Currency Carry Trades and Funding Risk*

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ABSTRACT

In this paper, we measure currency carry trade funding risk using stock market volatility and crash risk in Japan, the main funding currency country. We show that the measures of funding risk in Japan can explain 42% of the monthly currency carry trade returns during our sample period, 2000-2011. In addition, they explain 46% of the monthly foreign exchange volatility in our sample of ten main currencies, 28% of the speculators' net currency futures positions in Australian dollar versus Japanese yen, skewness in currency returns and currency crashes. We present a theoretical model that is consistent with these findings.

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The finance literature has confirmed the importance of funding constraints for asset pricing, supporting the theoretical research in Shleifer and Vishny (1997), Gromb and Vayanos (2002), and Brunnermeier and Pedersen (2009). For instance, Adrian, Etula, and Muir (2013) show the importance of broker-dealers' leverage in US in explaining the US stock and bond returns. Related to the currency market, Brunnermeier, Nagel and Pedersen (2009) link speculators' funding constraints in US dollar to skewness in carry trade returns, the speculators' trading activity, as well as to the expected and realized returns on currency carry trading. Hattori and Shin (2009), in turn, demonstrate the importance of the funding conditions in Japan for the global currency markets, by showing how the conditions in the Japanese interbank market translate into large currency flows in and out of Japan in connection to currency carry trading. Other papers that link speculators' funding constraints to currency market returns include Jylhä and Suominen (2011) and Barroso and Santa-Clara (2012).[1]

Recently, Adrian and Shin (2010) argued that, in modern financial markets, changes in financial institutions equity prices affect directly their ability to lend to other market participants. In line with this, and in line with the findings in Hattori and Shin (2009), we show evidence that the equity market conditions in Japan explain a remarkable part of the global exchange rate volatility, speculators' currency derivatives positions, and exchange rate correlations. For instance, 17% of the changes in the non-commercial traders' net futures positions in Australian dollar and Japanese yen at the Commodity Futures Trading Commission in US can be explained by changes in the Japanese financial sector stock index.

[1]When estimating the carry trade returns, we study a sample of ten industrialized countries and look at the currency carry trades that invest in one to five currencies with the highest interest rates, and borrow in the one to five currencies with the lowest interest rates. In addition, we study separately the most common carry trade according to popular press: borrowing the Japanese yen and investing in the Australian dollar. As is well documented (see e.g. Bekaert, 1996; Burnside, Eichenbaum, Kleshchelski and Rebelo, 2011), such currency carry trades have historically provided good returns to investors due to the failure of the uncovered interest rate parity.

In addition, we demonstrate the importance of funding risk, i.e. the degree of time variation in funding constraints, in explaining several currency market related phenomena. Again following the same logic, we use equity market risks in Japan as proxies for carry traders' funding risk. In particular, our two proxies for funding risk are the option implied volatility and crash risk in the Japanese stock market, estimated following the approach in Santa-Clara and Yan (2010). These measures of funding risk for Japan can explain as much as 42% of monthly carry trade returns during our sample period 2000-2011. In addition, they explain 46% of the monthly currency volatility against USD for the average currency in our sample.

We have several additional results that highlight the importance of funding risk. We show for instance that the same equity market risks in Japan can explain a large fraction of the time variation in the monthly currency correlations between carry trade investment and funding currencies (e.g. 23% of the time variation in the correlation between Australian dollar and Japanese yen). In addition, our measures of funding risk can explain skewness in currency returns (particularly for the carry trade investment currencies), as well as currency crash risk. They can also explain speculators' trading activity: our measure of funding risk in Japan alone explains 28% of the time variation in the net currency futures positions of non-commercial traders in Australian dollar and Japanese yen at the Commodity Futures Trading Commission in US. Moreover it is really the funding-currencies equity market risk that matters, not the global equity market risks in general. We stress this result by showing that the funding risk in Japan (or even the funding risk in another funding country, Switzerland) makes the same measures for US redundant, in regressions explaining carry trade returns.

Our empirical results bridge several earlier findings presented in the literature related to currency carry trade returns and currency market volatility, by showing linkages between funding conditions (as discussed in Brunnermeier, Nagel and Pedersen, 2009) for speculators, the volatility in the currency market (as described in Menkhoff et al., 2012), and currency crash risk (see e.g. Jurek, 2009; Ichiue and Koyama, 2011). Our research provides support for those earlier papers, which argue that the historical returns on currency carry trading reflect limited speculative capital. Furthermore, our results complement the earlier literature linking equity and foreign exchange markets (see for instance Hau and Rey, 2005; Korajczyk and Viallet, 1992).

On a broader scope, our paper is related to previous work on the importance of "peso problems" for understanding abnormal returns. Even if market crashes fail to materialize in-sample, it is possible to use forward-looking option prices to estimate implied risk in the underlying security and thus measure investors' expectations of such events. Along these lines, Santa-Clara and Yan (2010) use S&P500 options to estimate US equity market implied risk, and they find support for the peso explanation of the equity premium puzzle. Here we show that these measures of implied risk in the equity market of a carry trade funding-currency country can explain carry trade returns, therefore also supporting a risk-based explanation for the forward premium puzzle.

To provide structure for our empirical investigation, we set up a stylized model that extends the currency carry trade model presented in Jylhä and Suominen (2011). In our model there are two countries, whose nominal fixed income securities offer different returns due to differences in the two countries' investors' per capita inflation risk. When the correlation between the two countries' inflation risk is high and the number of investors that can engage in international fixed income transactions is small, speculators engage in carry trading. In our model, similarly as in Brunnermeier and Pedersen (2009) and Gromb and Vayanos (2002), speculators face funding constraints. In addition, we assume that there is time variation in the level of funding constraints, causing funding risk. Our model is consistent with the empirical findings discussed above.

The rest of the paper is organized as follows. In Section I we present our stylized model. Section II describes the data and Section III discusses the estimation of currency carry trade returns and funding risk. In Section IV we present our empirical findings, while Section V concludes the paper.

I. The Model

A. Setup

Our model builds upon Jylhä and Suominen (2011). We assume that there are two countries $\{i, j\}$, each with N citizens where N is normalized to one. The citizens produce and consume a single commodity and use money in the production of this commodity. We also assume that country i's production function generates $f(m_{i,t})$ goods in period $t+1$, where $m_{i,t}$ denotes agents' real money holdings of country i's currency in period t. The production function takes the logarithmic form $f(m_{i,t}) = A_{i,t}\ln(m_{i,t})$, where $A_{i,t}$ denotes the stochastic marginal productivity, known to the agents at time t. The marginal productivity, in turn, follows an autoregressive process of the $AR(1)$ form:

$$A_{i,t} = \overline{A} - \alpha_A \left(A_{i,t-1} - \overline{A}\right) + \epsilon_{i,t}, \tag{1}$$

where $\overline{A}$ and α_A are positive constants and $\epsilon_i \sim N\left(0, \sigma^2_{A_i}\right)$.

The purchasing power of country i's money in period t is denoted by $\pi_{i,t}$, so that M_i units of country i's currency have a real purchasing power of $m_{i,t} = M_i \pi_{i,t}$. Agents choose their optimal real money holdings given information available at time t, allowing us to endogenously determine the parameters of the conditional distribution of $\pi_{i,t}$ in equilibrium.

Besides money, there are two other storage technologies in each country. First there is a risk-free asset with real return r_f in perfectly elastic supply. Second, there is a one-period default-free zero coupon bond, sold at a real market price $p_{i,t}$, that pays one unit of country i's nominal currency at time $t+1$. The risk in this asset comes from the uncertain purchasing power of money in period $t+1$. Both countries' risky assets are in zero net supply.[2]

[2] As Fama and Farber (1979), we assume that all consumers first hedge their money holdings in the bond market, and only then look at their bond investments. In this case, the effective supply of bonds, denoted in country i's currency, is country i's money supply $\overline{M}_i$.

We assume overlapping generations of myopic agents, who live for two periods, invest when they are young and consume when they are old. Before dying, they sell their money holdings to the next generation of agents. Period t investors value their next period consumption c_{t+1} using a CARA-utility function, $u(c_{t+1}) = -E_t e^{-ac_{t+1}}$, where a denotes risk aversion. Furthermore, let us denote by $b_{i,t}$ the quantity of country i's nominal zero coupon bonds, with a face value of one, that an agent purchases (or sells) in period t (in addition to his short position in country i's bonds, that comes from hedging his currency holdings). Similarly, let $b_{j,t}$ refer to purchases of country j's bonds.

We assume that the financial markets are segmented: a fraction $(1 - k_i) > 0$ of country i's investors have prohibitively high transaction costs of investing abroad, i.e. to hold money or interest bearing securities in a foreign currency. Fraction k_i of country i's investors, on the other hand, are unrestricted. We call the restricted investors "domestic investors" and the unrestricted ones "speculators". To keep the model parsimonious, in contrast to Jylhä and Suominen (2011), we take the number of speculators as given.[3] Our second point of departure from Jylhä and Suominen (2011) is to assume that investors face borrowing constraints, as in Brunnermeier and Pedersen (2009) and Gromb and Vayanos (2002). The main innovation in our model, however, is to assume time variation in the severity of the borrowing constraints. We assume that the borrowing constraint for country i bonds at time t is given by $b_{i,t} \geq -h_{i,t}$, with $h_{i,t} > 0$. Furthermore, evaluated at time t, the next period's borrowing constraint is random:

$$h_{i,t+1} = \overline{h} - \alpha_h \left(h_{i,t} - \overline{h}\right) + \delta_{i,t+1}, \tag{2}$$

where $\overline{h}$ and α_h are positive constants and $\delta_{i,t} \sim N(0, \sigma_h^2)$, independent of $\epsilon_{i,t}$. Without loss of generality, we assume $\alpha_A = \alpha_h = \alpha$. Given condition (2), in our model the investors face

[3] Jylhä and Suominen (2011) study a model where the number of speculators is endogenous and assume that investors must pay a fee $\Phi > 0$ to obtain access to international money markets. The cost Φ proxies for several different types of real and informational barriers to becoming a currency trader.

not only funding constraints, but also funding risk. In contrast to the financial markets, there are no barriers in the product market.

Therefore, assuming that period t investors are endowed with a real wealth w_t at the beginning of period t, country i's speculators at time t maximize:

$$\begin{aligned} \underset{m_{i,t},b_{i,t},b_{j,t}}{Max} \; -E_t e^{-ac_{t+1}} \quad \text{s.t.} \qquad (3) \\ c_{t+1} &= \left(w_t - m_{i,t} + p_{i,t}\frac{m_{i,t}}{\pi_{i,t}}\right)(1+r_f) + f(m_{i,t}) + \sum_{n=i,j} b_{n,t}\left(\pi_{n,t+1} - p_{n,t}(1+r_f)\right) \\ b_{i,t} &\geq -h_{i,t}, \quad b_{j,t} \geq -h_{j,t}, \end{aligned}$$

where E_t refers to the expectation operator conditional on time t information set. The domestic investors in country i, in turn, solve the following optimization problem:

$$\begin{aligned} \underset{m_{i,t},b_{i,t}}{Max} \; -E_t e^{-ac_{t+1}} \quad \text{s.t.} \qquad (4) \\ c_{t+1} &= \left(w_t - m_{i,t} + p_{i,t}\frac{m_{i,t}}{\pi_{i,t}}\right)(1+r_f) + f(m_{i,t}) + b_{i,t}\left(\pi_{i,t+1} - p_{i,t}(1+r_f)\right) \\ b_{i,t} &\geq -h_{i,t}. \end{aligned}$$

Equilibrium prevails when each agent's action maximizes his expected utility. Finally, note that country i's citizens do not benefit from country j's currency in their production activities.

B. The Equilibrium

B.1. Equilibrium Conditions

Since there are no restrictions in the product market, purchasing power parity (PPP) implies that the period t exchange rate (at which country j's currency can be exchanged to country i's currency) is given by $S_t^{j,i} = \pi_{j,t}/\pi_{i,t}$. We will for the moment assume that the borrowing constraints do not bind for the domestic investors. We later verify this assumption. Now, define $M_{i,t}^{d}$ as the *per capita* supply of country i's zero coupon bonds that must, in equilibrium, be purchased by the domestic investors of country i. We use a superscript d to denote a domestic investor and a superscript s to denote a speculator. In other words, if the speculators hold $k_i b_{i,t}^{s,i} + k_j b_{i,t}^{s,j}$ units of country i's bonds (where the sub-index i in $b_{i,t}^{s,j}$ refers to the country in whose currency the investment is made and the superscript j refers to the country where speculator s is originally from), we define $M_{i,t}^{d}$ as:

$$M_{i,t}^{d} = \frac{\overline{M}_i - k_i b_{i,t}^{s,i} - k_j b_{i,t}^{s,j}}{1 - k_i}. \tag{5}$$

Taking expectations and the first order condition of (4) with respect to domestic investors' bond holdings $b_{i,t}^{d}$, and using the market clearing condition $b_{i,t}^{d} = M_{i,t}^{d}$, we obtain that the price of the zero coupon bond, $p_{i,t}$, in country i at time t is:

$$p_{i,t}\left(1 + r_f\right) = E_t \pi_{i,t+1} - a\sigma_i^2 M_{i,t}^{d}, \tag{6}$$

where $\sigma_i^2 \equiv var\left(\pi_{i,t+1}\right)$ denotes the variance of the purchasing power of country i's currency (conditional on time t information). Moreover, recall that $f\left(m_{i,t}\right) = A_{i,t}\ln(m_{i,t})$. Taking the first order condition of (3) and (4) with respect to $m_{i,t}$ and, using it together with condition (6), implies:

$$E_t \pi_{i,t+1} = \left(1 + r_f\right)\pi_{i,t} - \frac{A_{i,t}}{\overline{M}_i} + a\sigma_i^2 M_{i,t}^{d}. \tag{7}$$

From conditions (6) and (7), the exchange rate can now be stated as a function of the two countries zero-coupon bond prices:

$$S_t^{j,i} = \frac{\pi_{j,t}}{\pi_{i,t}} = \frac{p_{j,t}\overline{M}_i\overline{M}_j\left(1 + r_f\right) + A_{j,t}\overline{M}_i}{p_{i,t}\overline{M}_i\overline{M}_j\left(1 + r_f\right) + A_{i,t}\overline{M}_j}, \tag{8}$$

and the Sharpe ratio for the real returns on bond investments is:

$$SR_{i,t} = \frac{r_{i,t} - r_f}{\sigma_i / p_{i,t}} = a\sigma_i M_{i,t}^d. \tag{9}$$

These results show that the Sharpe ratio on bond investments is increasing in the parameter of risk aversion a, inflation risk σ_i, and the *per capita* supply of bonds in the domestic market $M_{i,t}^d$. In the case of an autarky, where k_i and k_j are zero, $M_{i,t}^d = \overline{M}_i$, where $\overline{M}_i$ is the local money supply. In such perfectly segmented markets, the Sharpe ratio for bonds is higher in the country with the higher *per capita* inflation risk, $\overline{M}_i\sigma_i$. Let us denote by H the country with the higher *per capita* inflation risk and by L the country with the lower *per capita* inflation risk. In the case of autarkies, the higher Sharpe ratio in country H, as compared to country L, is necessary to attract sufficient investment into the risky bonds of country H, clearing the market despite the higher amount of risk being sold.

Let us now look at the speculators' problem. Taking the first order condition of (3) with respect to the speculators' investment into country i's bonds, $b_{i,t}^s$, implies:

$$b_{i,t}^s = \frac{E_t \pi_{i,t+1} - p_{i,t}\left(1 + r_f\right) - b_{j,t}^s a\rho\sigma_i\sigma_j + \lambda_{i,t}/a}{a\sigma_i^2}, \tag{10}$$

where $\rho \equiv corr_t\left(\pi_{i,t+1}, \pi_{j,t+1}\right)$ equals the correlation between the two countries' purchasing power, and λ denotes the Lagrangian multiplier, so that $\lambda_{i,t} \geq 0$ and $\lambda_{i,t}\left(b_{i,t}^s + h_{i,t}\right) = 0$. Again, the i and j sub-indices refer to the currency in which the investment is made. There is no superscript for countries, as the speculators from both countries make similar investments. Using (5) and (6) in (10), we can now solve for the equilibrium bond holdings.

B.2. Solving for the Equilibrium

The higher Sharpe ratio in country H's bonds implies that speculators are always long in these bonds. Therefore the borrowing constraint is potentially binding only for country L

bonds. We then characterize our economy in two states: 1) the borrowing constraints do not bind and 2) the speculators' borrowing constraint in country L is binding.

Case 1: Borrowing constraint is not binding The equilibrium is the same as in Jylhä and Suominen (2011).[4] Solving the set of equations above, we obtain that, in equilibrium, all speculators hold identical portfolios:

$$b_i^{s*} = \frac{\overline{M}_i \sigma_i (1 + k_i) - \overline{M}_j \sigma_j \rho (1 - k_i)}{\sigma_i [(1 - \rho^2)(1 + k_i k_j) + (1 + \rho^2)(k_i + k_j)]} \tag{11}$$

of country i's bonds, while the domestic investors hold:

$$b_i^{d*} = M_i^{d*} = \frac{\overline{M}_i \sigma_i (1 + k_i - \rho^2 + \rho^2 k_j) + \overline{M}_j \sigma_j \rho (k_i + k_j)}{\sigma_i [(1 - \rho^2)(1 + k_i k_j) + (1 + \rho^2)(k_i + k_j)]} \tag{12}$$

of such bonds. The asterisk is used to denote an equilibrium value. Using (12) in equations (6) and (9) gives us an easy characterization of the equilibrium bond prices and Sharpe ratios in our economy.

Note from (12) that, in both countries, the supply of bonds that domestic investors hold is strictly positive (therefore verifying our earlier assumption that domestic investors are long in bonds) and implying also positive Sharpe ratios. Note also from (11) that, in equilibrium, the speculators are indeed always long in country H's bonds. Moreover, if ρ is high enough, i.e., $\rho > \overline{\rho}$ with $\overline{\rho} \equiv \left(\overline{M}_L \sigma_L\right) / \left(\overline{M}_H \sigma_H\right)$, and k_L is small enough, i.e., $k_L < \overline{k}_L$ with $\overline{k}_L \equiv \left(\overline{M}_H \sigma_H \rho - \overline{M}_L \sigma_L\right) / \left(\overline{M}_H \sigma_H \rho + \overline{M}_L \sigma_L\right)$, the speculators are short the country L bonds, thus engaging in a carry trade. For the remainder of the paper, we will assume $\rho > \overline{\rho}$ and $k_L < \overline{k}_L$.

[4] This unconstrained equilibrium is stable for sufficiently high $\overline{h}$ and sufficiently small σ_h. In this region, the borrowing constraint becomes binding only if a sudden funding crash occurs, i.e. there is a sharp decline in h_L. Since the probability of this tail event can be made arbitrarily small, we follow the usual practice in the literature and neglect it in the solution of case 1.

Case 2: Borrowing constraint in country L is binding For sufficiently low $\overline{h}$ and sufficiently low σ_h, it is easy to show that there exists a constrained equilibrium where the speculators' borrowing constraint in country L is binding and speculators still enter into a carry trade.[5] In such an equilibrium, using conditions (7) and (10), we have:

$$\begin{aligned} b^s_{L,t} &= -h_{L,t}, \\ b^s_{H,t} &= \frac{\overline{M}_H}{1+k_L} + \frac{(1-k_H)\,\rho\sigma_L}{(1+k_L)\,\sigma_H} h_{L,t}, \end{aligned} \tag{13}$$

which, together with condition (6), implies:

$$\begin{aligned} (1+r_f)\,p_{L,t} &= E_t\pi_{L,t+1} - a\sigma^2_L \left(\frac{\overline{M}_L + (k_L+k_H)\,h_{L,t}}{1-k_L} \right), \\ (1+r_f)\,p_{H,t} &= E_t\pi_{H,t+1} - a\sigma^2_H \left(\frac{\overline{M}_H}{1+k_L} - \frac{(k_L+k_H)\,\rho\sigma_L}{\sigma_H\,(1+k_L)} h_{L,t} \right). \end{aligned} \tag{14}$$

From conditions above, it is easy to show that funding constraints (lower h_L) lead to a smaller b^{s*}_H and larger (i.e. smaller in absolute value) b^{s*}_L. Moreover the bond investments of domestic investors, b^{d*}_L and b^{d*}_H, remain positive.

C. Model Predictions

In the previous subsection, we characterized the equilibrium in the cases of binding and non-binding borrowing constraints. We now turn to the model implications, in terms of the effect of funding conditions and funding risk on exchange rates and speculators' activity.

[5] In this region, the borrowing constraint can be made binding with probability close to 1. As above, we neglect tail events in solving for the constrained equilibrium.

C.1. Exchange Rate Volatility and Correlations

Hypothesis 1: When the borrowing constraint is binding, exchange rate volatility is higher. In addition, higher funding risk, σ_h, leads to higher currency volatility. Given the structure of the shocks in the model, we conjecture and verify that the purchasing power π also follows an auto-regressive process and thus its conditional expectation depends on the current value according to $E_t\pi_{i,t+1} = \overline{\pi}_i - \alpha_{\pi,i}(\pi_{i,t} - \overline{\pi}_i)$, with $\overline{\pi}_i$ constant.[6] Using condition (7), we can therefore determine $\overline{\pi}_i$ and $\alpha_{\pi,i}$ as functions of the underlying parameters. In the case of the non-binding borrowing constraint, this implies:

$$\pi^U_{i,t} = \overline{\pi}^U_i + \frac{A_{i,t} - \overline{A}}{\overline{M}_i(1 + r_f + \alpha)}, \tag{15}$$

where U denotes the unconstrained equilibrium, and

$$\overline{\pi}^U_i = \frac{\overline{A}}{r_f\overline{M}_i} - \frac{aM^d_i\sigma^2_i}{r_f}. \tag{16}$$

Given that condition (7) also holds for both countries in the case where the constraints are binding, similar arguments yield:

$$\begin{aligned}
\pi^C_{L,t} &= \overline{\pi}^C_L + \frac{A_{L,t} - \overline{A}}{\overline{M}_L(1 + r_f + \alpha)} - \frac{a\left(\sigma^2_L\right)^C(k_L + k_H)\left(h_{L,t} - \overline{h}\right)}{(1 - k_L)(1 + r_f + \alpha)}, \\
\pi^C_{H,t} &= \overline{\pi}^C_H + \frac{A_{H,t} - \overline{A}}{\overline{M}_H(1 + r_f + \alpha)} + \frac{a\sigma^C_L\sigma^C_H\rho^C(k_L + k_H)\left(h_{L,t} - \overline{h}\right)}{(1 + k_L)(1 + r_f + \alpha)},
\end{aligned} \tag{17}$$

[6] Assuming autoregressive processes for the fundamental shocks is not crucial to our results. For instance, white noise processes yield the same conclusions on the currency variances and correlations. The main difference is that, in the latter case, the conditional expectation of π (as well as prices) will be constant.

where:

$$\begin{aligned}
\pi_L^C &= \frac{\overline{A}}{r_f \overline{M}_L} - \frac{aE\left(M_{L,t}^d\right)\sigma_L^2}{r_f} = \frac{\overline{A}}{r_f \overline{M}_L} - \frac{a\left(\sigma_L^2\right)^C\left[\overline{M}_L + \left(k_L + k_H\right)\overline{h}\right]}{r_f\left(1-k_L\right)}, \\
\pi_H^C &= \frac{\overline{A}}{r_f \overline{M}_H} - \frac{aE\left(M_{H,t}^d\right)\sigma_H^2}{r_f} = \frac{\overline{A}}{r_f \overline{M}_H} + \frac{a\sigma_L^C\sigma_H^C\rho^C\left(k_L + k_H\right)\overline{h}}{r_f\left(1+k_L\right)} - \frac{a\left(\sigma_H^2\right)^C\overline{M}_H}{r_f\left(1+k_L\right)}.
\end{aligned} \tag{18}$$

Here C denotes the constrained equilibrium. Using these conditions for the purchasing power, we can calculate the corresponding variances (conditional on time t information) for the non-binding case:

$$Var_t\left(\pi_{i,t+1}^U\right) \equiv \left(\sigma_i^2\right)^U = \frac{\sigma_{A_i}^2}{\left[\overline{M}_i\left(1+r_f+\alpha\right)\right]^2}, \tag{19}$$

and for the binding case:

$$\begin{aligned}
Var_t\left(\pi_{L,t+1}^C\right) &\equiv \left(\sigma_L^2\right)^C = \left(\sigma_L^2\right)^U + \left(\frac{a\left(k_L+k_H\right)\sigma_h\left(\sigma_L^2\right)^C}{\left(1-k_L\right)\left(1+r_f+\alpha\right)}\right)^2 > \left(\sigma_L^2\right)^U, \\
Var_t\left(\pi_{H,t+1}^C\right) &\equiv \left(\sigma_H^2\right)^C = \left(\sigma_H^2\right)^U + \left(\frac{a\sigma_L^C\sigma_H^C\rho^C\left(k_L+k_H\right)\sigma_h}{\left(1+k_L\right)\left(1+r_f+\alpha\right)}\right)^2 > \left(\sigma_H^2\right)^U.
\end{aligned} \tag{20}$$

Equation (20) shows that the volatilities of the two countries exchange rates with respect to the risk-free asset are higher in the constrained case. In addition, they increase with σ_h. As we show below, the correlation between the two countries purchasing power is lower in the constrained equilibrium and it decreases with σ_h. This implies that also the volatility of the exchange rate between carry-short and carry-long currencies, $S_t^{L,H}$, is higher in the constrained equilibrium and it increases with the funding risk σ_h.

Hypothesis 2: When the borrowing constraint is binding, the correlation between purchasing power in carry-long and -short countries is lower. In addition, higher funding risk, σ_h, decreases this correlation. Using conditions (15) and (17) above, we can calculate how the correlation between the two countries' purchasing power varies between the unconstrained and constrained equilibria and, in the latter case, how it varies with funding risk. For the unconstrained equilibrium, we have:

$$Corr_t\left(\pi_{i,t+1}^U, \pi_{j,t+1}^U\right) \equiv \rho^U = \frac{\sigma_{A_i,A_j}}{\sigma_{A_i}\sigma_{A_j}} = \rho_A, \tag{21}$$

while, for the constrained equilibrium, it can be shown that:

$$Corr_t\left(\pi_{i,t+1}^C, \pi_{j,t+1}^C\right) \equiv \rho^C = \frac{\rho^U}{\frac{\sigma_L^C\sigma_H^C}{\sigma_L^U\sigma_H^U}\left[1 + \frac{\left(a\sigma_L^C(k_L+k_H)\sigma_h\right)^2}{\left(1-k_L^2\right)\left(1+r_f+\alpha\right)^2}\right]}, \tag{22}$$

and therefore $\rho^C < \rho^U$. Thus, the correlation between carry-long and -short currencies - where each currency is measured *vis-a-vis* the risk-free asset - decreases with tightening of borrowing constraints. Moreover condition (22), along with condition (20), shows that ρ^C is decreasing in funding risk, σ_h^2.

C.2. Skewness and Currency Crashes

Hypothesis 3: Tightening of funding conditions are associated with exchange rate skewness and currency crashes We characterized above both the unconstrained and constrained equilibria. To simplify the analysis, we always ignored the possibility of switches between the two regimes. It is difficult to fully characterize the equilibrium in the region where the probability of funding constraints being binding is strictly between zero and one. Nevertheless, to illustrate the possibility of currency crashes, let us for the moment assume that agents are naïve and assume that, in the region where the funding constraints are binding (not binding) they will remain binding (not binding) also in the next period. Under these assumptions, we are able to explicitly show what happens in the region where there is a regime switch such that the funding constraints start to bind, i.e., in the region around $h_{L,t} = -b_L^{s*}$.

Using equations (16) and (18), it can be shown that there is a decline in both $\overline{\pi}_L$ and $\overline{\pi}_H$ when $h_{L,t}$ decreases below the critical level. This occurs as the higher variances of currencies and their lower correlation lead a) to unwinding of carry trades given (13), namely a decline in b_H^{s*}, and b) to an increase in the currency risk premium, due to the higher currency variability as can be seen from conditions (16) and (18). The currency crash is depicted in Figure 1.

[Figure 1 here]

Note that our model also makes predictions on currency skewness. In the region where the constraints are not binding, the exchange rate fluctuations are smaller, given (20), therefore leading to skewness in currency returns. In addition, the sign of the skewness for the investment currencies is negative, while, due to the currency crash at the point of the switch of the regime, the sign of skewness for the funding currencies (relative to the risk free asset) is undetermined.

C.3. Speculative Activity and Currency Carry Trade Returns

Hypothesis 4: The level of funding conditions and funding risk affect speculators' positions It is clear from the equations in (13) that the level of funding conditions in country L, h_L, directly affects the amount of country L bonds that speculators can short. In addition, it affects the amount of speculators' investment in country H. Moreover, in the region where the constraint is binding, conditions (13) and (22) imply that the funding risk, σ_h, reduces speculative investment in currency H, therefore leading to unwinding of long-side carry trades. Both effects confirm hypothesis 4.

Hypothesis 5: Tightening of funding constraints, or an increase in funding risk, is associated with poor carry trade returns Given conditions (13) and the fact that condition (22) implies that $\left(\rho^C \sigma_L^C\right)/\sigma_H^C$ is decreasing in σ_h, in the region where the borrowing constraint is binding, a decrease in h_L or an increase in funding risk σ_h lead to unwinding of carry trades. This in turn implies, given (18), an appreciation (depreciation) of the carry-short (-long) currencies, an increase (decrease) in carry-short (-long) currencies' interest rates, and thus poor carry trade returns.

II. The Data

A. Currency Data

Exchange rate data for the period between January 2000 and December 2011 is collected from Reuters (WM/R) at Datastream. It includes daily spot rates, as well as 1-month forward rates, and all quotes are expressed as foreign currency units (FCU) per USD. Following Lustig et al. (2011) or Menkhoff et al. (2012), we focus on a sample of ten developed countries: Australian dollar (AUD), Canadian dollar (CAD), Danish krone (DKK), Euro (EUR), Japanese yen (JPY), New Zealand dollar (NZD), Norwegian krone (NOK), Swedish krona (SEK), Swiss franc (CHF) and UK pound (GBP).

As a proxy for carry trade activity, we follow Brunnermeier et al. (2009) and use the futures position data from the Commodity Futures Trading Commission (CFTC), available at a weekly frequency.

B. Stock Market Options Data

For the estimation of funding risk, we use data on European options of stock market indices from four different countries - US, Australia, Japan and Switzerland. For the US, we use data on S&P 500 index options traded on the Chicago Board Options Exchange (CBOE); for Australia, data on S&P/ASX 200 index options traded on Australian Stock Exchange (ASX); for Japan, data on Nikkei 225 index options traded on Osaka Securities Exchange (OSA); and, for Switzerland, data on SMI 50 index options traded on Eurex (EUX). US and Japanese samples start in January 2000, while the series for Australia and Switzerland start in February and July 2001, respectively. All options are traded in local currency and we use end-of-day data obtained from Thomson Reuters. The stock market indices and LIBOR interest rates for different maturities (from 1 week to 1 year) are also obtained from Datastream.

Starting with daily data on the different stock index options, we first apply a similar filtering process as Santa-Clara and Yan (2010). We drop contracts with missing data; maturity is restricted to be longer than 10 days and shorter than 1 year; we keep only options with moneyness (i.e. stock price divided by the strike price) between 0.85 and 1.15; cases with open interest of fewer than 100 contracts are excluded (except for ASX200 options, for which this information is mostly non-available); we use only put options and apply option parity to obtain the corresponding call prices; contracts that have too low prices are excluded[7]; cases that imply option mispricing (i.e. violation of boundary conditions) are also dropped. For the remaining sample, we calculate Black-Scholes implied volatilities and delete those contracts for which this value cannot be determined. In Appendix, Table A.1 shows the mean implied volatilities, as well as the numbers of option contracts for each market.

III. Modeling Carry Trade Returns and Funding Risk

In this section, we first present the carry trade strategy and associated returns for different portfolio constructions. Second, we estimate stock market volatility and jump intensity for selected countries using data on the respective stock market option indices. We later argue that these measures are good indicators of funding risk in those countries' currencies.

[7] The cutoff prices are 0.125 USD for S&P500, 12.5 Yen for Nikkei225, 0.1875 AUD for ASX200 and 0.125 SWF for SMI50.

A. The Returns to Currency Carry Trade

The carry trade investor borrows in low interest rate currencies and invests in high interest rate currencies, thus making positive expected returns due to the failure of the uncovered interest rate parity. The carry trade can also be implemented using forward exchange rate contracts (see for example Galati et al., 2007). Following this latter approach, we calculate monthly returns using one-month forward rates. We first sort currencies according to their forward discounts[8], and then borrow (invest in) the currency with the smallest (largest) forward discount. We denote this long-short strategy by HmL (High-minus-Low). Typically Japanese yen and Swiss franc are considered the standard "funding currencies", while Australian and New Zealand dollars are considered the two major "investment currencies". Therefore a very popular strategy among investors consists of going short the Japanese yen and going long the Australian dollar. We consider this strategy, which we denote by $AUmJP$ (Australian dollar minus Japanese yen), and present its return over time on Figure 2.

[Figure 2 here]

For robustness purposes, we also consider two alternative strategies: going long (short) in the three currencies with the three largest (smallest) forward discounts ($HmL3$); going long (short) in the five currencies with the five largest (smallest) forward discounts ($HmL5$).

Table I shows the summary statistics of the monthly returns on these carry trade portfolios. Compared to our estimates, Menkhoff et al. (2012) report a higher average return for the period covering December 1983 to August 2009. This difference is consistent with the findings of Jylhä and Suominen (2011), who find that carry trade returns have decreased over time.

[Table I here]

[8]The forward discount is defined as $FD = fw/e - 1$, where e is the spot exchange rate (denominated in FCU's per USD) and fw is the forward exchange rate.

B. Estimating Funding Risk

B.1. Motivation

Adrian and Shin (2010) argue and show evidence that, in a financial system where balance sheets are continuously marked to market, asset price changes appear immediately as changes in net worth. Financial intermediaries respond actively, by adjusting the size of their balance sheet. Given this, we argue that risks in the equity market affect investors relying on funding from intermediaries. In addition, the funding conditions can be currency-specific since stresses on banks' balance sheets can cause shortage of funding in a given currency (see McGuire and von Peter, 2009).

As Japanese yen is the most significant funding currency in carry trades, we are particularly interested in the functioning of the Japanese financial markets and the potential shortages of yen funding. Hattori and Shin (2009) have already shown that there is significant time variation in the availability of yen funding and time variation in yen carry trade. Following their approach, we show in the Appendix that there is significant comovement between the net interbank assets of foreign banks of Japan, their net interoffice accounts, and carry trade activity. First, we confirm the existence of a strongly negative correlation (equal to -65.10% over our sample period) between the net interbank assets and the net interoffice accounts of foreign banks in Japan (see Figure A.1). Hattori and Shin (2009) interpret this to be evidence consistent with the hypothesis that foreign banks channel yen funding out of Japan through their local offices. To show further support for the idea that funding conditions in Japan affect carry trade activity, we show that the net interoffice accounts are also closely related to carry trade activity in Japanese yen futures (see Figure A.2). In times when the carry trade is building up and speculators are shorting yen futures, we observe foreign banks borrowing in the Japanese interbank market and then sending these funds outside of Japan. Moreover, and in line with the arguments presented in Adrian and Shin (2010), we find a striking relation between the equity prices of Japanese financial institutions and their yen lending to foreign financial institutions, as depicted in Figure A.3. Our evidence therefore suggests that the strength of the Japanese stock market is a key determinant of the carry trade activity. This motivates our measure of funding risk, discussed in the following subsection.

B.2. Our Measure of Funding Risk

We use index option data to estimate stock market risk (both diffusion and jump components) as it is perceived ex ante by investors. Our goal is to relate these measures, estimated for both long and short carry countries, with exchange rate dynamics and speculators' activity. For this purpose, we focus on four markets: the US (the benchmark currency), Australia (a typical 'investing currency', in which investors go long)[9], as well as Japan and Switzerland (the typical 'funding currencies', commonly shorted by speculators).

We follow Santa-Clara and Yan (2010) and model stochastic volatility as a Brownian motion and the jump risk as a Poisson process, which is assumed to have stochastic intensity. In particular, for each of the four countries above, the dynamics of the stock market index S is modeled as follows:

$$\begin{aligned} dS &= \left(r + \phi - \lambda\mu_Q\right) Sdt + YSdW_S + QSdN \\ dY &= \left(\mu_Y + \kappa_Y Y\right) dt + \sigma_Y dW_Y \\ dZ &= \left(\mu_Z + \kappa_Z Z\right) dt + \sigma_Z dW_Z \\ \ln\left(1+Q\right) &\sim N\left(\ln\left(1+\mu_Q\right) - \frac{1}{2}\sigma_Q^2, \sigma_Q^2\right). \end{aligned} \tag{23}$$

Here r is the constant risk-free interest rate. The diffusive variance of the stock return is $\nu = Y^2$. N is a Poisson process, such that $\Pr\left(dN = 1\right) = \lambda dt$, where the stochastic arrival intensity is given by $\lambda = Z^2$. Moreover, both Z and Y follow Ornstein-Uhlenbeck

[9] Another natural candidate for a long currency would be New Zealand. However data on stock index options for this country is not available, thus restricting our sample choice.

processes, with long-run means of μ_Y/κ_Y and μ_Z/κ_Z, mean-reversion speeds of κ_Y and κ_Z, and volatilities given by σ_Y and σ_Z respectively.[10] Q is the percentage jump size, which is assumed to follow an independent log-normal distribution. The drift on the stock market index is adjusted for the average jump size with the term $\lambda\mu_Q$, and ϕ is the risk premium on the stock market index. W_S, W_Y, and W_Z are Brownian motions and they are allowed to be interdependent according to a constant correlation matrix Σ.

Santa-Clara and Yan (2010) show that, for a representative investor who has wealth W and allocates it entirely to the stock market, the risk premium ϕ can be expressed as a function of Y and Z. Under this risk-adjusted probability measure, the inverse Fourier transformation of a function of the state variables is used to obtain the price $P = f(S, Y, Z; K, T)$ of a European call option with strike price K and maturity date T (e.g. Lewis, 2000).

We apply Santa-Clara and Yan (2010) quasi-maximum likelihood approach[11] and estimate the model for each country every week, using data for the stock index and four put option contracts $\{S_t, P_t^1, P_t^2, P_t^3, P_t^4\}$.[12] P_t^1 and P_t^2 are assumed to be observed without error and used to imply the state variables Y_t and Z_t, while P_t^3 and P_t^4 are used to compute the pricing errors. Table II reports summary statistics for the implied time series of diffusive volatility $\sqrt{\nu}$ and jump intensity λ, for the two funding currencies and the US.

[Table II here]

Our US estimates are consistent with those obtained by Santa-Clara and Yan (2010), but we do find higher average volatility most likely due to the financial crisis period. Moreover, although volatility and jump intensity are correlated within and across countries, they still display different behavior over time, as illustrated by Figure 3.

[10] Applying Ito's lemma, one can find the processes for V and λ. The drift and covariance terms will not be linear in the state variables, making it a linear-quadratic jump-diffusion model.

[11] The estimation approach is described in detail in their paper, so we omit the details here. We also thank the authors for kindly making their estimation code available.

[12] P_t^1 and P_t^2 have the shortest maturity (greater than 15 days and as close as possible to 30 days), P_t^3 and P_t^4 have the second shortest maturity (greater than 45 days and as close as possible to 60 days). P_t^1 and P_t^3 are closest to at-the-money, while P_t^2 and P_t^4 are closest to moneyness of 1.05.

[Figure 3 here]

IV. Empirical Findings

We now turn to testing the five hypotheses regarding the relation between funding risk, exchange rates, and speculators' activity. Given the importance of Japanese financial conditions to carry trade funding liquidity discussed above, we use the volatility and jump intensity estimated from stock options in Japan as our measures of funding risk. As the next sections will show, these measures perform striking well in explaining currency dynamics, speculators' activity, and carry trade returns. Moreover they outperform common measures of funding risk used in the literature, such as the TED spread. They also prove robust to the inclusion of a simple index of financial sector equity performance in Japan. Finally, very similar results are obtained with the measures calculated from stock options in Switzerland, therefore confirming the important role of the low-yield currencies.[13]

A. Explaining FX Volatility and Correlations with Funding Risk

Hypotheses 1 and 2 in Section I.C predict that increased funding risk leads to higher variability in both funding and investing currencies, as well as to a lower correlation between carry-short and carry-long currencies.

To test Hypothesis 1, we use a monthly measure of exchange rate volatility. For each currency, we calculate the standard deviation of daily currency returns (i.e. the symmetric of daily exchange rate changes against the USD) over the last month. The monthly measure of currency volatility, denoted by FX^{σ}, is calculated as the average of the individual standard deviations. We then regress the log of the average volatility on the funding risk in

[13] The unreported results for Switzerland are available upon request.

Japan, measured as the (month average) of the volatility and jump likelihood.[14] To adjust for heteroskedasticity and serial correlation in the monthly regression residuals, we report Newey-West standard errors. Table III presents the results. The estimated coefficients are positive, confirming that currency volatility is increasing in funding risk.

[Table III here]

As Table III shows, the volatility and crash risk in the Japanese stock market alone explain, on average, a staggering 46% of monthly currency volatility. Table III also includes alternative measures of funding risk commonly used in the literature. In particular we consider the TED spread (measured as the difference between the 3-months LIBOR dollar rate and the 3-months T-Bill rate) and we find that it performs significantly worse than the Japanese crash risk. As a robustness test, and motivated by the empirical evidence discussed in subsection B.1, we also include the Japanese financial sector stock index in the regression. The financial sector equity prices in Japan can explain 19% of the currency volatility and they remain statistically significant in all regression specifications. Hypothesis 1 is therefore validated in the data.

Hypothesis 2 is also confirmed by our empirical results. In order to show it, we calculate the correlation coefficient between our investing (or 'long') currency, Australian dollar, and our funding (or 'short') currency, Japanese yen. As above, the correlation is calculated monthly (using daily data over the previous month) and we then regress it on our monthly average measures of funding risk. As can be seen from Table IV, the estimated coefficient for crash risk is negative and the corresponding adjusted R^2 is 23%, confirming our hypothesis that the correlation between investing and funding currencies decreases when funding conditions tighten.

[14] We also tried two alternative specifications: (i) using daily data on exchange rates, we calculated volatility over the previous week and then performed weekly regressions of FX^{σ} on funding risk; (ii) again using daily data, we calculated volatility over the previous month, and then performed rolling weekly regressions. All three alternatives deliver similar conclusions, but the specification shown is preferred as it is less noisy than (i) and avoids potential issues with the overlapping data used in (ii).

[Table IV here]

B. Explaining Currency Crashes and Skewness with Funding Risk

The cross-section differences in currency skewness are well-known in the literature. Consistent with previous work, we also find that average skewness is positive and highest for Japanese yen (the main carry trade funding currency), while negative and lowest for Australian and New Zealand dollars (the main carry trade investing currencies).

In our model, if the funding constraints do not bind, the currency variability is smaller. When funding constraints start binding, as depicted in Figure 1, there is first a currency crash in both the funding and investment currencies. Any further tightening of funding constraints, in turn, leads to further depreciation of the investment currencies but an appreciation of the funding currencies. Given these effects, our model predicts that the currency returns are negatively skewed for the investment currencies, but not necessarily so for the funding currencies. Therefore, let us investigate if countries' different exposures to funding risk help to explain the cross-sectional differences in exchange rate skewness. Following Brunnermeier et al. (2009), we calculate realized skewness from daily exchange rate returns within (overlapping) quarterly time periods, and then take the time-series average. We measure the countries' exposure to funding risk by the estimated coefficient of regressing individual monthly currency returns on monthly average Japanese crash risk, λ.

Figure 4 shows a clear positive relationship between countries' exposures to funding risk and currency skewness, i.e. returns to currencies with large negative coefficients for λ (such as Australia or New Zealand dollars) are negatively skewed. The relationship between high interest rate differentials and negative skewness, observed in Brunnermeier et al. (2009), is therefore explained by heterogeneous country exposure to funding risk. Overall, the result supports the prediction that the stock market risks in funding currency countries are a significant factor in explaining the negative skewness of investment currency returns.

[Figure 4 here]

In addition, our model predicts that a strong tightening of credit conditions is associated with crashes of the investment currencies and large appreciations of the funding currencies. To test these predictions in the data, we estimate a probit model where the dependent variable is the crash currency likelihood. We start by constructing a carry portfolio, that holds the long-carry currency (AUD) and shorts the low-yield currency (JPY), and we calculate its return against a basket of six non carry-currencies during that month. The dependent variable takes value 1 if there is a crash in this portfolio (defined as a negative return lower than minus one standard deviation on a given month) and 0 otherwise. The results are presented in Table V, where we show that increases in funding crash risk λ indeed lead to a higher likelihood of currency crashes. As before, we also present the results for the TED spread with very similar conclusions. Therefore Hypothesis 3 is confirmed empirically.

[Table V here]

C. Explaining Speculative Activity and Carry Trade Returns with Funding Risk

C.1. Speculators' Trading Activity

We now turn to the effect of funding risk on trading activity in the currency market. We follow Brunnermeier et al. (2009) and use the futures position data from the CFTC as a proxy for carry trade activity, measured at weekly frequency. In particular, we use the net (long minus short) futures position of noncommercial traders in the foreign currency, expressed as a percentage of total open interest of all traders.[15] Noncommercial traders represent the investors that use futures for speculative purposes.

[15] A positive futures position is equivalent to a currency trade in which the foreign currency is the investment currency and the USD is the funding currency.

Table VI shows the results from regressing speculative activity on funding risk, for both individual currencies involved in carry trades and the long-short position (long AUD/short JPY).

[Table VI here]

Funding risk measures from Japan are able to explain 28% of the long-short positions in AUD/JPY (the TED spread can explain 18%). Furthermore, we obtain negative coefficients for the funding risk when explaining the long-short flows, i.e. a worsening of borrowing conditions causes unwinding of carry trades. This finding can also be understood by the futures positions held in individual currencies - an increase in funding risk causes the long position in investment currencies to decrease and the (short) position in funding currencies to increase. Moreover, and as predicted by condition (13), funding risk has greater impact on carry-long currencies than on carry-short currencies. Therefore Hypothesis 4 is empirically verified.

C.2. Carry Trade Returns

We now turn to the effect of funding risk on currency carry trade returns. We follow the common procedure in the literature and decompose the effect of both the diffusive volatility and the crash likelihood into expected and unexpected components. An analysis of the partial autocorrelations of each weekly time series shows that they are best modeled with three autoregression lags, as the shocks extracted in this way seem to be serially uncorrelated. In particular, we fit an $AR(3)$ model to each one of the implied state variables $\sqrt{\nu}$ and λ. The expected market risks are the fitted values of the estimation, and we denote them by $\sqrt{\nu}^e$ and λ^e; the residuals, denoted by $\sqrt{\nu}^u$ and λ^u, are used as our estimation of the unexpected innovations.[16]

[16]The residuals behave quite differently in the cross-section. For example, the correlations between the 'unexpected crash risks' vary from a minimum of -1.18% (non-significant correlation between US and Japan) to a maximum of 29.7% (between US and Switzerland).

If the abnormal returns to carry trades increase in funding risk as the model predicts, then higher expected market risk at time t, $\sqrt{\nu}^e$ and λ^e, should lead to higher expected carry trade returns, while the effect of positive unexpected shocks (residuals), i.e. positive $\sqrt{\nu}^u$ and λ^u, should be associated with negative contemporaneous returns. To confirm this conjecture, we regress monthly carry trade returns on the monthly averages of expected funding risk and residuals. We also include lagged residuals of crash risk in our regressions as, due to the slow moving capital (e.g. see Duffie, 2010), the market reaction may be slow (lagged residuals of volatility are not statistically significant and therefore are omitted). As expected, we obtain positive coefficients on the fitted values and negative estimates for the residuals. Table VII presents the results for the different carry trade portfolios, using stock market related risks in Japan.

[Table VII here]

Noting the very high R^2's of the regressions, it is clear that funding risk in carry-short countries has a remarkably high explanatory power for carry trade returns, thus validating Hypothesis 5.[17] Moreover, we note that the funding-country equity market risks have a more important effect than the same factors calculated from the US market.[18] For instance, the R^2 of the regression of HmL returns on US equity market volatility and crash risk is below 24%, substantially lower than the fit of 36% found for the case of Japan. This point is further stressed in Table VIII, where we include both Japanese and US measures. First, the predictive power of funding risk for carry trade returns is stronger for the case of Japan. Second, in a full regression, only the Japanese measures remain statistically significant. Both conclusions also hold when considering Switzerland as the funding country.

[17] As a robustness check, Table A.2 in Appendix shows the same results for the Switzerland funding risk measures.

[18] During the period under study, the US interest rate levels are both below the median level (in the early 2000's and after 2008) as well as above the median level (between late 2004 and 2008). Therefore the role of the US dollar as either a funding or investing currency has changed over time.

Overall the inclusion of other measures of funding risk, such as the TED spread or VIX, does not affect the statistical significance of the stock market risks in the funding currencies.[19] Very similar conclusions confirming the robustness of our results are obtained using the US stock returns, the Japanese financial sector index, or the innovations in global FX volatility (as in Menkhoff et al., 2012).

[Table VIII here]

V. Conclusion

In this paper we develop a new measure of funding risk, allowing us to confirm the importance of funding constraints in currency speculation, therefore extending the results in Brunnermeier, Nagel, and Pedersen (2009). We measure funding risk for carry trades using the equity options' implied stock market volatility and crash risk in Japan, the most typical carry trade funding country. This measure seems to be a good proxy for speculators' ability in obtaining funds for carry trading, as it has a remarkably strong explanatory power for currency carry trade returns and speculators' trading activity.

Developing a stylized model of currency carry trades that allows for funding risk, we are able to make several new predictions regarding currency speculation and its effect on exchange rates. In particular, in our model, a deterioration of funding conditions for speculators leads to a regime switch from the unconstrained to the constrained economy. This switch brings about higher exchange rate volatility, lower correlation between investing and funding currencies, causes negative skewness for investing currencies, and currency crashes. In addition, the associated unwinding of carry trades causes poor returns to currency carry traders. We find that these predictions are all supported by the data.

[19] A decomposition of carry trade returns on interest rate and currency effects (not presented here) shows that the TED spread seems to have a much greater relation to the interest rate component, while funding risk is more important to explain the currency effect.

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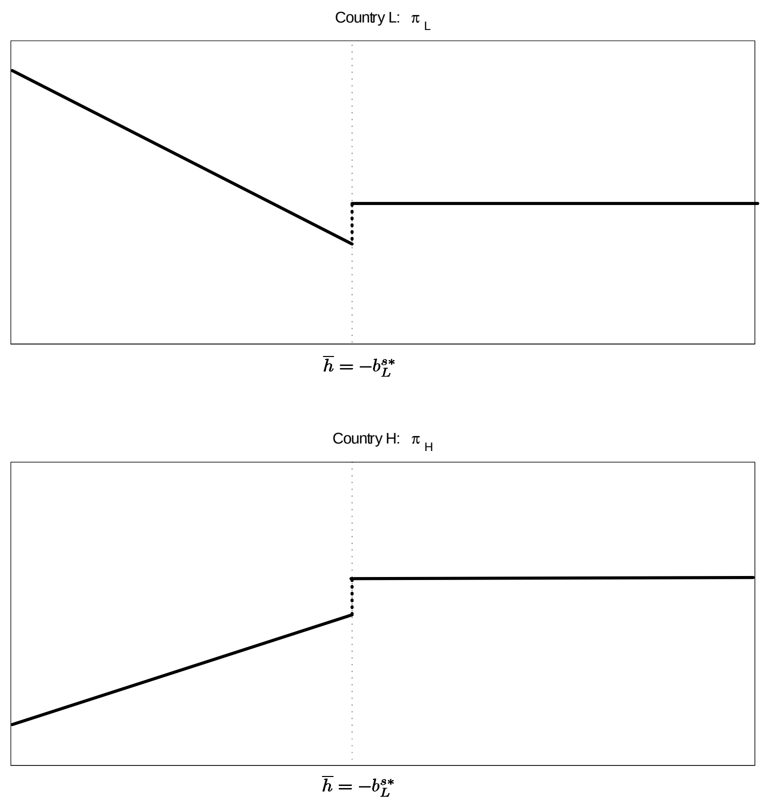

Figure 1. The Effect of $\overline{h}$ on Exchange Rates. This Figure shows the dynamics of the purchasing power for each country, as a function of the average funding conditions, $\overline{h}$. The first plot shows the case for the funding currency (Country L), while the second plot shows the case for the investment currency (Country H).

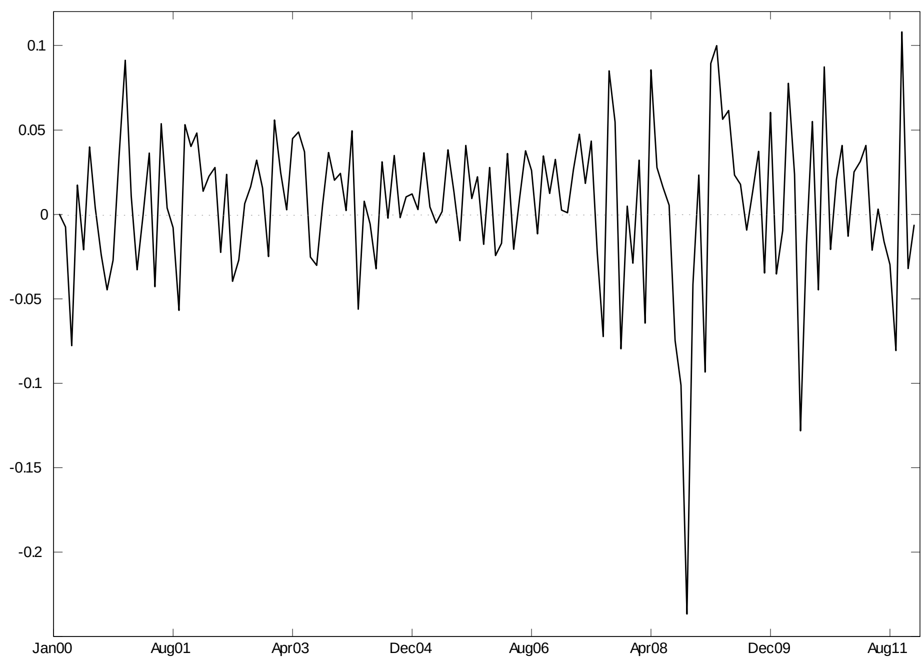

Figure 2. Monthly Carry Trade Returns for the AUmJP Strategy. This Figure shows the monthly returns of the $AUmJP$ carry trade strategy, which corresponds to an investment strategy where investors borrow in Japanese yen and invest in Australian dollar. Results are presented for the period covering January 2000 to December 2011.

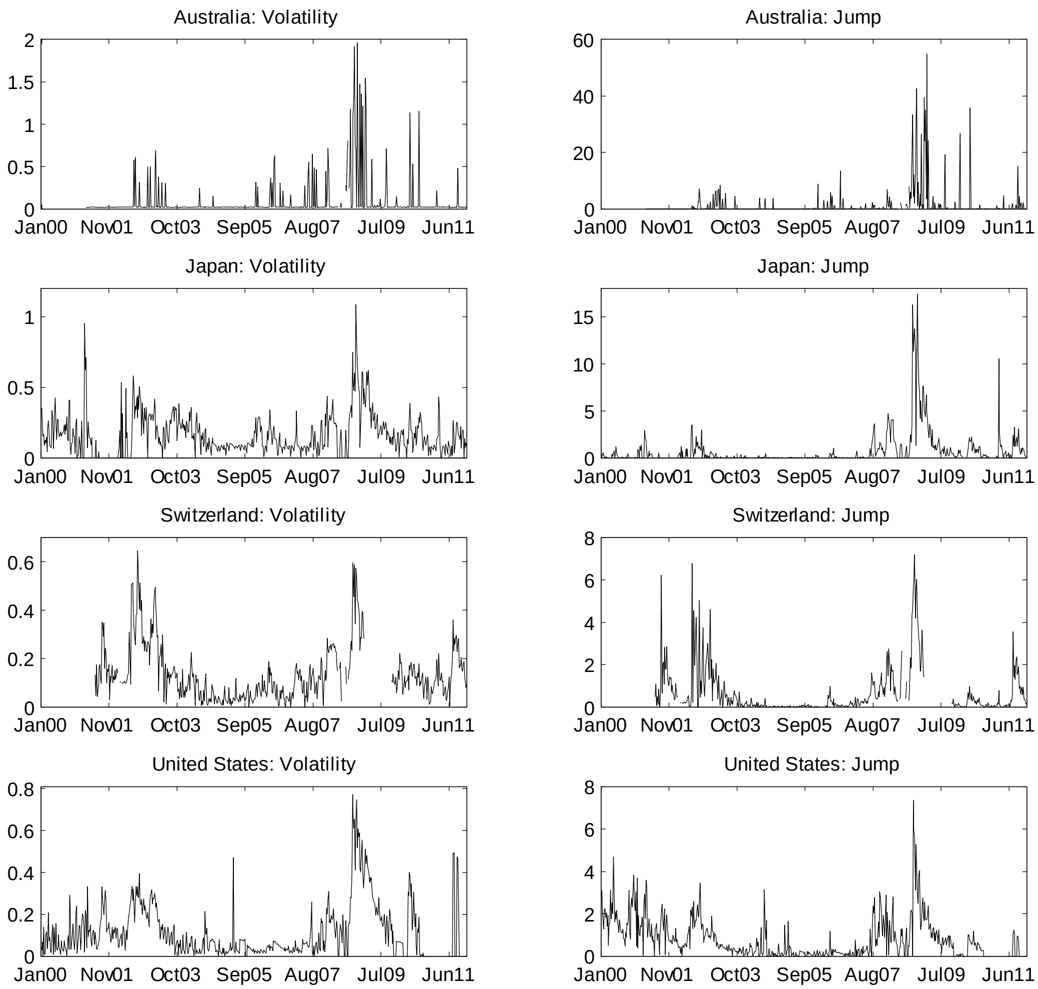

Figure 3. Volatility and Jumps. This Figure shows the estimated time series of the diffusive volatility (left column) and jump intensity (right column) for each market. Both risk measures are estimated from option data on stock market indices. The time period covered is January 2000 to December 2011. The data for Australia and Switzerland start in 2001.

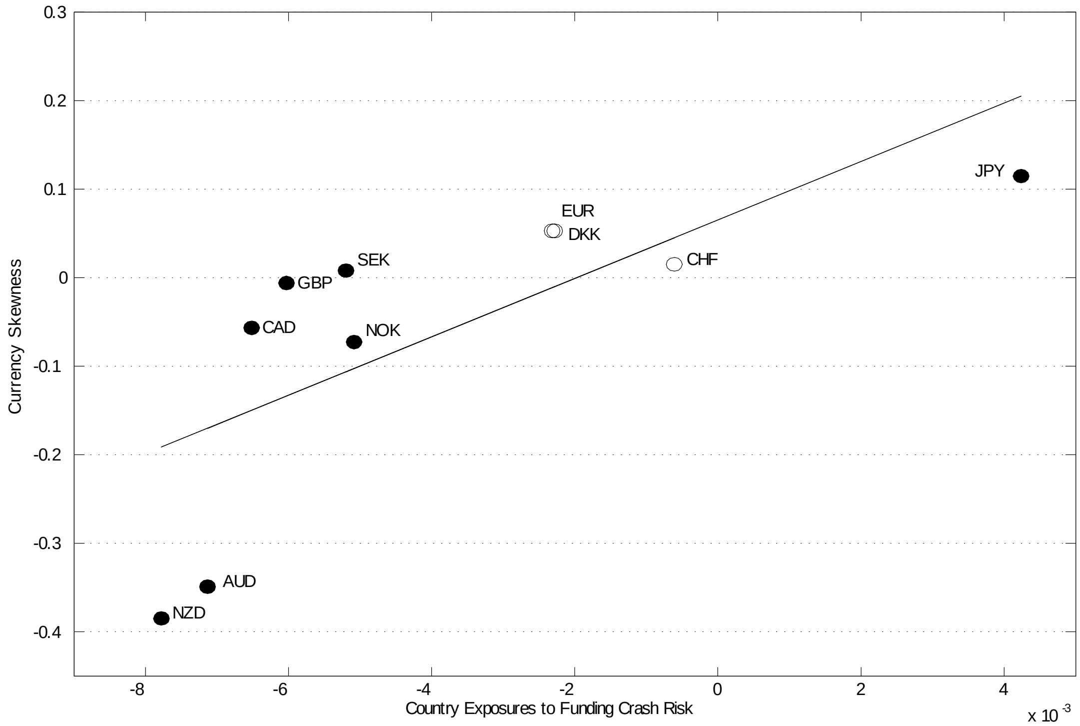

Figure 4. Skewness and Funding Risk. This Figure shows the positive relationship between the country exposures to funding risk and average currency skewness. The exposures to funding risk are the estimated coefficient from a regression of individual monthly currency returns on the monthly average Japanese crash risk. All the coefficients in these individual regressions are statistically significant at one percent level, with the exception of CHF, DKK, and EUR (corresponding to the unfilled markers). For the currency skewness, we use daily exchange rate returns within (overlapping) quarterly time periods, and then take the time-series average. The line shows the fitted values of regressing currency skewness on country exposures, and the corresponding fit is 51%.

Table I
Monthly Carry Trade Returns: Summary Statistics

This table shows the summary statistics of the monthly returns on the different carry trade strategies. It includes the mean, standard deviation, skewness, kurtosis and median. The total number of observations is 144 months. Numbers in parentheses show the standard error of the mean returns.

Strategy	Mean	Std. Dev.	Skewness	Kurtosis	Median
HmL	0.0070	0.0416	-1.3407	7.3109	0.0111
	(0.0035)				
AUmJP	0.0059	0.0459	-1.2298	7.8532	0.0103
	(0.0038)				
HmL3	0.0040	0.0244	-0.8174	5.3299	0.0065
	(0.0020)				
HmL5	0.0022	0.0173	-0.8826	5.7698	0.0041
	(0.0014)				

Table II
Our Measures of Funding Risk: Volatility and Crash Risk

This table shows the summary statistics of the implied state variables, i.e. the diffusive volatility $\sqrt{\nu}$ and the jump intensity λ. Both variables are estimated using option data from the stock markets. It includes the mean, standard deviation, skewness, kurtosis, autocorrelation and the correlation between volatility and crash risk for each case. Results are presented for the main carry-investing country, Australia, for the main carry-funding countries, Japan and Switzerland, as well as for the benchmark market, US.

Countries		Mean	Std.Dev.	Skewness	Kurtosis	Autocorr.	$Corr(\sqrt{v}, \lambda)$
Australia	$\sqrt{\nu}$	0.09	0.24	4.64	27.44	0.32	0.30
	λ	1.29	5.21	6.24	47.19	0.27	
Japan	$\sqrt{\nu}$	0.18	0.14	1.87	8.83	0.71	0.54
	λ	0.83	1.93	4.83	31.53	0.80	
Switzerland	$\sqrt{\nu}$	0.14	0.12	1.66	6.01	0.85	0.68
	λ	0.66	1.12	2.89	12.54	0.72	
United States	$\sqrt{\nu}$	0.13	0.13	1.85	6.94	0.84	0.50
	λ	0.89	0.96	2.09	9.88	0.70	

Table III
Exchange Rate Volatility and Funding Risk

This table shows the explanatory power of funding risk in Japan for the average monthly log currency standard deviation, denoted by $\ln(FX^{\sigma})$. For each currency in the sample of ten developed countries, the volatility is calculated monthly using the daily exchange rate changes against USD. ν and λ are the monthly average volatility and jump likelihood, computed from stock option data in Japan. Model (1) shows that the funding risk measures in Japan alone, in particular crash risk, are able to explain 46% of FX volatility. Models (2) and (3) show that alternative measures of funding risk, such as the TED spread or the Japanese financial index (JP Fin.), perform significantly worse in explaining currency volatility. Model (4) shows the regression results when including all measures. JP Fin. is obtained from Datastream and divided by 100 for expositional purpose. For each estimated coefficient, the corresponding t-statistics are computed using Newey-West standard errors (with a lag of five months). ** (*) shows statistical significance at 1 (5) percent. The numbers in brakets show the mean Variance Inflation Factor (VIF), where values of VIF smaller than 10 as shown indicate absence of multicollinearity issues.

$ln(FX^{\sigma})$	(1)		(2)		(3)		(4)	
	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat
λ^{JP}	0.1099**	6.46	——		——		0.0728**	4.10
$\sqrt{\nu}^{JP}$	0.2603	0.83	——		——		0.1749	0.59
JP Fin.	——		-0.0952**	-3.21	——		-0.0755**	-3.43
TED	——		——		0.2317*	2.31	0.1180*	2.31
const.	-5.1784**	-97.89	-4.7104**	-34.97	-5.1698**	-94.23	-4.9334**	-64.3
$Adj.R^2$	46.29%		18.61%		17.79%		54.37%	
VIF	[1.78]						[2.99]	

Table IV
Exchange Rate Correlations and Funding Risk

This table shows the explanatory power of crash risk for the correlation coefficient between the main long currency (Australian Dollar) and the main short currency (Japanese Yen). The correlation coefficient is calculated monthly, using the daily exchange rate changes against USD. ν and λ are the monthly average volatility and jump likelihood, computed from stock option data in the Japanese market. Model (1) shows that the funding risk measures in Japan alone, in particular crash risk, are able to explain 23% of currency correlation. Models (2) and (3) show the results for alternative measures of funding risk, the Japanese financial index (JP Fin.) and the commonly used TED spread. The Japanese financial sector index is obtained from Datastream and divided by 100 for expositional purpose. Model (4) shows the regression results when including all measures. The t-statistics shown in the second column are computed using Newey-West standard errors (with a lag of five months). ** (*) shows statistical significance at 1 (5) percent.

AU/JP	(1)		(2)		(3)		(4)	
	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat
λ^{JP}	-0.1300**	-3.58	——		——		-0.0673*	-2.16
$\sqrt{\nu}^{JP}$	0.0384	0.10	——		——		0.0432	0.13
JP Fin.	——		0.0501	1.25	——		0.0507	1.92
TED	——		——		-0.3542**	-5.07	-0.2577**	-3.26
const.	0.2885**	3.16	0.0162	0.11	0.3893**	5.41	0.2056	1.90
$Adj.R^2$	23.10%		1.86%		20.28%		28.45%	

Table V
Currency Crashes and Funding Risk

This table shows the explanatory power of funding risk for currency crashes. We estimate a probit model, where the dependent variable takes value 1 if there is a crash in the currency carry portfolio, and 0 otherwise. The 'carry portfolio' consists on holding the long-carry currency (AUD) and shorting the low-yield currency (JPY), and we calculate its return against a basket of six currencies (which does not include the investment or the funding currencies) during that month. We define a crash when the portfolio return is lower than (minus) 1 standard deviation. In Model (1), we show that changes in funding risk estimated from Japanese stock options data ($\Delta\lambda$), both contemporaneous and lagged, can explain 27% of currency crash. Model (2) considers the same type of regression for the TED spread. Model (3) shows the result when including only contemporaneous changes and Model (4) considers all variables. Contemporaneous and lagged changes of the Japanese financial sector index or stochastic volatility are not statistically significant, so they are excluded here. The z-statistics are computed using robust standard errors and ** (*) shows statistical significance at 1 (5) percent. The last row shows pseudo-R^2s.

	(1)		(2)		(3)		(4)	
	Coef.	z-stat	Coef.	z-stat	Coef.	z-stat	Coef.	z-stat
$\Delta\lambda^{JP}$								
L0.	0.9148**	2.63	——		0.6522*	2.08	1.9317**	3.48
L1.	0.1834	1.68	——		——		1.0221*	2.49
L2.	0.3421**	2.56	——		——		1.4137**	2.97
L3.	0.6614*	2.29	——		——		1.8674**	4.16
ΔTED								
L0.	——		2.3471*	2.50	1.5774*	2.40	3.3636	1.82
L1.	——		1.7988**	3.12	——		0.1328	0.14
L2.	——		0.6304	1.63	——		-3.4263*	-2.05
L3.	——		0.3573	0.38	——		-3.2563*	-2.36
const.	-1.5650**	-8.66	-1.4450**	-6.03	-1.5601**	-7.47	-2.1882**	-5.75
$PseudoR^2$	26.82%		29.52%		30.23%		54.12%	

Table VI
Weekly Carry Trade Activity

This table shows the explanatory power of funding risk for the weekly carry trade activity. The dependent variables are the net futures position in AUD minus net futures position in JPY, as well the positions in individual currencies AUD, GBP, CHF and JPY. As before, ν and λ are the volatility and jump likelihood, computed from stock option data in Japan. In Panel A, Model (1) shows that the funding risk measures in Japan alone are able to explain 28% of the composite futures position. Models (2) and (3) show that alternative measures of funding risk, such as the Japanese financial index (JP Fin.) or the commonly used TED spread, perform significantly worse. Model (4) shows the regression results when including all measures. Panel B shows the explanatory power of funding risk in Japan for futures positions in individual currencies. The number of weeks considered is 626. The t-statistics are computed using robust standard errors and ** (*) shows statistical significance at 1 (5) percent.

Panel A: Futures AU-JP

	(1)		(2)		(3)		(4)	
	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat
λ^{JP}	-0.0353**	-4.64	——		——		-0.0046	-0.52
$\sqrt{\nu}^{JP}$	-0.9380**	-8.85	——		——		-0.7309**	-6.90
JP Fin.	——		0.0010**	10.13	——		0.0009**	7.65
TED	——		——		-0.1515**	-6.10	-0.1291**	-3.97
const.	0.4861**	21.31	-0.0938**	-2.58	0.3518**	19.83	0.1825**	4.31
Adj.R^2	27.59%		17.53%		5.50%		36.45%	

Panel B: Futures Positions in Individual Currencies

	Futures AUD		Futures GBP		Futures CHF		Futures JPY	
	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat
λ^{JP}	-0.0128**	-2.82	-0.0259**	-4.60	-0.0145*	-2.23	0.0251**	4.22
$\sqrt{\nu}^{JP}$	-0.5371**	-8.10	-0.3860**	-5.07	0.1499	1.44	0.3605**	4.31
const.	0.3868**	26.58	0.1027**	5.62	-0.0815**	-3.74	-0.1011**	-5.91
Adj.R^2	14.80%		10.64%		0.31%		11.59%	

Table VII
Explaining Monthly Carry Trade Returns with Funding Risk in Japan

This table shows the results of regressing monthly carry trade returns on funding risk, calculated from option data on the Japanese stock market. ν^e and λ^e are the monthly averages of fitted values for the volatility and jump likelihood. ν^u and λ^u are the average residuals and correspond to the unexpected component of risk. Four portfolio strategies are shown, AUmJP, HmL, HmL3 and HmL5, with corresponding returns calculated for the period covering January 2000 to December 2011 (for a total of 144 observations). The t-statistics are computed using robust standard errors and ** (*) shows statistical significance at 1 (5) percent.

Strategy	AUmJP		HmL		HmL3		HmL5	
	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat
λ^e	0.0168**	2.95	0.0148*	2.40	0.0106**	2.83	0.0050*	2.02
$\sqrt{\nu}^e$	0.0761	1.34	-0.0121	-0.23	0.0330	0.97	0.0164	0.67
λ^u								
L0.	-0.0670**	-8.55	-0.0576**	-8.48	-0.0344**	-7.39	-0.0222**	-6.84
L1.	-0.0214*	-2.38	-0.0281**	-2.98	-0.0167**	-2.68	-0.0058	-1.55
L2.	-0.0367**	-4.48	-0.0413**	-4.66	-0.0175**	-3.90	-0.0058*	-2.22
L3.	-0.0110*	-2.17	-0.0184**	-2.65	-0.0137**	-3.25	-0.0073**	-2.67
$\sqrt{\nu}^u$								
L0.	-0.2586*	-1.96	-0.0033	-0.03	-0.0901	-1.12	-0.0813	-1.59
const.	-0.0217*	-2.17	-0.0032	-0.35	-0.0110	-1.89	-0.0049	-1.22
$Adj.R^2$	42.25%		36.30%		33.65%		35.55%	

Table VIII
Carry Trade Returns: US Measures and Japanese Funding Risk

This table compares the explanatory and predictive power of Japanese and US measures for monthly AUmJP carry trade returns. For each market, ν^e and λ^e are the monthly average fitted values of the volatility and jump likelihood, and ν^u and λ^u are the average residuals (corresponding to the unexpected component of risk). In model (1), we consider the predictive power of Japanese funding risk, by using as independent variables the fitted values (known by investors in the beginning of month) and only lagged residuals. Model (2) shows that the same predictive regression with US measures yields much weaker results. In model (3), for robustness purposes, we use all measures together with changes in TED spread and changes in VIX over the previous month. The t-statistics are computed using robust standard errors and ** (*) shows statistical significance at 1 (5) percent.

		(1)		(2)		(3)	
		Coef.	t-stat	Coef.	t-stat	Coef.	t-stat
Japan	λ^e	-0.0147	-1.27	——		0.0089	0.96
	$\sqrt{\nu}^e$	-0.2036**	-2.64	——		-0.0285	-0.26
	λ^u						
	L0.	——		——		-0.0381**	-3.21
	L1.	0.0225	1.22	——		-0.0160	-1.09
	L2.	-0.0049	-0.32	——		-0.0381**	-3.64
	$\sqrt{\nu}^u$						
	L0.	——		——		-0.1259	-0.75
	L1.	0.6280**	3.82	——		0.1969	0.91
	L2.	0.4363**	2.83	——		0.0458	0.36
US	λ^e	——		-0.0252*	-2.17	-0.0096	-0.57
	$\sqrt{\nu}^e$	——		-0.0461	-0.58	-0.0592	-0.85
	λ^u						
	L0.	——		——		-0.0003	-0.01
	L1.	——		0.0494	1.96	0.0355	0.90
	L2.	——		0.0350	1.58	0.0074	0.26
	$\sqrt{\nu}^u$						
	L0.	——		——		-0.2268	-1.08
	L1.	——		-0.0697	-0.35	-0.1453	-0.70
	L2.	——		0.2081	0.91	0.4138*	2.23
ΔTED		——		——		-0.0244**	-2.72
ΔVIX		——		——		-0.0017	-1.60
const.		0.0548**	4.13	0.0343**	2.87	0.0185	0.87
$Adj.R^2$		16.92%		2.98%		56.91%	

Appendix

Table A.1
Implied Volatilities across Markets

This table shows the Black-Scholes implied volatilites for all options. The first column for each country presents the average implied volatility and the second column the corresponding standard deviation. Results are shown for different levels of moneyness and time to maturity. The first column shows the three classes of moneyness considered, where "Low" corresponds to $S/K < 0.95$, "Mid" corresponds to $0.95 < S/K < 1.05$, and "High" corresponds to $S/K > 1.05$. The second column refers to time to maturity measured in days. The last row shows the number of option contracts (after filtering) and the number of trading days for each market.

		Australia		Japan		Switzerland		US	
S/K	T	Mean	St.Dev.	Mean	St.Dev.	Mean	St.Dev.	Mean	St.Dev.
Low	< 45	0.376	0.187	0.308	0.132	0.278	0.128	0.303	0.114
	$[45, 90]$	0.268	0.102	0.242	0.079	0.209	0.085	0.272	0.088
	> 90	0.236	0.079	0.222	0.051	0.196	0.055	0.249	0.069
Mid	< 45	0.281	0.186	0.251	0.110	0.195	0.089	0.226	0.103
	$[45, 90]$	0.198	0.106	0.237	0.076	0.191	0.075	0.246	0.095
	> 90	0.164	0.078	0.220	0.061	0.197	0.058	0.255	0.071
High	< 45	0.387	0.234	0.313	0.129	0.256	0.092	0.305	0.112
	$[45, 90]$	0.248	0.130	0.270	0.090	0.228	0.079	0.301	0.094
	> 90	0.161	0.073	0.234	0.064	0.219	0.054	0.285	0.074
Contracts (days)		191,989 (2,630)		52,959 (2,561)		246,197 (2,311)		154,076 (2,541)	

Table A.2
Explaining Monthly Carry Trade Returns with Funding Risk in Switzerland

This table shows the results of regressing monthly carry trade returns on funding risk, calculated from option data on the Swiss stock market. ν^e and λ^e are the monthly averages of fitted values for the volatility and jump likelihood. ν^u and λ^u are the average residuals and correspond to the unexpected component of risk. Four portfolio strategies are shown, AUmJP, HmL, HmL3 and HmL5, with corresponding returns calculated for the period covering January 2000 to December 2011 (for a total of 144 observations). The t-statistics are computed using robust standard errors and ** (*) shows statistical significance at 1 (5) percent.

Strategy	AUmJP		HmL		HmL3		HmL5	
	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat
λ^e	-0.0231	-0.93	-0.0202	-1.01	-0.0011	-0.09	-0.0022	-0.25
$\sqrt{\nu}^e$	0.1809*	2.35	0.1725*	2.20	0.0664	1.54	0.0333	1.02
λ^u								
L0.	-0.0682**	-2.96	-0.0541**	-2.85	-0.0335**	-3.12	-0.0234**	-3.37
L1.	0.0225	0.53	0.0041	0.12	-0.0059	-0.28	-0.0006	-0.05
L2.	0.0019	0.07	-0.0220	-1.03	-0.0061	-0.48	0.0023	0.25
L3.	-0.0011	-0.05	-0.0255	-1.21	-0.0147	-1.19	-0.0046	-0.54
$\sqrt{\nu}^u$								
L0.	-0.4664*	-4.37	-0.2635*	-2.27	-0.2509**	-4.48	-0.1746**	-3.85
const.	-0.0054	-0.40	-0.0055	-0.50	-0.0056	-0.85	-0.0014	-0.33
$Adj.R^2$	37.75%		31.99%		29.38%		28.08%	

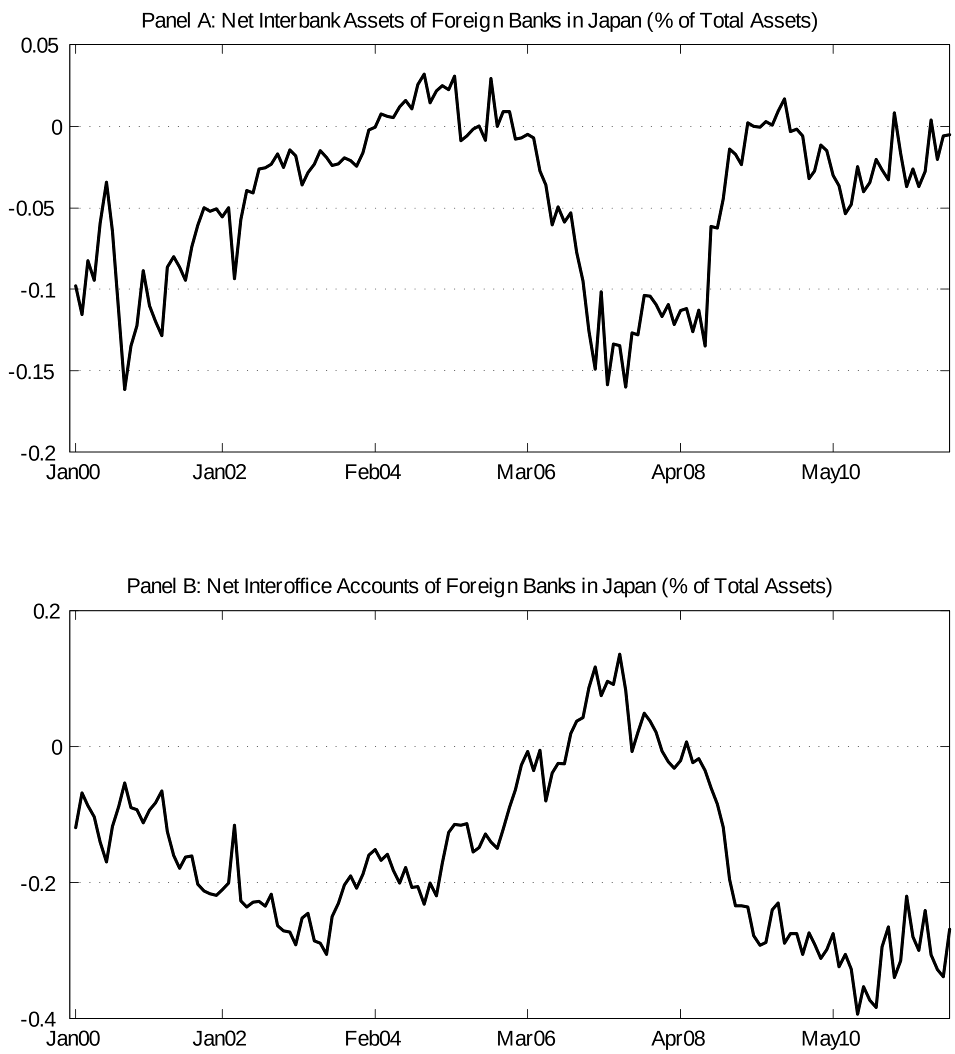

Figure A.1. Balance Sheet Components of Foreign Banks in Japan. Panel A shows the time-series of the monthly net interbank assets of foreign banks in Japan, measured as call loans minus call money and expressed in percentage of the total financial assets of those banks. Similarly, the aggregate net interoffice accounts (Panel B) is measured as the asset minus liabilities interoffice components, expressed as a percentage of total financial assets of those banks. The data is available from Bank of Japan. Over our sample period, the correlation coefficient between the two series is -65.10%. This strongly negative relation is in line with the findings in Hattori and Shin (2009), and can be interpreted as evidence that the Japan offices of the foreign banks are channeling yen liquidity out of Japan.

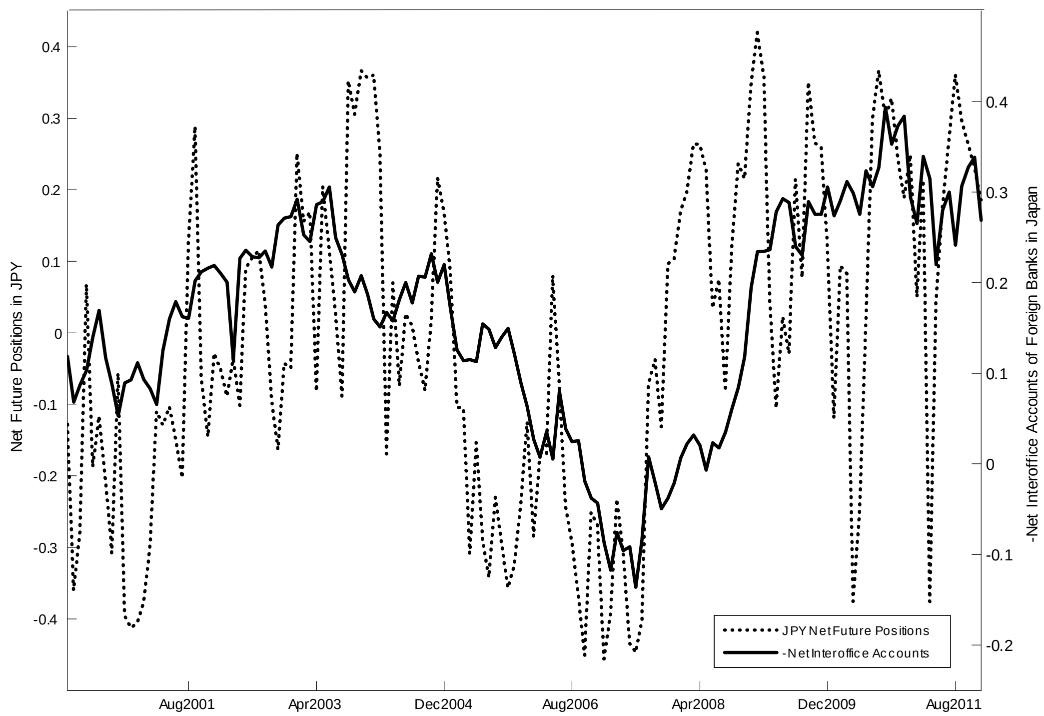

Figure A.2. Carry Trade Activity and Net Interoffice Accounts in Japan. This Figure shows the comovement of the (monthly average) of net future postions in JPY and the (symmetric) of the monthly net interoffice accounts of foreign banks in Japan. The net future positions are calculated as the long minus short futures CFTC position on noncommercial traders in JPY, expressed as a percentage of total open interest of all traders. The aggregate net interoffice accounts of foreign banks in Japan is measured as the asset minus liabilities interoffice components (available from Bank of Japan), expressed as a percentage of total financial assets of those banks. Over our sample period, the correlation coefficient between the net future positions in JPY and the net interoffice accounts is -51.54%. For illustration purposes, the plot shows the symmetric of the net interoffice accounts (a positive value implies that foreign banks hold a net long position in Japanese assets).

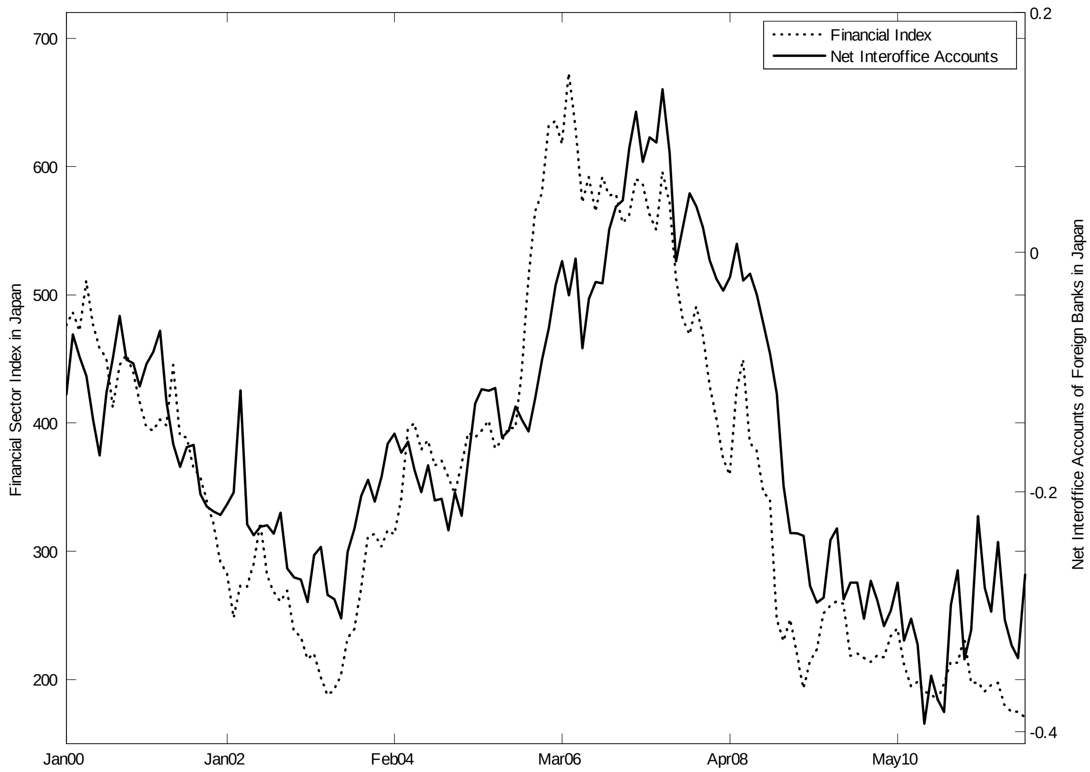

Figure A.3. Financial Conditions in Japan. This Figure shows the comovement of the Japanese financial sector index (taken from Datastream) and the net interoffice accounts of foreign banks in Japan. The aggregate net interoffice accounts of foreign banks in Japan are measured as the asset minus liabilities interoffice components (available from Bank of Japan), expressed as a percentage of total financial assets of those banks. Over our sample period, the correlation coefficient between the two series is 87.23%.

Currency Carry Trades and Funding Risk

Sara Ferreira Filipe
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Matti Suominen
Aalto University

Conference on Japanese Financial Markets - Tokyo, July 3

Introduction: Currency Carry Trade

The investment strategy...

- Exploits the failure of the uncovered interest parity;
- Consists in borrowing low interest rate currencies and investing in high interest rate currencies.

Introduction: Currency Carry Trade

The investment strategy...

- Exploits the failure of the uncovered interest parity;
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...and the returns to speculation:

- The carry trade strategy yields high average payoffs and Sharpe ratios;
- Traditional risk measures cannot account for these payoffs (e.g. Burnside et al., 2010).

Related Literature

Recent literature has shown the importance of funding constraints for asset pricing:

- Shleifer and Vishny (1997), Gromb and Vayanos (2002), Brunnermeier and Pedersen (2009)

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In the currency markets:

- Brunnermeier, Nagel, and Pedersen (2009) link speculators' funding constraints to currency skewness and carry trades.
- Hattori and Sin (2009) demonstrate the importance of funding conditions in Japan for global currency markets.
- Jylhä and Suominen (2011) show that the flow of new money to hedge funds affects exchange rates.

Related Literature

Equity and leverage:

- Adrian and Shin (2010) argue that changes in financial equity prices affect leverage.
- Adrian, Etula, and Muir (2013) show the importance of broker-dealers' leverage for US stock and bond returns.

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Importance of "peso problems" for abnormal returns:

- Santa-Clara and Yan (2010) use option data for implying the ex ante risk assessed by investors and measure jump risk from realized stock returns.
- Burnside et al. (2010) find that the average carry trade payoff reflects a peso problem (high values of the SDF in peso state).

Our Paper

The Measure of Funding Risk

We measure "carry trade funding risk" using stock market volatility and crash risk in Japan.

- Risks in the equity market affect investors relying on funding from intermediaries.
- To account for peso problems, we use stock option data in Japan to infer stochastic volatility and crash risk..
- The strength of the stock market in carry-short countries is a key determinant of speculative activity.
- There is significant comovement between net interbank assets of foreign banks in Japan, their net interoffice accounts, and carry trade activity.

Our Paper
Main Findings

Our empirical measures of funding risk perform striking well, explaining:

- 42% of the monthly carry trade returns;
- 46% of the monthly FX volatility in developed countries;
- 28% of speculative activity in currency futures;
- differences in the cross-sectional skewness of exchange rate returns;
- and the occurrence of currency crashes.

Our Paper

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- differences in the cross-sectional skewness of exchange rate returns;
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We present a stylized two-country model that rationalizes the findings above.

Model Setup

Two-countries $\{i, j\}$ with N citizens, $N = 1$.

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Agents in country i have a production function that generates:

$$f(m_{i,t}) = A_{i,t} \ln(m_{i,t})$$

— $A_{i,t}$: stochastic marginal productivity, known at time t where $A_{i,t} = \overline{A} - \alpha\left(A_{i,t-1} - \overline{A}\right) + \epsilon_{i,t}$ and $\epsilon_i \sim N\left(0, \sigma^2_{A_i}\right)$

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Agents in country i have a production function that generates:

$$f\left(m_{i,t}\right) = A_{i,t} \ln\left(m_{i,t}\right)$$

- $A_{i,t}$: stochastic marginal productivity, known at time t where $A_{i,t} = \overline{A} - \alpha\left(A_{i,t-1} - \overline{A}\right) + \epsilon_{i,t}$ and $\epsilon_i \sim N\left(0, \sigma^2_{A_i}\right)$

- $m_{i,t}$: real money holdings of country i's currency in period t
- Purchasing power of country i's money in period t is $\pi_{i,t}$:

$$m_{i,t} = M_i \pi_{i,t}$$

Setup

Two other storage technologies in each country:

- Risk-free asset with real return r_f

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OG model:

- Agents live two periods, invest when young and consume when old.
- CARA-utility function: $u\left(c_{t+1}\right) = -E_t e^{-ac_{t+1}}$
- Financial markets are segmented:
  - $(1-k_i)$ of country i's investors are “domestic".
  - k_i of country i's investors are “speculators”.

Setup

Investors face time-varying borrowing constraints:

— $b_{i,t}$ is the quantity of country i's bonds that an agent purchases (or sells) in period t.

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Setup

Investors face time-varying borrowing constraints:

- $b_{i,t}$ is the quantity of country i's bonds that an agent purchases (or sells) in period t.
- Agents can only borrow $h_{i,t}$ of currency i: $b_{i,t} \geq -h_{i,t}$.
- We assume that there is funding risk:

$$h_{i,t+1} = \overline{h} - \alpha \left(h_{i,t} - \overline{h} \right) + \delta_{i,t+1}$$

where $h_{i,t} > 0$, $\delta_{i,t} \sim N\left(0, \sigma_h^2\right)$, and $\delta_{i,t}$ independent of $\epsilon_{i,t}$.

The Equilibrium

Constrained $(1 - k_i)$ "domestic investors":

$$\underset{m_{i,t}, b_{i,t}}{Max} - E_t e^{-ac_{t+1}}$$

$$c_{t+1} = \left(w_t - m_{i,t} + p_{i,t} \frac{m_{i,t}}{\pi_{i,t}}\right)(1 + r_f) + f(m_{i,t}) + b_{i,t}\left(\pi_{i,t+1} - p_{i,t}(1 + r_f)\right)$$

$$b_{i,t} \geq -h_{i,t}$$

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$$b_{i,t} \geq -h_{i,t}$$

Unconstrained k_i "speculators":

$$\underset{m_{i,t}, b_{i,t}. b_{j,t}}{Max} - E_t e^{-ac_{t+1}}$$

$$c_{t+1} = \left(w_t - m_{i,t} + p_{i,t} \frac{m_{i,t}}{\pi_{i,t}}\right)(1 + r_f) + f(m_{i,t}) + \sum b_t\left(\pi_{t+1} - p_t(1 + r_f)\right)$$

$$b_{i,t} \geq -h_{i,t}, \quad b_{j,t} \geq -h_{j,t}$$

The Equilibrium

Solving for the Equilibrium

First order conditions with respect to b's and m's determine the equilibrium interest rates and currency exchange rates.

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Sharpe ratio for the real returns on bond investments:

$$SR_{i,t} = a\sigma_i M_{i,t}^d$$

- In autarky $M_{i,t}^d = \overline{M}_i$ and per capita inflation risk is $\sigma_i \overline{M}_i$.

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- In autarky $M^d_{i,t} = \overline{M}_i$ and per capita inflation risk is $\sigma_i \overline{M}_i$.

Let $H(L)$ be the country with higher (lower) inflation risk.

- Higher SR in H: speculators are always long in bonds.
- Borrowing constraint only potentially binding for L bonds.

The Equilibrium

Solving for the Equilibrium

BC not binding

- Domestic investors' holdings are strictly positive and speculators always go long in country H's bonds
- For ρ (k_L) high (small) enough, speculators short L bonds.

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Solving for the Equilibrium

BC not binding

- Domestic investors' holdings are strictly positive and speculators always go long in country H's bonds
- For ρ (k_L) high (small) enough, speculators short L bonds.

BC binding in L

- For sufficiently low $\overline{h}$ and σ_h, there is a carry trade constrained equilibrium.
- Funding constraints decrease $b^s_{H,t}$ and increase $b^s_{L,t}$.

Model Predictions

H1. Currency variance is higher in the constrained equilibrium.

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Model Predictions

H1. Currency variance is higher in the constrained equilibrium.

H2. The correlation between carry funding and carry investment currencies is lower due to funding risk.

H3. Tightening of funding conditions is associated with exchange rate skewness and currency crashes.

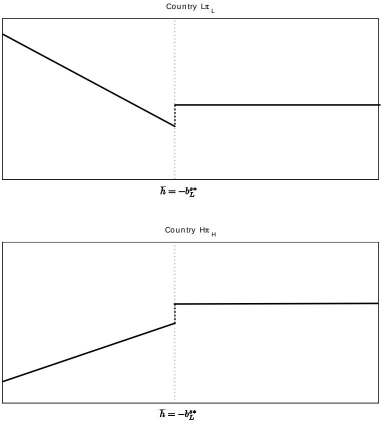
H4. Funding risk affects speculators' positions (effect is higher for investment currencies).

H5. An increase in funding risk is associated with poor carry trade returns.

Model Predictions

Consider naïve agents who believe that constraints always bind/do not bind.

Then there is a regime switch where the constraint starts binding.



Carry Trade Returns

Currency Data

Exchange rate data:

- Sample period: January 2000 - December 2011
- Daily spot rates and 1-month forward rates (expressed as foreign currency units per USD)
- Currencies of ten developed countries: AUD, CAD, DKR, EUR, JPY, NZD, NKR, SEK, SWF and UKP
- Source: Datastream

Carry Trade Returns

Portfolio returns

Four portfolios:

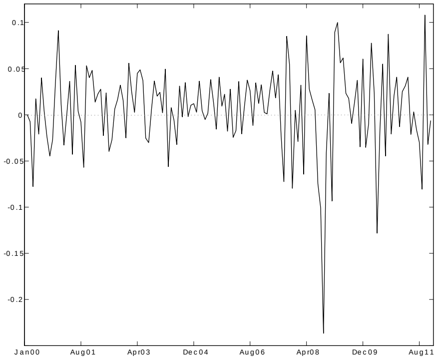
- *HML*
- *HML3*
- *HML5*
- *AUD/JPY*

Carry Trade Returns

Portfolio returns

Four portfolios:

- *HML*
- *HML*3
- *HML*5
- *AUD*/*JPY* ⟵



Funding Risk

Stock Market Options Data

European options of stock market indices:

- End-of-day data on put options traded in local currency.
- Stock market indices of four countries:
  - US (S&P500), the benchmark country
  - Japan (Nikkei225), the typical funding country
  - Switzerland (SMI50), usually also a funding country
  - Australia (S&P/ASX200), the typical investing country
- Source: Thomson Reuters

Funding Risk

Estimating Funding Risk

We assume funding countries' equity capital determines agents' funding conditions.
→We look at the funding countries' equity market risks

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→We look at the funding countries' equity market risks

Even though crashes rarely materialize in-sample, we can use option markets to infer the probability of crashes.
→We look at implied volatility and crash risk in equity index options from different countries (Japan, Switzerland, US, Australia).

Funding Risk

Estimating Funding Risk

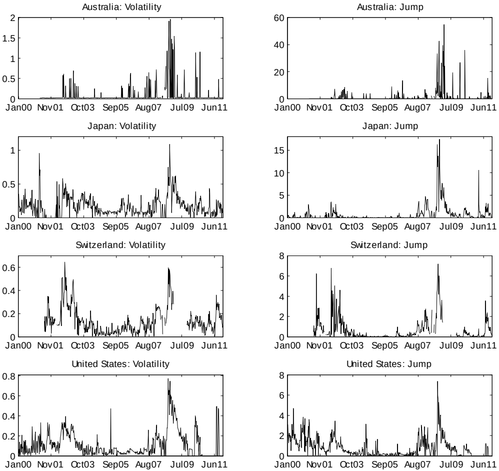
We follow Santa-Clara and Yan (2010) and, for each country, we model the stock market index as:

$$\begin{aligned} dS &= \left(r + \phi - \lambda \mu_Q\right) S dt + Y S dW_S + Q S dN \\ dY &= \left(\mu_Y + \kappa_Y Y\right) dt + \sigma_Y dW_Y \\ dZ &= \left(\mu_Z + \kappa_Z Z\right) dt + \sigma_Z dW_Z \\ \ln\left(1+Q\right) &\sim N\left(\ln\left(1+\mu_Q\right) - \frac{1}{2}\sigma_Q^2, \sigma_Q^2\right). \end{aligned}$$

where N is a Poisson process, $v = Y^2$, and $\lambda = Z^2$.

Funding Risk

Estimating Funding Risk



Predictions and Empirical Results

Currency Volatility

Explaining currency volatility with funding risk:

$ln(FX^{\sigma})$	(1)		(2)		(3)		(4)	
	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat
λ^{JP}	0.1099**	6.46	—		—		0.0728**	4.10
$\sqrt{\nu}^{JP}$	0.2603	0.83	—		—		0.1749	0.59
JP Fin.	—		-0.0952**	-3.21	—		-0.0755**	-3.43
TED	—		—		0.2317*	2.31	0.1180*	2.31
const.	-5.1784**	-97.89	-4.7104**	-34.97	-5.1698**	-94.23	-4.9334**	-64.3
$Adj.R^2$	46.29%		18.61%		17.79%		54.37%	
VIF	[1.78]						[2.99]	

Predictions and Empirical Results

Correlations

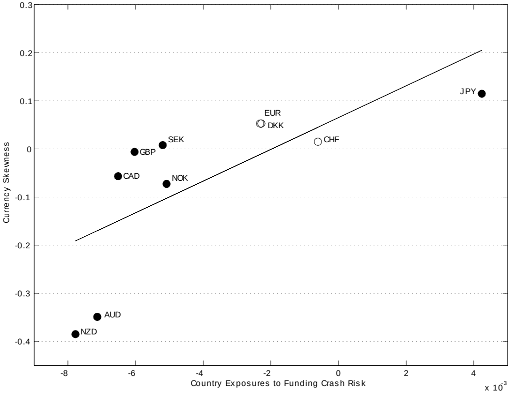
Explaining the correlation between AU and JP with funding risk:

AU/JP	(1)		(2)		(3)		(4)	
	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat
λ^{JP}	-0.1300**	-3.58	—		—		-0.0673*	-2.16
$\sqrt{\nu}^{JP}$	0.0384	0.10	—		—		0.0432	0.13
JP Fin.	—		0.0501	1.25	—		0.0507	1.92
TED	—		—		-0.3542**	-5.07	-0.2577**	-3.26
const.	0.2885**	3.16	0.0162	0.11	0.3893**	5.41	0.2056	1.90
Adj.R²	23.10%		1.86%		20.28%		28.45%	

Predictions and Empirical Results

Exchange Rate Skewness

Currency skewness and country exposures to funding risk:



Predictions and Empirical Results

Currency Crashes

Explaining large currency movements with funding risk:

	(1)		(2)		(3)		(4)	
	Coef.	z-stat	Coef.	z-stat	Coef.	z-stat	Coef.	z-stat
$\Delta\lambda^{JP}$								
L0.	0.9148**	2.63	—		0.6522*	2.08	1.9317**	3.48
L1.	0.1834	1.68	—		—		1.0221*	2.49
L2.	0.3421**	2.56	—		—		1.4137**	2.97
L3.	0.6614*	2.29	—		—		1.8674**	4.16
ΔTED								
L0.	—		2.3471*	2.50	1.5774*	2.40	3.3636	1.82
L1.	—		1.7988**	3.12	—		0.1328	0.14
L2.	—		0.6304	1.63	—		-3.4263*	-2.05
L3.	—		0.3573	0.38	—		-3.2563*	-2.36
const.	-1.5650**	-8.66	-1.4450**	-6.03	-1.5601**	-7.47	-2.1882**	-5.75
$Pseudo R^2$	26.82%		29.52%		30.23%		54.12%	

Predictions and Empirical Results

Speculative Activity

As proxy for carry trade activity, we use the futures position at weekly frequency (source: CFTC).

Explaining futures AU-JP with funding risk:

	(1)		(2)		(3)		(4)	
	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat
λ^{JP}	-0.0353**	-4.64	—		—		-0.0046	-0.52
$\sqrt{\nu}^{JP}$	-0.9380**	-8.85	—		—		-0.7309**	-6.90
JP Fin.	—		0.0010**	10.13	—		0.0009**	7.65
TED	—		—		-0.1515**	-6.10	-0.1291**	-3.97
const.	0.4861**	21.31	-0.0938**	-2.58	0.3518**	19.83	0.1825**	4.31
$Adj.R^2$	27.59%		17.53%		5.50%		36.45%	

Predictions and Empirical Results

Speculative Activity

...and explaining future positions in individual currencies:

	Futures AUD		Futures GBP		Futures CHF		Futures JPY	
	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat
λ^{JP}	-0.0128**	-2.82	-0.0259**	-4.60	-0.0145*	-2.23	0.0251**	4.22
$\sqrt{\nu}^{JP}$	-0.5371**	-8.10	-0.3860**	-5.07	0.1499	1.44	0.3605**	4.31
const.	0.3868**	26.58	0.1027**	5.62	-0.0815**	-3.74	-0.1011**	-5.91
$Adj.R^2$	14.80%		10.64%		0.31%		11.59%	

Predictions and Empirical Results

Carry Trade Returns

To investigate the explanatory power of funding risk to carry trade returns, we decompose λ and ν into expected and unexpected components:

- Fit an AR(3) model
- Expected component: fitted values λ^e and ν^e
- Unexpected component: residuals λ^u and ν^u

Predictions and Empirical Results

Carry Trade Returns

Strategy	AUmJP		HmL		HmL3		HmL5	
	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat
λ^{s}	0.0168**	2.95	0.0148*	2.40	0.0106**	2.83	0.0050*	2.02
$\sqrt{\nu^{s}}$	0.0761	1.34	-0.0121	-0.23	0.0330	0.97	0.0164	0.67
λ^{u}								
L0.	-0.0670**	-8.55	-0.0576**	-8.48	-0.0344**	-7.39	-0.0222**	-6.84
L1.	-0.0214*	-2.38	-0.0281**	-2.98	-0.0167**	-2.68	-0.0058	-1.55
L2.	-0.0367**	-4.48	-0.0413**	-4.66	-0.0175**	-3.90	-0.0058*	-2.22
L3.	-0.0110*	-2.17	-0.0184**	-2.65	-0.0137**	-3.25	-0.0073**	-2.67
$\sqrt{\nu^{u}}$								
L0.	-0.2586*	-1.96	-0.0033	-0.03	-0.0901	-1.12	-0.0813	-1.59
const.	-0.0217*	-2.17	-0.0032	-0.35	-0.0110	-1.89	-0.0049	-1.22
Adj. R^2	42.25%		36.30%		33.65%		35.55%	

Conclusion

Carry trade funding risk is an importante determinant of currency rates, their skewness and volatility.

Funding risk affects speculative activity and speculators' returns from carry trading.

It is the funding risk from short-carry currencies (Japan and, to a lesser extent, Switzerland) that matters most.

Conclusion

THANK YOU FOR YOUR ATTENTION!

Currency Carry Trades and Funding Risk

Sara Ferreira Filipe & Matti Suominen

Discussion by

Masahiro Watanabe, *University of Alberta*

IRF Conference

Tokyo, July 3, 2013

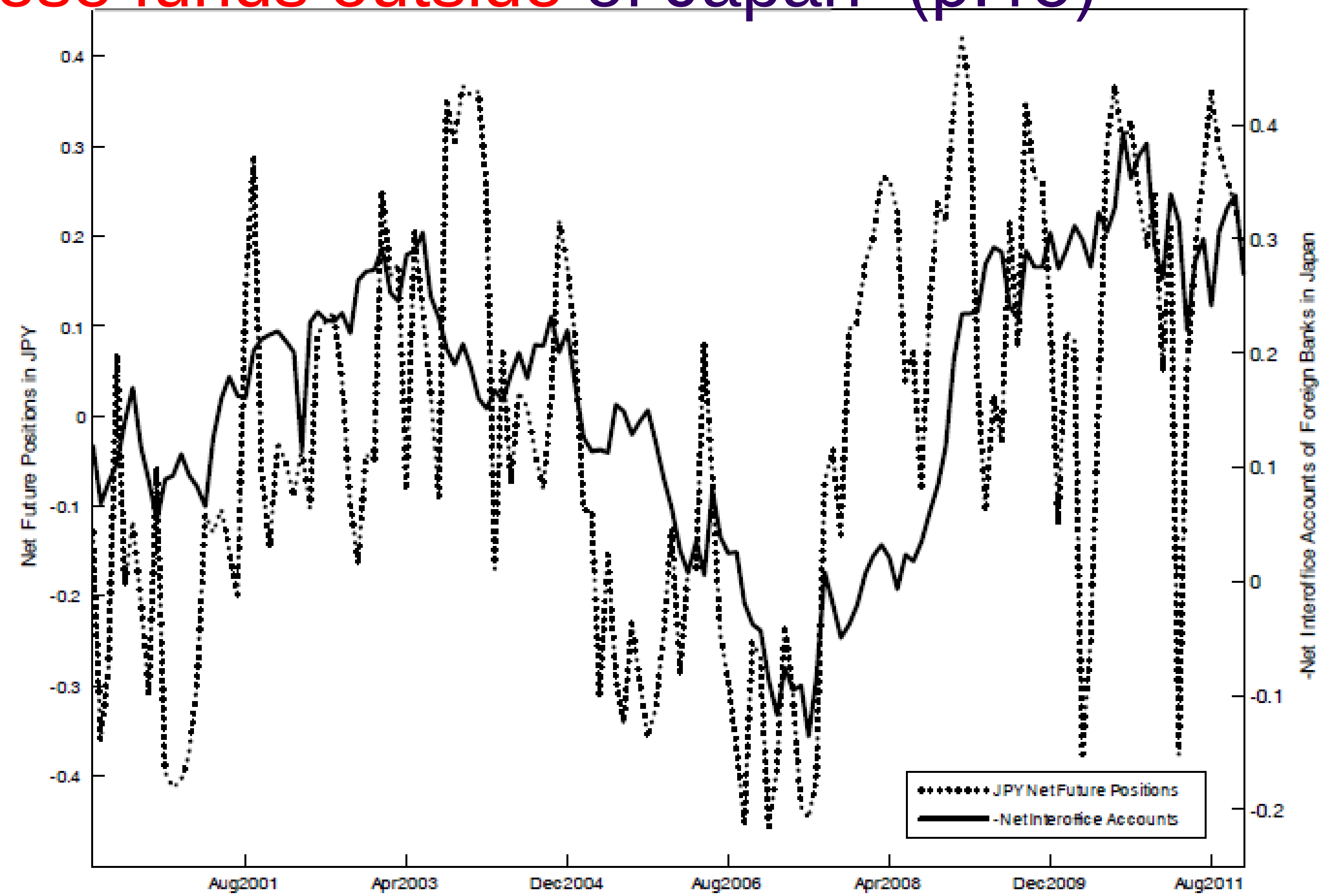
Summary

- Funding risk in Japan explains 42% of monthly FX carry trade returns 2000-2011
- Explains 46% of monthly FX volatility of ten main currencies
- 28% of the speculators' net currency futures positions in AUD and JPY
- Explains skewness and currency crashes
- Presents a theoretical model for support

- I find these results nice, plus the followings:

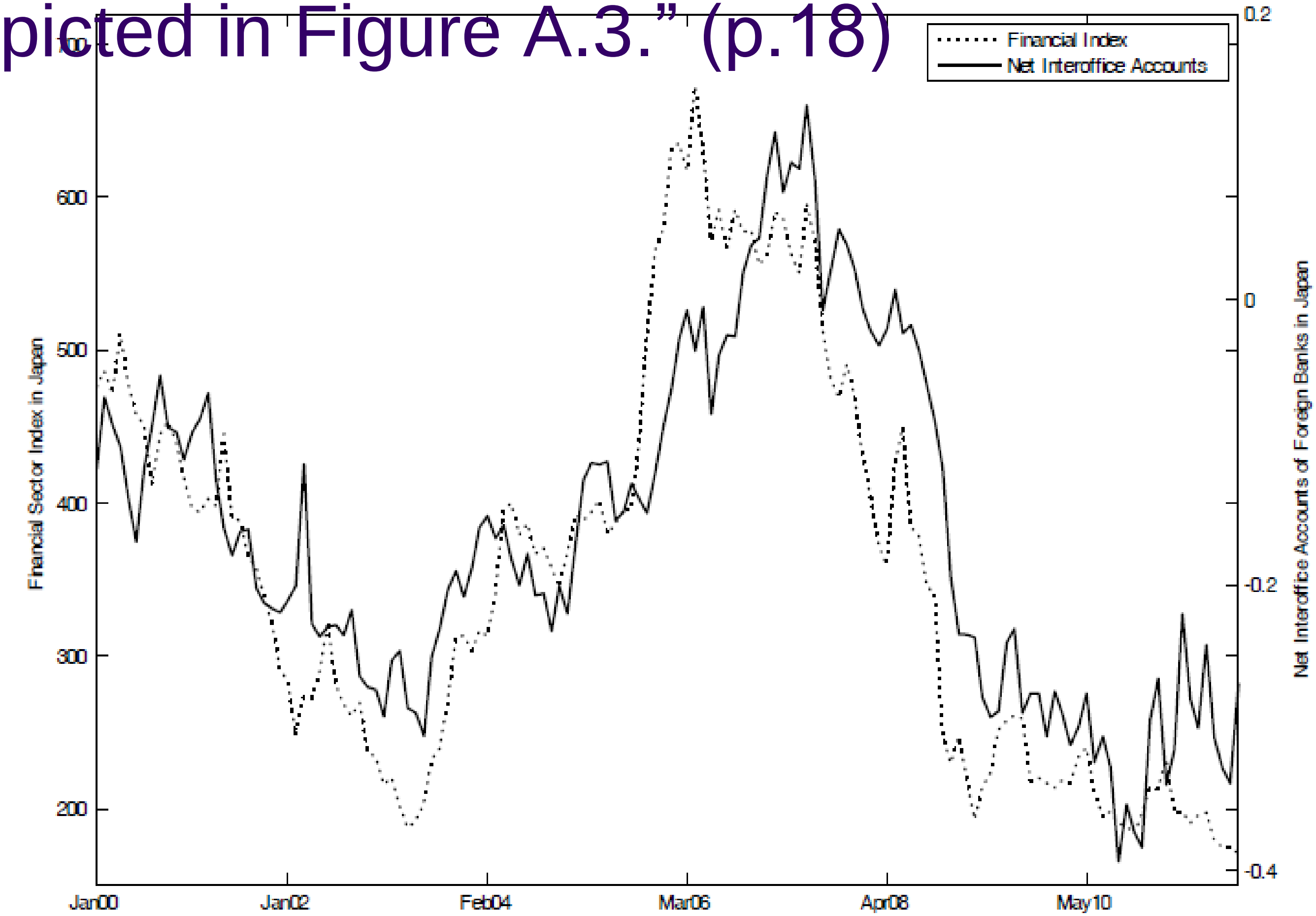
JPY Futures Position & Net Interoffice Accounts of Foreign Banks in Japan

- "… we observe foreign banks borrowing in the Japanese interbank market and then sending these funds outside of Japan" (p.18)



JP Fin. Sector Index & Net Interoffice Accounts of Foreign Banks in Japan

- "We find a striking relation between the equity prices of Japanese financial institutions and their yen lending to foreign financial institutions, as depicted in Figure A.3." (p.18)



On The Empirics

- Measure of funding constraint
  - Can stock index and options measure something else than funding risk?
- US TED spread and the Japanese financial sector index do much worse
  - How about a Japanese equivalent of the TED spread?
  - A more direct measure?
- Is it possible to perform a structural estimation of the model (given that you do have one)?

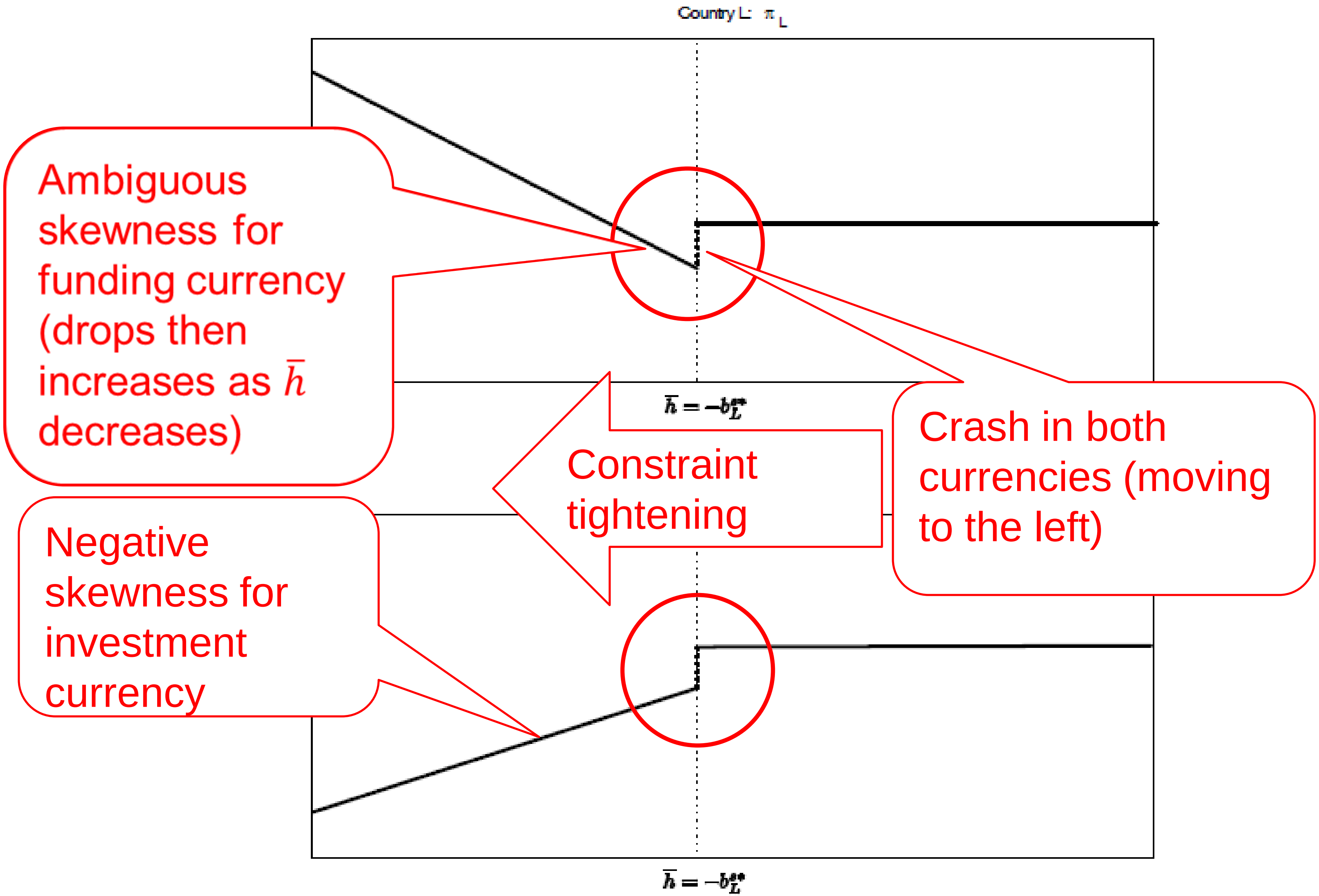
On Theory: FX Volatility

- Prediction: FX volatility is higher:
  - when borrowing constraint is binding
  - under higher funding risk
- Intuitive
- But this requires the borrowing constraint to be time-varying
- Motivated e.g. by downward liquidity spiral (Brunnermeier & Pedersen (2009))
- In model, tightening & loosening of constraint equally contributes to currency volatility ($Var_t(\pi_{t+1})$ in Eq(20) invariant to sign of shock)

Skewness and Crashes

- Hypothesis 3: “Tightening of funding conditions is associated with exchange rate skewness and currency crashes”
- “Crashes” or “regime switch” are the result of ignoring the possibility of binding constraint when unconstrained, and vice versa
- Really the constraint should smoothly bind
- Authors do recognize this ignorance (Footnotes 4 & 5)

Figure 1: Purchasing power & constraint



More on Approximation

- Beyond the standard practice of allowing negative prices, some quantities can be negative ratios
- π_L and π_H can be negative due to CARA-normal
- $S^{L,H} = \pi_L / \pi_H$ can be negative and large, in particular when constrained
  - Ratio of normals (Fieller-Hinkley distribution)
- OLG stationary?

Speculators’ Positions

- Hypothesis 4: “The level of funding conditions and funding risk affect speculators’ positions”
- Would you reword this (more informative than “affect”)?

Currency trade returns

- Hypothesis 5: “Tightening of funding constraints, or an increase in funding risk, is associated with poor carry trade returns”
- Nice
- If the constraint binds smoothly:
  - Would the carry trade return also decrease smoothly without a crash?
  - Would the funding currency have unambiguously positive skewness?

Minor Comments

- Moneyness is defined as “stock price divided by the strike price” (p.16). This is for calls, but authors “use only put options and apply option parity to obtain the corresponding call prices.” Moneyness for which options?
- Confusing notation: λ is used as both the Lagrange multiplier and empirical jump intensity

Conclusion

- Empirical result is very convincing
- Theoretical model is full fledged
- Some minor gap between them, but perhaps such a complaint is too demanding
- Recommended reading on carry trades