examines the policy effects of term premiums by an impulse response analysis, and Section 4 concludes.

2 Model

The model follows a standard small-open dynamic general equilibrium model with long-term bonds. The home country (HC) economy consists of households, an arbitrager, and several types of firms, which produce consumption-goods, intermediate-goods, export-goods, and import-goods, respectively. In a spirit of a small-open economy model, the foreign country (FC) economy is assumed to be independent of the HC economy, and it is described as a small-scale new Keynesian model. Each agent's behavior in the HC as well as the FC are described in turn.

2.1 Household

A continuum of households in the HC supplies a differentiated labor force indexed by $h \in (0,1)$ to obtain wage income, $W_t(h)L_t(h)$, where $W_t(h)$ denotes the nominal wage and $L_t(h)$ denotes hours worked for each household h. In addition, because the households are owners of all types of firms and arbitragers in the economy, they also obtain their aggregate profits, D_t, as another source of income. The households allocate the income to the consumption basket, C_t, and savings. The consumption basket consists of domestic and foreign consumption goods,

$$C_t = \left[(1-\delta)^{\frac{1}{\eta}} C_{d,t}^{\frac{\eta-1}{\eta}} + \delta^{\frac{1}{\eta}} C_{f,t}^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}} \tag{1}$$

where $C_{d,t}$ and $C_{f,t}$ are domestic and imported consumption goods, respectively. The price level for consumption basket (i.e., CPI) is defined by

$$P_t C_t = P_{d,t} C_{d,t} + P_{f,t} C_{f,t}.$$

where $P_{d,t}$ and $P_{f,t}$ are prices for domestic and imported consumption goods. The savings take two forms: nominal one-period domestic bonds, B_t, and long-term domestic bonds, B_t^L. The long-term bonds are formulated as perpetuities which pay a decaying coupon κ^s at $t+1+s$ as in Woodford (2001). The households are assumed to pay time-varying transaction cost ζ_t per-unit of long-term bonds as in Chen, Curdia, and Ferrero (2012). This transaction cost, which is supposed to describe a preferred habitat behavior of investors, is a source of term premiums in this model, and follows the exogenous process,

$$\zeta_t - \zeta = \rho_\zeta \left(\zeta_{t-1} - \zeta\right) + \varepsilon_{\zeta,t}.$$

In a quantitative analysis, we consider $\varepsilon_{\zeta,t}$ is a policy shock to change term premiums, and examine the response of inflation rates as well as exchange rates to this policy shock.

The households face the budget constraint,

$$P_t C_t + B_t + (1+\zeta_t) P_t^L B_t^L = R_{t-1} B_{t-1} + P_t^L R_t^L B_{t-1}^L + W_t(h) L_t(h) + D_t \qquad (2)$$

where P_t^L is the price of long-term bonds and $R_t^L = \frac{1}{P_t^L} + \kappa$ is the long-term interest rate. Note that the households cannot invest in foreign bonds but invest only in domestic bonds. This limited participation assumption for households is a key to understanding the effect of long-term interest rates on the exchange rate as discussed later. The households choose their consumption C_t and short-term and long-term bonds, B_t and B_t^L, to maximize their lifetime utility,

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\log\left(C_t - \varkappa C_{t-1}\right) - \psi \frac{L_t(h)^{1+\nu}}{1+\nu} \right]$$

subject to the budget constraint (1) and (2). $\beta \in (0,1)$ is a constant discount factor and $\varkappa$ is a parameter for habit formation.

There are competitive labor agencies who aggregate labor services by each households h into a homogeneous labor L_t using the following CES aggregator,

$$L_t = \left(\int_0^1 L_t(h)^{\frac{1}{\lambda_w}} dh \right)^{\lambda_w},$$

where $\lambda_w > 1$ is a markup parameter. Let $W_{h,t}$ be the nominal wage rate for household h. The aggregate nominal wage W_t is defined as

$$W_t = \left(\int_0^1 W_t(h)^{\frac{1}{1-\lambda_w}} di \right)^{1-\lambda_w},$$

and the demand function for each household's labor service is then derived as a result of profit maximization of the labor agencies,

$$L_t(h) = \left(\frac{W_t(h)}{W_t} \right)^{\frac{\lambda_w}{1-\lambda_w}} L_t. \tag{3}$$

Given this demand function for their labor services, the households monopolistically supply differentiated labor forces $L_t(h)$ and set wages $W_t(h)$ on a staggered basis à la Calvo (1983). In each period, a fraction $0 < \xi_w < 1$ of households set the wages by the partial indexation rule, $W_t(h) = (\pi_{t-1}e^{\gamma_{t-1}})^{\iota_w} (\pi e^{\gamma})^{1-\iota_w} W_{t-1}(h)$, where π_{t-1} and $e^{\gamma_{t-1}}$ are the aggregate inflation rate and the aggregate productivity growth rate in period $t-1$, and π and e^{γ} are their steady state values. The remaining fraction $1-\xi_w$ of households chooses $\tilde{W}_t(h)$ to maximize,

$$\max_{\tilde{W}_t(h)} E_t \sum_{s=0}^{\infty} (\beta\xi_w)^s \left[\Xi_{t+s}\tilde{W}_{t+s}(h)L_{t+s}(h) - \psi \frac{L_{t+s}(h)^{1+\nu}}{1+\nu} \right]$$

where Ξ_t is marginal utility of consumption in nominal terms,

$$P_t\Xi_t \equiv \frac{1}{C_t - \varkappa C_{t-1}} - \frac{\beta\varkappa}{C_{t+1} - \varkappa C_t}.$$

The nominal wage rates $\tilde{W}_{t+s}(h)$ are determined by the following low of motion,

$$\tilde{W}_{t+s}(h) = (\pi_{t-1}e^{\gamma_{t-1}})^{\iota_w} (\pi e^{\gamma})^{1-\iota_w} \tilde{W}_{t+s-1}(h)$$

for $s \geq 1$, and the labor demand $L_{t+s}(h)$ is determined by (3) and $\tilde{W}_{t+s}(h)$. As a result of each household's optimization, wage inflation dynamics can be described by a recursive structure in the two auxiliary variables, $x^w_{1,t}$ and $x^w_{2,t}$, that satisfy

$$\left[\frac{1 - \xi_w \left(\frac{w_{t-1}}{w_t} \Pi^*_{w,t} \right)^{\frac{1}{1-\lambda_w}}}{1-\xi_w} \right]^{1-\lambda_w} = \left(\frac{\lambda_w}{w_t} \frac{x^w_{1,t}}{x^w_{2,t}} \right)^{\frac{1-\lambda_w}{1-(1+\nu)\lambda_w}}$$

where $w_t = W_t/P_t$ and $\Pi^*_{w,t} = (\pi_{t-1}e^{\gamma_{t-1}})^{\iota_w}(\pi e^{\gamma})^{1-\iota_w}/(\pi_t e^{\gamma_t})$. Those two auxiliary variables, $x^w_{1,t}$ and $x^w_{2,t}$, follow the laws of motion

$$x^w_{1,t} = \psi L_t^{1+\nu} + \beta\xi_w E_t\left[\left(\frac{w_t}{w_{t+1}}\Pi^*_{w,t+1}\right)^{\frac{\lambda_w(1+\nu)}{1-\lambda_w}} x^w_{1,t+1}\right]$$

$$x^w_{2,t} = \Lambda_t L_t + \beta\xi_w E_t\left[\left(\frac{w_t}{w_{t+1}}\right)^{\frac{\lambda_w}{1-\lambda_w}} \left(\Pi^*_{w,t+1}\right)^{\frac{1}{1-\lambda_w}} x^w_{2,t+1}\right]$$

where $\Lambda_t = P_t A_t \Xi_t$.

2.2 Consumption-Good Firm

The domestic consumption-good firm produces the final good, $Y_{d,t}$, by aggregating the intermediate goods, $Y_{d,t}(i)$, using the following CES aggregator,

$$Y_{d,t} = \left(\int_0^1 Y_{d,t}(i)^{\frac{1}{\lambda_c}} di\right)^{\lambda_c},$$

where $\lambda_c > 1$ is a markup parameter. Let $P_{d,t}(i)$ be the price of each intermediate good. The price index for domestic intermediate goods, $P_{d,t}$, is then defined as

$$P_{d,t} = \left(\int_0^1 P_i(i)^{\frac{1}{1-\lambda_c}} di\right)^{1-\lambda_c},$$

and the demand for each intermediate good is then derived as a result of profit maximization of the representative consumption good firm,

$$Y_{d,t}(i) = \left(\frac{P_{d,t}(i)}{P_{d,t}}\right)^{\frac{\lambda_c}{1-\lambda_c}} Y_{d,t}. \tag{4}$$

2.3 Intermediate-Good Firm

A continuum of intermediate-good firms indexed by i produces differentiated intermediate goods using labor, $L_t(i)$, and imported intermediate inputs, $Z_t(i)$, according to the following technology,

$$Y_{d,t}(i) = [Z_t(i)]^{\alpha}[A_t L_t(i)]^{1-\alpha}, \tag{5}$$

where A_t is the labor-argumenting aggregate productivity at period t. Let $\gamma_t = A_t/A_{t-1}$ and assume that γ_t follows the process,

$$\log\left(\frac{\gamma_t}{\gamma}\right) = \rho_\gamma \log\left(\frac{\gamma_{t-1}}{\gamma}\right) + \varepsilon_{\gamma,t}.$$

As a result of intermediate-good firms' optimization, the nominal marginal cost $MC_{d,t}$ is derived as,

$$MC_{d,t} = \frac{(P_{f,t})^{\alpha} W_t^{1-\alpha}}{\alpha^{\alpha}(1-\alpha)^{1-\alpha} A_t^{1-\alpha}}$$

where $P_{f,t}$ is the price of imported goods.

Under monopolistic competition, intermediate-good firm i faces consumption-good firms' demand $Y_{d,t}(i) = (P_{d,t}(i)/P_{d,t})^{\frac{\lambda_c}{1-\lambda_c}} Y_{d,t}$ and maximizes its discounted profits by setting the price of its differentiated products on a staggered basis à la Calvo (1983). In each period, a fraction $1-\xi_d \in (0,1)$ of intermediate-good firms reoptimizes prices, while the remaining fraction ξ_d indexes prices to a weighted average of past and steady-state inflation $(\pi_{d,t-1})^{\iota_d} \pi^{1-\iota_d}$, where $\iota_d \in [0,1]$ is the relative weight on past inflation and $\pi_{d,t} = P_{d,t}/P_{d,t-1}$. Hence, the intermediate-good firm i that reoptimizes prices in the current period chooses its prices so as to maximize,

$$\max_{\tilde{P}_{d,t}(i)} E_t \sum_{s=0}^{\infty} (\beta\xi_d)^s \, \Xi_{t+s} \left[\tilde{P}_{d,t+s}(i) - v_{d,t} MC_{d,t+s}\right] Y_{t+s}(i)$$

where $v_{d,t}$ is a marginal cost shock for domestic intermediate-good firms, and it follows the process,

$$\log(v_{d,t}) = \rho_d \log(v_{d,t-1}) + \varepsilon_{d,t}.$$

Also, $\tilde{P}_{d,t+s}(i)$ is determined by the following law of motion,

$$\tilde{P}_{d,t+s}(i) = (\pi_{d,t})^{\iota_d} (\pi)^{1-\iota_d} \tilde{P}_{d,t+s-1}(i)$$

for $s \geq 1$, and the demand for $Y_{d,t+s}(i)$ is determined by (4) and $\tilde{P}_{d,t+s}(i)$. As a result of the intermediate-good firms' optimization, inflation dynamics $\pi_{d,t}$ can be described by a recursive structure in the two auxiliary variables, $x_{1,t}^d$ and $x_{2,t}^d$, that satisfy

$$\left[\frac{1-\xi_d \left(\Pi_{d,t}^*\right)^{\frac{1}{1-\lambda_d}}}{1-\xi_d}\right]^{1-\lambda_d} = \lambda_c \frac{x_{1,t}^d}{x_{2,t}^d}$$

where $\Pi_{d,t}^* = (\pi_{d,t-1})^{\iota_d} \pi^{1-\iota_d}/\pi_{d,t}$. Those two auxiliary variables, $x_{1,t}^d$ and $x_{2,t}^d$, follow the laws of motion,

$$x_{1,t}^{d} = \Lambda_t y_{d,t} v_{d,t} mc_{d,t} + \beta \xi_d E_t \left(\Pi_{d,t+1}^{*}\right)^{\frac{\lambda_c}{1-\lambda_c}} x_{1,t+1}^{d}$$
$$x_{2,t}^{d} = \Lambda_t p_{d,t} y_{d,t} + \beta \xi_d E_t \left(\Pi_{d,t+1}^{*}\right)^{\frac{1}{1-\lambda_c}} x_{2,t+1}^{d}$$

where $y_{d,t} = Y_{d,t}/A_t$, $mc_{d,t} = MC_{d,t}/P_t$, and $p_{d,t} = P_{d,t}/P_t$.

2.4 Imported-Good Firm

The imported-good firms are classified into two groups: imtermediate-good firms and final-good firms. A continuum of intermediate-good firms indexed by f purchases foreign goods from abroad at the foreign price P_t^*, and sell them to the final-good firm as differentiated foreign goods $Y_{f,t}(f)$ at the price of $P_{f,t}(f)$. Then, the final-good firm aggregates these differentiated imported goods into the final imported good $Y_{f,t}$ using the CES aggregator, and sell it at the price of $P_{f,t}$. The final imported good is used for consumption $C_{f,t}$ or intermediate inputs for domestic intermediate-good firms, Z_t.

The demand function for each intermediate good $Y_{f,t}(f)$ is derived as a result of profit maximization of the final-good firm as,

$$Y_{f,t}(f) = \left(\frac{P_{f,t}(f)}{P_{f,t}}\right)^{\frac{\lambda_f}{1-\lambda_f}} Y_{f,t}. \tag{6}$$

Given this demand function, the intermediate-good firms monopolically supply differentiated intermediate goods. Since the intemediate-good firms in the imported sector purchase foreign goods from abroad, their nominal marginal cost, $MC_{f,t}$, is defined as,

$$MC_{f,t} = \frac{P_t^*}{Q_t}$$

where Q_t is the nominal exchange rate. Also, a marginal cost shock, $v_{f,t}$, is assumed to exist and follow the process,

$$\log\left(v_{f,t}\right) = \rho_f \log\left(v_{f,t-1}\right) + \varepsilon_{f,t}.$$

Then, by assuming the optimal price setting under the staggered prices with partial indexation, the inflation dynamics of imported price, $\pi_{f,t} = P_{f,t}/P_{f,t-1}$, are described by two auxiliary variables as similarly to those of domestic prices in the previous subsection. Since the imported firms set the imported prices in the home currency on a staggered basis, they cannot reflect all of fluctuations in their marginal cost caused by exchange rate changes, thus making the pass-through to the imported prices not perfect in the short-run.

2.5 Exported-Good firm

The exported-good firms purchase domestic consumption goods $Y_{d,t}$, and sell them to foreign customers at the price of $P_{x,t}^*$ in a foreign currency basis. The demand function for exported goods $Y_{x,t}$ in an international market is assumed to depend on the relative price of exported goods to foreign price level, $P_{x,t}^*/P_t^*$, the foreign output gap, y_t^*, and a trade balance shock, v_x, and it is determined by the following reduced form demand function,

$$Y_{x,t} = A_t \left(\frac{P_{x,t}^*}{P_t^*} \right)^{\frac{\lambda_x}{1-\lambda_x}} (y_t^*)^{\theta} \exp(v_{x,t}). \tag{7}$$

where λ_x and θ are parameters for elasticity of demand to relative price of exported goods and foreign output gap, respectively. Also, the trade balance shock follows

$$\log(v_{x,t}) = \rho_x \log(v_{x,t-1}) + \varepsilon_{x,t}.$$

Given this demand function, the exported-good firms monopolically supply exported goods. Since the exported-good firms purchase domestic consumption goods and sell them to foreign customers, their nominal marginal cost, $MC_{x,t}$, is defined as,

$$MC_{x,t} = P_{d,t}.$$

The exported firms are assumed to set the exported prices *in the foreign currency* on the staggered basis with partial indexation, and maximize their profits *in the home currency.* Therefore, the exchange rate has effects on the export prices in home currency and consequently on their profits in home currency. The inflation dynamics of imported price, $\pi_{x,t} = P_{x,t}^*/P_{x,t-1}^*$, are described by two auxiliary variables as similarly to those of domestic prices in the previous subsection.

2.6 Arbitragers

In order to close the international bond market, we introduce a risk-neutral arbitrager who trades domestic and foreign bonds to maximize its instantaneous profits. For replicating the empirical fact that the UIP condition tends to hold for long-term interest rates rather than short-term interest rates, we assume that the arbitrager can trade only domestic and foreign *long-term* bonds and cannot trade domestic and foreign short-term bonds. That is, their optimization problem is formulated as,

$$\max_{B_t^L, B_t^{L*}} E_t \left[\beta_{A,t} \left\{ (R_{t+1}^{L*} + \phi_{t+1}) \frac{P_{t+1}^{L*}}{Q_{t+1}} B_t^{L*} + R_{t+1}^L P_{t+1}^L B_t^L \right\} - \left(\frac{P_t^{L*}}{Q_t} B_t^{L*} + P_t^L B_t^L \right) \right],$$

where P_t^{L*}, R_{t+1}^{L*}, and B_t^{L*} are the price, the return and the amount of foreign long-term bonds and $\beta_{A,t}$ is a discount factor for the arbitrager. The foreign long-term bonds are formulated as perpetuities which pay a decaying coupon κ^s at $t+1+s$ as similar to the domestic long-term bonds, and consequently the relationship $R_t^{L*} + \phi_t = 1/P_{A,t}^{L*} + \kappa$ is satisfied. To ensure the existence of the steady-state in the small-open economy, it is assumed that there exists a tiny time varying risk-premium on foreign bonds, ϕ_t, which is determined by the following rule,

$$\phi_t - \phi = -\Phi \left(B_t^{L*} - B^{L*} \right) + v_{q,t}.$$

Here, $v_{q,t}$ is a real exchange rate shock and assumed to follow the process,

$$v_{q,t} = \rho_q v_{q,t-1} + \varepsilon_{q,t}.$$

where $\varepsilon_{q,t}$ is an iid shock. This rule for ϕ_t means that the time varying risk premium on foreign bonds increase (decrease) when net foreign assets decrease (increase), thus working as pushing back the amount of foreign assets to their steady state value. Without this risk-premium, there would not exist the steady state for foreign assets.[3] The arbitragers' profits are assumed to be distributed to households in a lump-sum manner.

By combining the arbitrager's first order conditions with respect to B_t^L and B_t^{L*}, and deleting the discount factor $\beta_{A,t}$, the following UIP condition with respect to long-term

[3]See Schumitt-Grohe and Uribe (2003) for more details about the method to close the small-open economy including the risk premium on foreign bonds.

interest rates is derived,

$$E_t\left[\frac{P^{L*}_{A,t+1}}{P^{L*}_{A,t}}\left(R^{L*}_{t+1}+\phi_{t+1}\right)\frac{Q_t}{Q_{t+1}}\right]=E_t\left[\frac{P^{L}_{t+1}}{P^{L}_{t}}R^{L}_{t+1}\right]. \tag{8}$$

This UIP condition with respect to long-term interest rates points out that the expected change in exchange rates is determined by the difference between the expected return for holding domestic long-term bonds for one period and that for holding foreign long-term bonds for one period.

2.7 Central Bank

The central bank in the home country sets short-term nominal interests depending on the year-on-year inflation rate and output growth rate. In particular, it follows the Taylor-type policy rule with interest rate smoothing,

$$R_t=(R_{t-1})^{\rho_R}\left[R\left(\frac{\left[\Pi_{j=1}^{4}\pi_{t-j+1}\right]^{1/4}}{\bar{\pi}_t}\right)^{1+\phi_\pi}\left(\frac{\left[\Pi_{j=1}^{4}g^{y}_{t-j+1}\right]^{1/4}}{e^{\gamma}}\right)^{\phi_y}\right]^{1-\rho_R}v_{m,t}$$

where $g^y_t=Y_{d,t}/Y_{d,t-1}$ and $\bar{\pi}_t$ is the target inflation rate for the central bank. The target inflation rate is assumed to be time varying and follow the process,

$$\log\left(\frac{\bar{\pi}_t}{\bar{\pi}}\right)=\rho_{tp}\log\left(\frac{\bar{\pi}_{t-1}}{\bar{\pi}}\right)+\varepsilon_{tp,t}.$$

The central bank can deviate from the rule by adjusting a monetary policy shock, $v_{m,t}$. The monetary policy shock in period t consists of two parts: a temporary interest rate shock in period t and a interest rate news shock in $t-12$. That is,

$$\log\left(v_{m,t}\right)=\rho_m\log\left(v_{m,t-1}\right)+\varepsilon_{m,t}$$
$$\varepsilon_{m,t}=\hat{\varepsilon}_{m,t}+\tilde{\varepsilon}_{m,t-12}$$

where $\hat{\varepsilon}_{m,t}$ and $\tilde{\varepsilon}_{m,t}$ are independent iid shocks. The interest rate news shock $\tilde{\varepsilon}_{m,t}$ is supposed to capture the following two things. First, it is supposed to capture the positive deviations from the policy rule due to the zero lower bound of nominal interest rates. Recently, even though the policy rule suggests central banks decrease nominal interest rates to negative values, they cannot decrease nominal interest rates due to the zero lower bound. Since this difficulty caused by the zero lower bound is known and influence the economy when it is recognized, such deviations should be captured by the news shock. Second, the interest rate news shock is supposed to capture the central banks' commitment to low interest rates. Since the central bank's commitment to future monetary easing has effects on inflation rates and real economy right after they announce the commitment, the policy effect through the "forward guidance" should be captured by the news shock as well.

2.8 Market Clearing

To close the model, the market clearing conditions for domestic and imported goods market should be satisfied. The market clearing condition for domestic goods is,

$$P_{d,t}Y_{d,t} = P_{d,t}C_{d,t} + I_d + \frac{P^*_{x,t}}{Q_t}Y_{x,t}$$

where I_d is nominal corporate investment. This market clearing conditions states that the domestic goods are allocated to consumption, investment, or export. Since capital accumulation is not explicitly modeled here, the nominal corporate investment is assumed to be constant. The market clearing condition for imported goods, on the other hand, is formulated as,

$$Y_{f,t} = C_{f,t} + Z_t,$$

which states that imported goods are used for consumption or intermediate inputs.

In addition to those two market clearing conditions, the capital market for foreign assets should be balanced. This condition is formulated as the current account condition as follows,

$$P^{L*}_{A,t}B^{L*}_t - \left(R^{L*}_t + \phi_t\right) P^{L*}_{A,t}B^{L*}_{t-1} = P^*_{x,t}Y_{x,t} - Q_t P_{f,t}Y_{f,t}.$$

This current account condition is derived by aggregating households' budget constraints and the arbitrager's profits and assuming zero net supply for domestic short-term and long-term bonds. The left hand side of this condition represents the income balance plus net increases in foreign assets while the right hand side represents the trade balance.

Note that the income balance is determined only by long-term bonds B_t^{L*} in this model, reflecting the assumption that households cannot access foreign bonds and the arbitrager trades only long-term bonds.

2.9 Foreign Country Economy

The foreign country (FC) economy is described as a simple New Keynesian economy with long-term bonds. According to the spirit of small open economy model, the FC economy is assumed to be not influenced by the HC's economic activity while it influences the HC economy through import/export and exchange rates.

The FC's output gap y_t^* and inflation rates π_t^* are described by the following IS curve,

$$\Lambda_t^* = \beta E_t \left[\Lambda_{t+1}^* \frac{R_t^* e^{\gamma_{t+1}^*}}{\pi_{t+1}^*} \right]$$

and Phillips curve,

$$\frac{\pi_t^*}{\pi^*} = \beta E_t \left(\frac{\pi_{t+1}^*}{\pi^*} \right) (y_t^*)^{\varpi} v_{p,t}^*,$$

where ϖ is a parameter for elasticity of inflation to output gap. The marginal utility of consumption, Λ_t^*, is defined by

$$\Lambda_t^* \equiv \frac{1}{y_t^* - \varkappa^* y_{t-1}^* e^{\gamma_t^*}} - \frac{\beta \varkappa^*}{y_{t+1}^* e^{-\gamma_{t+1}^*} - \varkappa^* y_t^*}.$$

where $\varkappa^*$ is a parameter for habit formation. Here, γ_t^* and $v_{p,t}^*$ are shocks to productivity growth and markups, respectively, and follow the process,

$$\log\left(\frac{\gamma_t^*}{\gamma^*}\right) = \rho_\gamma^* \log\left(\frac{\gamma_{t-1}^*}{\gamma^*}\right) + \varepsilon_{\gamma,t}^*$$
$$\log\left(v_{p,t}^*\right) = \rho_p^* \log\left(v_{p,t-1}^*\right) + \varepsilon_{p,t}^*.$$

Finally, nominal interest rates are determined by the central bank following the Taylor-type policy rule as in the HC,

$$R_t^* = \left(R_{t-1}^*\right)^{\rho_R^*} \left[R^* \left(\frac{\left[\Pi_{j=1}^4 \pi_{t-j+1}^*\right]^{1/4}}{\bar{\pi}_t^*} \right)^{1+\phi_\pi^*} \left(\frac{\left[\Pi_{j=1}^4 g_{t-j+1}^{y*}\right]^{1/4}}{e^{\gamma*}} \right)^{\phi_y^*} \right]^{1-\rho_R^*} v_{m,t}^*$$

where $g_t^{y*} = y_t^*/y_{t-1}^*$ and $v_{m,t}^*$ is a monetary policy shock following the process,

$$\log\left(v_{m,t}^*\right) = \rho_m^* \log\left(v_{m,t-1}^*\right) + \varepsilon_{m,t}^*.$$

For the FC economy, we do not incorporate an interest rate news shock but assume $\varepsilon_{m,t}^*$ is just an iid shock. As in the HC, the target inflation rate is time varying and follows the process,

$$\log\left(\frac{\bar{\pi}_t^*}{\bar{\pi}^*}\right) = \rho_{tp}^* \log\left(\frac{\bar{\pi}_{t-1}^*}{\bar{\pi}^*}\right) + \varepsilon_{tp,t}^*.$$

The long-term bonds B_t^{L*} are formulated as perpetuities which pay a decaying coupon κ^s at $t+1+s$. Since the long-term bonds entail a transaction cost ζ_t^* per-unit, there exist term premiums as in the HC. The price and return for the long-term bonds are denoted by P_t^{L*} and $R_t^{L*} = 1/P_t^{L*} + \kappa$, respectively. Note that since the foreign households do not have to pay risk-premium for holding the foreign long-term bonds unlike the arbitrager, the price of foreign long-term bonds *for the arbitrager* $P_{A,t}^{L*}$ is different from that for the foreign households, and their relationship is described as,

$$\frac{1}{P_{A,t}^{L*}} = \frac{1}{P_t^{L*}} + \phi_t.$$

That is, the price of foreign bonds for the arbitrager would increase (decrease) relative to that for the foreign households if the net foreign assets increase (decrease).

3 Quantitative Analysis

In this section, we conduct a quantitative analysis to investigate the effect of term premiums on inflation rates and exchange rates. In particular, the quantitative analysis is carried out under the assumption that the home and foreign country in the model correspond to Japan and the U.S., respectively. That is, we model Japan's economy as a small-open economy and focus on the effect of term premiums on Japanese inflation rates via the yen-dollar exchange rate dynamics. In what follows, we first set model parameters by calibration or Bayesian estimation using Japanese and the U.S. data, and then quantify the effect of term premiums by the impulse response analysis.

3.1 Estimation

Before estimating the model parameters, some parameter values are calibrated so that moment conditions are consistent with Japanese data or just calibrated to conventional values. The quarterly discount factor β is set to $1.005^{-\frac{1}{4}}$ for both countries, and the pace of decay for coupon of long-term bonds, κ, is set to satisfy $1/(1-\kappa)=40$, which means the long-term bond in this model is interpreted as the 10-year government bond. The values of steady-state growth rate of productivity, $\gamma=1.01^{\frac{1}{4}}$ and $\gamma^{*}=1.02^{\frac{1}{4}}$, are chosen so that the economy fits the past economic performance in Japan and the U.S. The target inflation rate at the steady-state, $\bar{\pi}$ and $\bar{\pi}^{*}$, are set to 1% in Japan and 2% in the U.S. based on central banks' behavior in each country. The sensitivity of risk-premium ϕ_t to the amount of foreign bonds is set to just an arbitrary small value, $\Phi=0.001$. The value of elasticity between domestic and imported consumption goods, η, is based on Bodenstein, Guerrieri, and Gust (2013) because there is little evidence for Japanese households. The Calvo parameters, ξ, are fixed at 0.8 except for domestic consumption goods, and the markup and indexation rate for wages, λ_w and ι_w, are set to 1.2 and 0.5, respectively. Finally, the value of (i) the fraction of imported goods in the consumption basket, δ, (ii) the share of imported intermediate goods in production function, α, and (iii) the nominal investment, I_d, are chosen by using the following moments as calibration targets: (i) $P_{f,t}C_{f,t}/(P_tC_t)=0.016$, (ii) $P_{f,t}Z_t/(P_{d,t}Y_{d,t})=0.1$, and (iii) $I_d/(P_{d,t}Y_{d,t})=0.15$. Table 1 summarizes the calibration values and targets.

The rest of parameters are estimated by a Bayesian method. In the model, there are 22 parameters for the domestic economy,

$$(\varkappa,\nu,\theta,\zeta,\lambda_d,\lambda_f,\lambda_x,\xi_d,\iota_d,\iota_f,\iota_x,\phi_\pi,\phi_y,\rho_{tp},\rho_m,\rho_R,\rho_\gamma,\rho_d,\rho_f,\rho_x,\rho_q,\rho_\zeta),$$

and 11 parameters for the foreign economy,

$$\left(\varkappa^*,\varpi^*,\phi_\pi^*,\phi_y^*,\zeta^*,\rho_{tp}^*,\rho_m^*,\rho_R^*,\rho_\gamma^*,\rho_p^*,\rho_\zeta^*\right).$$

Those 33 parameters as well as the variance of the following 14 structural shocks,

$$\left(\varepsilon_\gamma,\varepsilon_d,\varepsilon_f,\varepsilon_x,\varepsilon_q,\varepsilon_\zeta,\varepsilon_{tp},\tilde{\varepsilon}_m,\hat{\varepsilon}_m,\varepsilon_\gamma^*,\varepsilon_p^*,\varepsilon_\zeta^*,\varepsilon_{tp}^*,\varepsilon_m^*\right),$$

are estimated by the following 12 data sequences in Japan and the U.S.: Japanese GDP growth (*dGDP*), Japanese core CPI inflation (*dCPIXFV*), Japanese call rate (*CALL*), 3-year Japanese government bond yield (*Y12*), 10-year Japanese government bond yield (*Y40*), Japanese import price index inflation (*dIPI*), percent changes in Yen-dollar exchange rate (*dFXN*), Japanese net export-GDP ratio (*rTB*), the US GDP growth (*dUSGDP*), the US core CPI inflation (*dUSCPIXFV*), FF rate (*FF*), 10-year US government bond yield (*FR*). Then the measurement equations are formulated as:

$$
\begin{aligned}
dGDP &= \frac{gdp_t}{gdp_{t-1}} e^{\gamma_t} \times 100 - 100 \\
dCPIXFV &= \pi_t \times 100 - 100 \\
CALL &= (R_t - 1) \times 400 \\
Y12 &= \left[\frac{1}{12} E_t \sum_{j=1}^{12} R_{t+j-1} - 1 \right] \times 400 \\
Y40 &= \left(R_t^L - 1 \right) \times 400 \\
dIPI &= \pi_{f,t} \times 100 - 100 \\
dFXN &= \frac{Q_t}{Q_{t-1}} \times 100 - 100 \\
rTB &= \frac{\frac{P_{x,t}^*}{P_t Q_t} Y_{x,t} - \frac{P_{f,t}}{P_t} Y_{f,t}}{gdp_t} \times 100 \\
dUSGDP &= \frac{y_t^*}{y_{t-1}^*} e^{\gamma_t^*} \times 100 - 100 \\
dUSCPIXFV &= \pi_t^* \times 100 - 100 \\
FF &= (R_t^* - 1) \times 400 \\
FR &= \left(R_t^{L*} - 1 \right) \times 400
\end{aligned}
$$

where $gdp_t \equiv C_t + I_d + \frac{P_{x,t}^*}{P_t Q_t} Y_{x,t} - \frac{P_{f,t}}{P_t} Y_{f,t}$. By simultaneously using the call rate (i.e., the policy rate in Japan), 3-year bond rates, and 10-year bond rates in the measurement equations, the term structure of interest rates is expected to identify the shock to the short-term interest rate ($\hat{\varepsilon}_m$), the future short-term interest rate ($\tilde{\varepsilon}_t$), and the term premium ($\varepsilon_{\zeta,t}$). In order to avoid the effects of level shift in the yen-dollar exchange rate in the mid 1980s, the data used for estimation is from 1987Q1 to 2015Q3.

Table 2, 3, and 4 show the prior distribution for estimated parameters and their posterior mean. There are some features to be emphasized. First, we assume a very persistent process with small variance for the target inflation rate as its prior distribution. By doing so, the model can identify between the target inflation rate and actual inflation rates around the target. Second, the estimated variance for the imported price shock σ_f is very large. Since the energy imports has a large share in Japanese imports, this large variance of import price shocks seems to reflect large fluctuations in oil prices. Third, the Calvo parameter for domestic goods ξ_d is larger than conventional values. This estimation value probably reflects the fact that Japanese inflation barely changed even with the large fluctuation of imported prices.

3.2 Impulse Response

In this subsection, we quantitatively examine the effect of changes in term premiums on inflation rates and exchange rates, and investigate the mechanism behind the policy effects. In particular, we focus on the impulse responses of inflation rates and exchange rates to the term premium shock, $\varepsilon_{\zeta,t}$. Before conducting the quantitative exercise, the term premium is defined by the model variables. The first order condition for the domestic households with respect to long-term bonds B_t^L gives,

$$1+\zeta_t = \beta E_t \left[\frac{\Lambda_{t+1}}{\Lambda_t \pi_{t+1}} e^{-\gamma_{t+1}} \frac{P_{t+1}^L R_{t+1}^L}{P_t^L} \right], \tag{9}$$

where ζ_t is a transaction cost for holding long-term bonds. Considering that the transaction cost is the only source of term premiums in this model, fictitious long-term interest rates *without term* premiums$\tilde{R}_t^L$ can be computed by,

$$1 = \beta E_t \left[\frac{\Lambda_{t+1}}{\Lambda_t \pi_{t+1}} e^{-\gamma_{t+1}} \frac{\tilde{P}_{t+1}^L \tilde{R}_{t+1}^L}{\tilde{P}_t^L} \right]$$

where $\tilde{R}_t^L = 1/\tilde{P}_t^L + \kappa$, and the term premium is defined by $R_t^L - \tilde{R}_t^L$. Given this definition of term premium, the size of term premium shock $\varepsilon_{\zeta,t}$ inducing a one percent decline in term premiums can be computed.

Figure 2 shows the response of inflation rates (left figure) and exchange rates (right figure) to a one percent decline in term premiums. The figure points out that a one percent decline in term premiumsfor the 10-year Japanese government bond leads to (i) around one percent increase in inflation rates, and (ii) around sixty percent depreciation of the yen-dollar exchange rate. Since the term premiums in this model have effects on inflation rates only through changes in exchange rates, all of the changes in inflation rates in Figure 2 stem from the changes in exchange rates. Therefore, the small response of inflation rates along with the large response of exchange rates indicate that the pass-through rate to core CPI in Japan is relatively small (around 1 to 2 percent on impact).[4] Those impulse responses to a decline in term premiums might be consistent with the episode after the introduction of a massive purchasing program of long-term bonds in Japan in 2013, because the yen-dollar exchange rate has depreciated more than twenty percent since 2013 but the response of core inflation rates in Japan has been relatively small.

The mechanism behind the effects of term premiums on inflation rates and exchange rates is simple: A decline in term premiums caused by the negative shock to ζ_t leads to a decline in R_t^L and a rise in P_t^L through the Euler equation with respect to long-term bonds for domestic households (9). The rise in P_t^L then entails a decline in Q_t (i.e., a depreciation of currency) through the UIP condition (8), which is derived by the optimality condition for the arbitrager. Then, the depreciation of nominal exchange rates Q_t lead to the upward pressure on inflation rates through the following three channels. First, it increases the marginal cost for imported-good firms, $MC_{f,t}$, and consequently leads to inflationary pressure on imported consumption goods price, $P_{f,t}$. Second, the rise in imported goods price leads to a rise in marginal cost for domestic firms, $MC_{d,t}$, because they use imported goods as intermediate inputs Z_t, thus leading to inflationary pressure on domestic goods price, $P_{d,t}$. Third, in the face of the depreciation in Q_t, the exported-good firms tend to increase the amount of exports, $Y_{x,t}$, by reducing export prices. Since the increase in exports tighten the domestic consumption goods market, it

[4] This small pass-through in Japan is, however, consistent with empirical evidence using Japanese data. See, for example, Burstein and Gopinath (2014) as an extensive survey including Japanese case.

increases the domestic consumption goods prices, $P_{d,t}$.

While the mechanism behind the effect of term premiums sounds natural and a little bit straightforward, *it would not work without the limited participation assumptions for the households and the arbitrager.* To see this, let us imagine the economy where the households can access foreign bonds, and consequently the UIP condition is satisfied with respect to short-term interest rates as usual. In such an alternative economy, the first order conditions with respect to domestic short-term and long-term bonds as well as short-term foreign bonds provide the following three Euler equations for the domestic households:

$$1 = \beta R_t E_t \left[\frac{\Lambda_{t+1}}{\Lambda_t \pi_{t+1}} e^{-\gamma_{t+1}} \right], \tag{10}$$

$$1 + \zeta_t = \beta E_t \left[\frac{\Lambda_{t+1}}{\Lambda_t \pi_{t+1}} e^{-\gamma_{t+1}} \frac{P_{t+1}^L R_{t+1}^L}{P_t^L} \right], \tag{11}$$

and

$$1 = \beta R_t^* E_t \left[\frac{\Lambda_{t+1}}{\Lambda_t \pi_{t+1}} e^{-\gamma_{t+1}} \frac{Q_t}{Q_{t+1}} \right], \tag{12}$$

Suppose that the central bank lowers term premiums by adding a negative shock to the transaction cost, ζ_t. The equation (11) implies that prices of long-term bonds P_t^L would rise (i.e., long-term interest rates R_t^L would decline) in response to the decline in ζ_t. The equation (10) indicates, however, that the stochastic discount factor $\beta E_t \left[\frac{\Lambda_{t+1}}{\Lambda_t \pi_{t+1}} e^{-\gamma_{t+1}} \right]$ would not respond to the change in ζ_t at all and would not change as long as short-term interest rates R_t do not change. Therefore, if the covariance term is ignored, the equation (12) implies that the nominal exchange rate Q_t do not respond to the decline of ζ_t as well as the ensuing decline of R_t^L at all. In other words, without the limited participation assumptions, the change in term premiums caused by a shock to ζ_t would be just a "sideshow" for real economy and inflation rates in this alternative economy as described by Faust (2015).

4 Conclusion

This paper explores the possibility that term premiums influence the economy via exchange rate dynamics, particularly focusing on the fact that the UIP tends to hold for longer term interest rate differentials. We construct a small-open economy model with limited participation assumptions of asset markets, and estimate parameters using Japan and the U.S. data. A quantitative exercise through an impulse response analysis shows that changes in term premiums have sizable effects on inflation rates as well as exchange rates. The quantitative analysis implies the possibility that the long-term bond purchases conducted by central banks have somewhat supported inflation rates via exchange rate depreciation.

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Table 1: Calibration

Parameter	Value or target
Discount factor, β and β^*	0.998
Decaying coupon, κ	$1-\frac{1}{40}$
Productivity growth (Japan γ and the U.S. γ^*)	$1.01^{\frac{1}{4}}$ and $1.02^{\frac{1}{4}}$
Target inflation rate (Japan $\bar{\pi}$ and the U.S. $\bar{\pi}^*$)	$1.01^{\frac{1}{4}}$ and $1.02^{\frac{1}{4}}$
Sensitivity of risk premium, Φ	0.001
Elasticity between domestic and foreign goods, η	1.076
Calvo parameter, ξ_w, ξ_f, and ξ_x,	0.8
Wage markup, λ_w	1.2
Wage indexation, ι_w	0.5
Share of imported consumption goods, δ	$P_{f,t}C_{f,t}/\left(P_tC_t\right)=0.016$
Share of imported intermediate goods, α	$P_{f,t}Z_t/\left(P_{d,t}Y_{d,t}\right)=0.1$
Nominal investment, I_d	$I_d/\left(P_{d,t}Y_{d,t}\right)=0.15$

Table 2: Parameter Values for Japan

parameter	posterior mean	prior dist.	prior mean	prior stdev
$\varkappa$	0.31	Beta	0.4	0.1
ν	1.44	Gamma	1.0	0.5
θ	0.96	Gamma	1.0	0.5
ζ	0.0019	Beta	0.01	0.005
λ_d	4.52	Gamma	1.2	0.5
λ_f	1.37	Gamma	1.2	0.5
λ_x	2.65	Gamma	1.2	0.5
ξ_d	0.93	Beta	0.66	0.1
ι_d	0.33	Beta	0.5	0.2
ι_f	0.14	Beta	0.5	0.2
ι_x	0.48	Beta	0.5	0.2
ϕ_π	0.33	Gamma	0.5	0.25
ϕ_y	0.21	Gamma	0.5	0.15
ρ_{tp}	0.99	Beta	0.97	0.02
ρ_m	0.74	Beta	0.5	0.2
ρ_R	0.81	Beta	0.8	0.05
ρ_γ	0.65	Beta	0.5	0.2
ρ_d	0.20	Beta	0.5	0.2
ρ_f	0.29	Beta	0.5	0.2
ρ_x	0.98	Beta	0.5	0.2
ρ_q	0.76	Beta	0.5	0.2
ρ_ζ	0.94	Beta	0.5	0.2

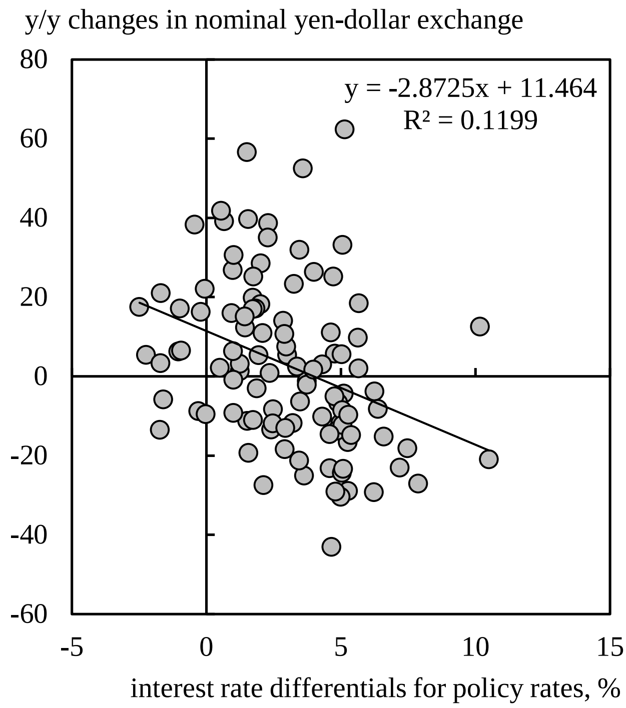
Table 3: Parameter Values for the U.S.

parameter	posterior mean	prior dist.	prior mean	prior stdev
$\varkappa^*$	0.42	Beta	0.4	0.1
ϖ^*	0.005	Beta	0.1	0.05
ϕ_π^*	1.20	Gamma	0.5	0.2
ϕ_y^*	1.19	Gamma	0.5	0.2
ζ^*	0.005	Beta	0.016	0.008
ρ_{tp}^*	0.99	Beta	0.97	0.02
ρ_m^*	0.61	Beta	0.5	0.2
ρ_R^*	0.73	Beta	0.8	0.1
ρ_γ^*	0.94	Beta	0.5	0.2
ρ_p^*	0.32	Beta	0.5	0.2
ρ_ζ^*	0.97	Beta	0.5	0.2

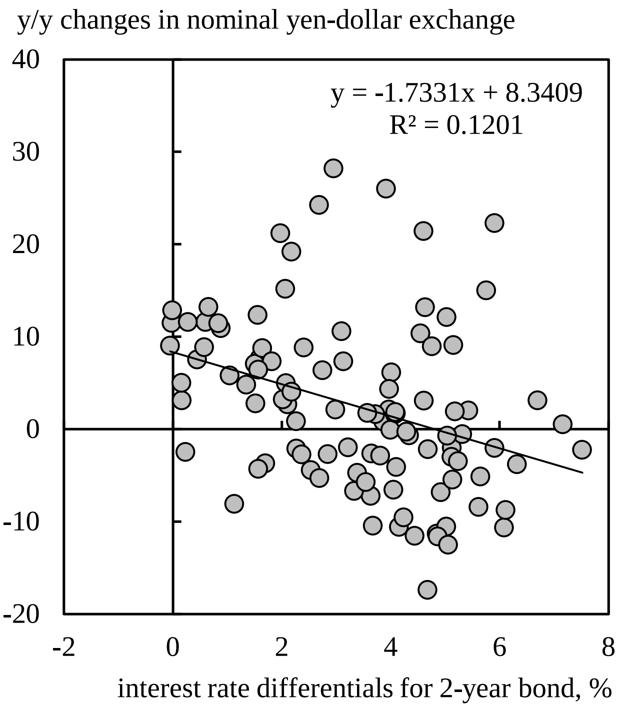
Table 4: Parameter Values for Standard Deviation

parameter	posterior mean	prior dist.	prior mean	prior stdev
σ_γ	0.71	Inv. Gamma	0.50	inf.
σ_d	55.00	Inv. Gamma	0.50	inf.
σ_f	90.91	Inv. Gamma	0.50	inf.
σ_x	0.08	Inv. Gamma	0.50	inf.
σ_q	0.15	Inv. Gamma	0.50	inf.
σ_ζ	0.12	Inv. Gamma	0.25	inf.
σ_{tp}	0.03	Inv. Gamma	0.05	inf.
$\tilde{\sigma}_m$	0.07	Inv. Gamma	0.50	inf.
$\hat{\sigma}_m$	0.04	Inv. Gamma	0.25	inf.
σ_γ^*	0.18	Inv. Gamma	0.50	inf.
σ_p^*	0.11	Inv. Gamma	0.50	inf.
σ_ζ^*	0.13	Inv. Gamma	0.25	inf.
σ_{tp}^*	0.03	Inv. Gamma	0.05	inf.
σ_m^*	0.11	Inv. Gamma	0.75	inf.

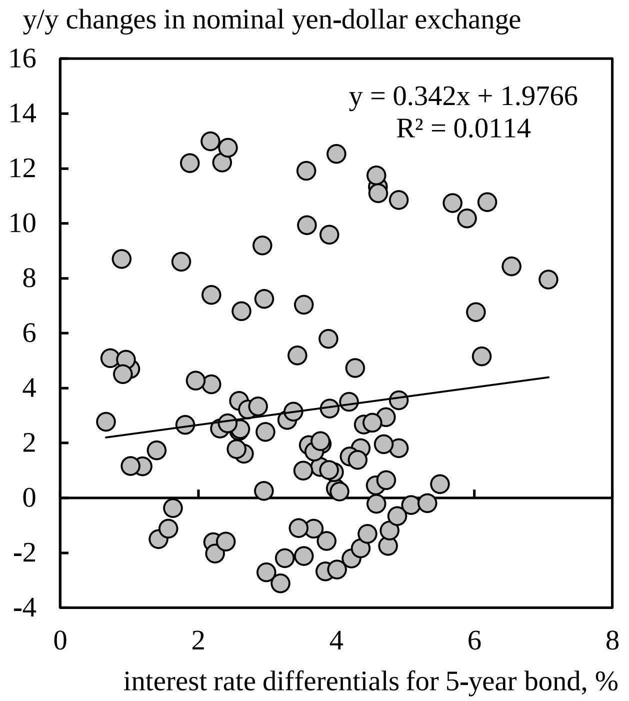
(1) Policy Rates



(2) 2-year Bond Yield



(3) 5-yaer Bond Yield



(4) 10-year Bond Yield

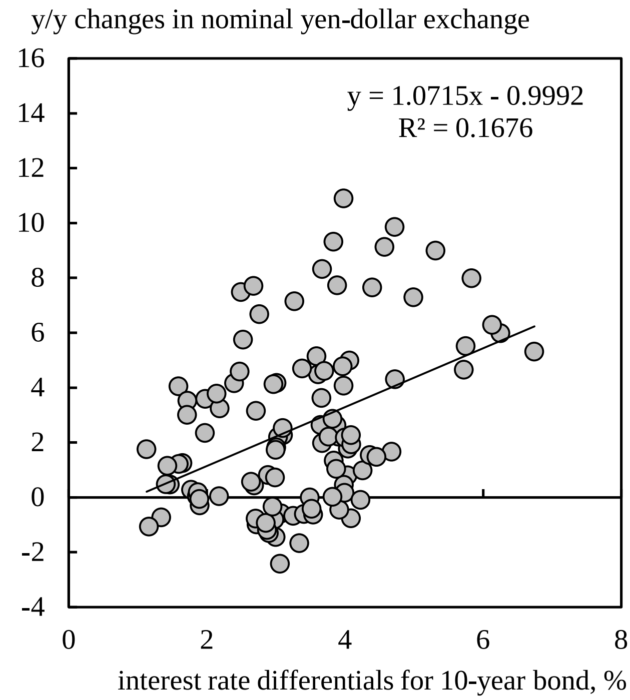


Fig. 1. Interest rate differentials and exchange rate dyanamics

Note: The figures plot interest rate differentials between *n* -year government bond yields in Japan and the U.S., $R_t(n)$- $R^*_t(n)$, and corresponding changes in yen-dollar exchange rate, $\ln Q_{t+n}$-$\ln Q_t$.

(1) Inflation Rate　　(2) Nominal Exchange Rate

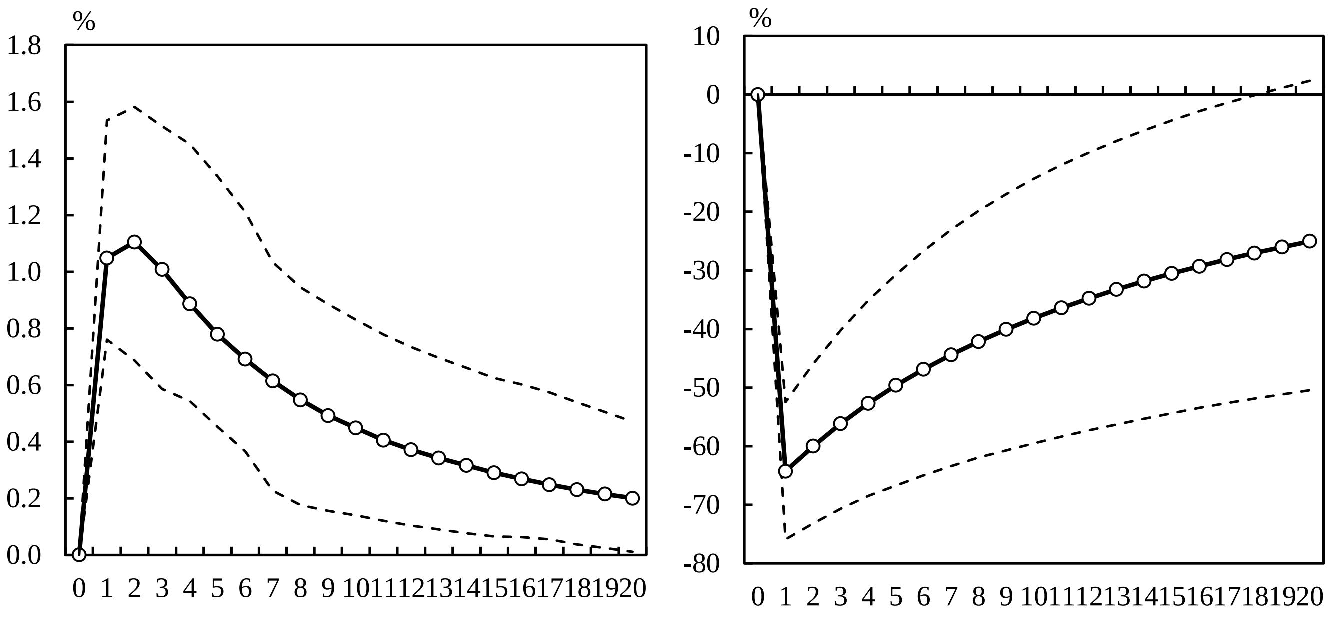


Fig. 2. Impulse Responses to Term Premium Shock

Note: The figures show responses of inflation rates and nominal exchange rates to a one percent decline in term premium. The dashed lines indicate 90 percent confidence intervals.