WHAT CARRIES THE CARRY TRADE?*

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Abstract

We build a partial equilibrium model to explain the carry trade and its eventful unwinding. We treat the foreign currency from a pure financial asset point of view. Collateral capacity of the carry trade positions entices traders to enter the speculation in our model and causes the deviation from the uncovered interest parity. We theorize that the leverage cycle is one possible source of the time-varying risk premium for holding the foreign currency. Empirically, we support our model prediction by showing that the carry trade is pervasive as the market-wide credit spread reverts to its long-run mean and that the carry trade unwinds when the credit spread is exogenously spiked.

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1 Introduction

The unraveling of the global financial crisis in 2008 also featured an unprecedented exchange rate movement, notably the dramatic appreciation of the Japanese yen. Figure 1 shows the sharp strengthening of the yen against the dollar in October 2008. The yen appreciation is understated in Figure 1 since the dollar itself also appreciates sharply against the majority of the world currencies at that time. Such a dramatic movement of the yen not only has eminent impact on the export-relying Japanese economy, but also rattles the global financial markets. It is because the yen is at the center of a specific type of currency speculation, called the carry trade. The low interest-rate environment in Japan has been providing the global financiers a low-cost funding. Said yen appreciation puts a burden on already stressed debtors all over the globe as it enlarges their liabilities. Once they rush to pay back their debts by buying up the yen, they run into a downward spiral because their collective purchase of the yen appreciates the currency further. The unprecedented swing of the yen thus calls for a better understanding of why and when the carry trade emerges.

A simple example of the carry trade is to borrow the low-interest Japanese yen, convert the proceeds to the high-interest dollar deposits, and reverse the sequence at the end of the investment horizon. To fixate the idea, let us denote the home country as Japan and the foreign country as the U.S[1]. It is profitable as long as the appreciation of the low-interest yen does not erase the gain from the interest rate differential. If the yen instead depreciates in the duration, the speculation is even more profitable. The speculation has been known to academics and practitioners at least as far back as the paper on the random-walk dominance in exchange rate predictions by Meese and Rogoff (1983). Without surprises, the practitioners in foreign exchange markets have been exploiting the carry trade. For example, Deutsche Bank has an index tracking a hypothetical carry trade portfolio (G10 Currency Future Harvest Index) since 1993.

Unfortunately, it is very difficult to document the exact volume and flow of the carry trade for at least two reasons: the majority of currency trades are conducted in the fragmented over-the-counter markets and there are no official reporting requirements for the cross-border transactions. Galati et al. (2007), for example, attempt to document the carry trade, but can only provide indirect evidence, such as profitability of the carry trade and risk-reversal. Risk-reversal compares to two similar out-of-money currency options and reveals the carry trade risk perceived by traders. On top of such documentation difficulties, there is not yet an agreed-upon definition of the carry trade. Gagnon and Chaboud (2007), in another attempt to document the carry trade, divide carry trades into two general categories. The canonical carry trade represents the ordinary borrowing and lending scheme discussed above. The derivatives carry trade is the term used to describe a speculation in which currencies at a forward premium are sold up-front, either through over-the-counter forward contracts or exchange-traded futures, and deliveries are done by spot-market

[1]Such designation does not have any country-specific preferences. It only helps the discussion as Japan is often the source of the carry trade funding, while the U.S. is not necessarily the destination of the carry trade money. High interest-rate countries, such as Australia and New Zealand, are more likely to receive the speculative capital inflow.

purchase when contracts expire. As long as covered interest parity[2] holds, the two schemes render identical results. Outside these two categories, Hattori and Shin (2007) argue that the inter-office loans of the multinational banks operating in Japan can also be classified as the broad yen carry trade[3]. Relying on others' documentation of the carry trade, we try to in our paper show a model that can capture the ups-and-downs of the speculation. The particular periods of carry trade unwinding that are reported and interest us are October 1998 (following LTCM crisis), May 2006 and February 2007 (during the subprime mortgage crisis), and October 2008 (the current ongoing crisis).

The carry trade is synonymous with the violation of uncovered interest parity (UIP) hypothesis. By an *ex ante* no-arbitrage condition, UIP says that holding the high-interest dollar must be negatively compensated by the expected depreciation of the dollar. UIP hypothesis has not been shown to be empirically valid. Instead of depreciating, the high-interest dollar tends to appreciate. Such a currency movement is favorable to the carry trade speculators. On average, the carry trades are profitable. The long-lasting excess returns from conducting the carry trade only makes the empirical anomaly more puzzling[4].

Empirical testing with rational expectation restriction often works on the regression of exchange rate changes on interest rate differentials. If the UIP hypothesis holds, the coefficient estimates should be no different from one. In a survey paper, Engel (1996) reports that the coefficient estimates in the majority of empirical studies are not only significantly different from one, but also shown to be negative. Hence the puzzle. Endeavors to explain the puzzle are abundant. Excess returns from any investment strategy often mean there is either an exceptional capability of the investor or a risk premium demanded by the investor. For the former, excess returns tend to go away as the market participants learn to mimic the proprietary trading and bid down the profits. On the other hand, excess returns associated with risk premia last for a long period of time. Since excess returns from conducting the carry trade do not go away with time, researchers naturally turn to the risk-premium explanation. Those attempts seem to hit an insurmountable obstacle, however.

Fama (1984) first shows that volatility of excess returns is larger than that of the expected exchange rate changes if the empirical regularity of the forward premium puzzle persists. Using both partial and general equilibrium models with representative agents, Lewis (1995) further shows that to explain the puzzle with a risk premium, the risk aversion level of the agents have to be unreasonably high. In this sense, the forward premium puzzle can be seen as a version of the

[2] The difference between the forward and the spot rates has to be identical to interest rate differential after accounting for transaction costs. It is called covered interest parity because every piece of information is known to investors at the time when the contract is written. It has, and have been shown empricially, to hold to rule out arbitrage opportunities.

[3] Gagnon and Chaboud (2007) go as far as claiming that any person or institution holding yen debts and foreign assets can be said to be conducting the yen carry trade. In such a view, Bank of Japan should be one of the largest carry traders.

[4] The violation of the UIP hypothesis is also known as the forward premium puzzle. If we replace the interest rate differential with the forward premium according the covered interest parity, it is clear why the puzzle is so named: the currency at a forward premium tends to depreciate.

equity premium puzzle popularized by Mehra and Prescott (1985). Given such difficulties with the risk-premium explanation, researchers turn to other micro-based explanations, such as the peso problem and learning (Lewis 1995) and adverse selection (Burnside et al. 2007). However, these attempts only help explain the puzzle over a short period of time. They cannot explain why excess returns are not exploited away by other, smarter investors. For the latest review of this line of literature, please see Chinn (2006).

Another way to look at the violation of UIP hypothesis is for traders to have persistent forecast errors. The authors of this line of papers believe the violation of UIP might only be a result of imperfect empirical exercises. Replacing the expectation of future exchange rates with *ex post* realizations plus a mean-zero forecast error term is consistent with rational expectation, but rules out the possibility of market participants' systematic forecast errors. The systematic forecast errors can come from traders' limited capacity to process every piece of news in the market, as in Bacchetta and van Wincoop (2008). It can also come from traders' aversion to ambiguity, as in Ilut (2008). However, the fact that market participants do not have the learning ability to correct their own past mistakes makes this type of arguments less convincing. It also cannot explain why there is no one in the market trying to exploit traders' systematic forecast errors.

The risk-premium explanation, together with the representative agent framework, seems to be the baby thrown out with bath water. There are continuous efforts by various authors to revive the risk-premium explanation to the forward premium puzzle. McCallum (1994), for example, explains the violation of UIP with the interaction of the exchange rate risk premium and the monetary policy rule. A more promising attempt is from Robert Barro. In Barro (2006), he reinvestigates risk premia from the angle of rare disasters, which is first proposed by Rietz (1988). They both have successfully explained the equity premium puzzle. Farhi and Gabaix (2008) successfully extend the idea to other international finance puzzles that include the forward premium puzzle. In Lustig et al. (2008), they propose a risk factor that has shown to explain the cross-country variations of carry trade returns. Together with one other country-specific risk factor, they show that carry trade returns are highly predictable in a multi-factor asset pricing model. That in turn supports the time-varying risk premium explanation for the carry trade's excess returns.

As the UIP literature converges on the time-varying risk premium explanation, we contribute to it by proposing one possible source of the time-varying risk premium: the leverage cycle. As Darvas (2009) points out, carry trades are often conducted with leverage in practice. Traders often supply only a small portion of their own capital. The returns on carry trade strategy can thus be magnified as long as traders have maintained the margin requirement. Darvas (2009) also shows that the leveraged carry trade portfolios indeed have greater profitability than those unleveraged ones, which are also discussed in Burnside et al. (2008), Jurek (2008) and Brunnermeier et al. (2008). The superiority, in terms of Sharpe ratio, of leveraged carry trade portfolios, however, is paid for with a high downside risk. Highly leveraged portfolios are sometimes completely liquidated when the extreme exchange rate movements are not in favor of the traders. The only theoretical carry trade model that incorporates leverage is Plantin and Shin (2008). They theorize a tension between positive and negative externalities of the increased amounts of carry trades. When there are more carry trades, traders create positive externalities because the simultaneous bets depreciate the yen. On the other hand, the depreciation of the yen also generates negative externalities since it also represents further deviation from the UIP hypothesis fundamental. The liquidity constraint, which represents the ability traders can borrow and is also synonymous with leverage, will eventually make the negative externalities outweigh the positive ones and force the unwinding of the carry trade.

Our modeling concept is from John Geanakoplos's long-term work on the leverage cycle. The culmination of his work, Fostel and Geanakoplos (2008), provides us with a fresh look at the carry trade. That financial assets' collateral capacity affects economic cycles is not new. Kiyotaki and Moore (1997), for example, show that the interaction between collateral capacity and asset prices can prolong, amplify, and propagate shocks. The novelty in Fostel and Geanakoplos (2008) is that collateral capacity is not a fixed ratio, but a time-varying variable that exhibits cyclical behavior. According to Geanakoplos, financial assets derive values not only from their fundamentals, such as future cash flows, but also from their capability to serve as collateral. The fluctuation of the collateral capacity constitutes the leverage cycle. Due to the pro-cyclical nature of the leverage cycle, price fluctuations of financial assets exacerbate. In our model, we show that the violation of UIP hypothesis is the equilibrium result. So is the unwinding of the carry trade. Without collateral capacity, carry trade positions, by UIP, have no values and no traders will enter the speculation. Simply because the positions themselves can serve as collateral, they are valuable *ex ante* and hence it is optimal for traders to hold such positions. UIP need not hold in the world with the leverage cycle. Since collateral capacity varies over time, a big, adverse movement of the leverage cycle can force traders to liquidate their positions and put the low-interest currency into an appreciation spiral, in a similar fashion as in Plantin and Shin (2008). Unlike their game-theoretical approach, ours has a tractable framework. We incorporate the market-wide credit spread as the driving variable of the leverage cycle. We will show that the mean-reverting credit spread drives the leverage cycle and the exchange rate movements in both reduced-form regressions and vector autoregressive analyses. To emphasize the impact of the leverage cycle and simplify the derivation, we stay clear from the macroeconomic view of exchange rates. Although we have a point of contact with that literature in interest rates, we treat them as exogenous variables. Our model is then a partial equilibrium.

2 A Partial-Equilibrium Carry Trade Model

2.1 Collateral in the Budget Constraint

The sector demanding financial assets in the economy is the trader sector whose members are homogeneous with utility function defined over current and future values of consumption,

$$U = E_t \sum_{i=0}^{\infty} \beta^i \frac{C_{t+i}^{1-\gamma}}{1-\gamma}, \tag{1}$$

where β is the discount factor capturing traders' impatience and γ is their risk aversion coefficient. The representative trader has endowment $(y_{t+i})_{i\geq 0}$ for each period and chooses consumption $(C_{t+i})_{i\geq 0}$ to maximize utility (1). Both endowment and consumption are of the same good. The trader can consume the good, save it in a bank to earn an risk-free interest at rate i_t^f, or purchase a financial asset. The financial asset is sold by creditors, which is a sector consisted of homogeneous representative creditors that will be discussed separately. The trader can acquire the financial asset with cash or on margin. However, for reasons to be explained in the Appendix, the trader can only buy the financial asset on margin. Therefore, he only has two choices for the unconsumed good: save it in the bank or use it as collateral to buy the financial asset. To acquire one unit of the asset, which is priced at p_t at time t, on margin, he has to provide his own good worth of $(1-\phi_t)p_t$ to the creditor. Here prices are in terms of the unit of the good. In other words, he owes $\phi_t p_t$ for every unit of the asset he acquires. $1-\phi_t$ is also known as the margin requirement.

To ease complications of using consumption as the only choice variable, we introduce the asset holding x_t, which is still determined by the consumption choice. The period budget constraint faced by the trader is

$$C_{t+1} \leq y_{t+1} + p_{t+1}x_t(1+D_{t+1}) - p_t x_t(1+i_t)\phi_t - p_{t+1}x_{t+1}(1-\phi_{t+1}), \tag{2}$$

where D_{t+1} is the per-unit dividend of the asset received at time $t+1$. The middle two terms on the right hand side of the budget constraint (2) are the effective unit of the asset holding carried over from the previous period, net of the payback. The trader posts $p_{t+1}x_{t+1}(1-\phi_{t+1})$ as collateral to acquire x_{t+1} units of the asset for consumption at time $t+2$. Here interest rate i_t is the real, effective rate the trader is facing. As stated before, the domestic risk-free rate will be denoted as i_t^f. We assume interest rates are exogenous. In Figure 2, we illustrate the trader's actions in a particular time interval. The margin requirement, or collateral, in this economy is different from the concept in stock markets. It is close to the margin requirement in currency trading. $p_t x_t(1-\phi_t)$ is not an amount set aside at time t as a protection to the creditor in case the trader defaults at time $t+1$. It is part of the transaction and will not be returned to the trader when the contract expires. What the trader gets in return at time $t+1$ is the asset he purchases at time t less the gross owed amount, exactly the middle two terms on the right hand side of the budget constrain (2).

Since it is not optimal to leave the good unconsumed, we substitute the binding constraint (2) into the objective (1) and take first order derivatives with respect to x_t to get the financial asset pricing formula,

$$p_t = \frac{\beta E_t[C_{t+1}{}^{-\gamma} \cdot p_{t+1}(1 + D_{t+1})]}{C_t^{-\gamma}(1 - \phi_t) + (1 + i_t)\phi_t \beta E_t C_{t+1}^{-\gamma}} \tag{3}$$

In a world where the trader is not allowed to buy the asset on margin, the price of the asset is determined by its payoff value $p_{t+1}(1+D_{t+1})$ and the marginal rate of substitution between current and future consumption, i.e.

$$PV_t = \beta E_t[(\frac{C_{t+1}}{C_t})^{-\gamma} \cdot p_{t+1}(1 + D_{t+1})], \tag{4}$$

where PV_t can be seen as the counter-factual, fundamental price of the asset. Although Equation (4) is formally obtained by setting $(\phi_{t+i})_{i\geq 0} = 0$, it has the spirit of the standard dividend discount model of asset pricing. We cannot, however, directly observe whether p_t is greater than PV_t. Later in Proposition 1 (to be completed), we will prove that p_t will be greater than PV_t. The result can roughly be translated into this statement: an asset is more valuable than its present value-justified value simply because it can be used as collateral.

Equation (3) describes the trader's behavior and will eventually be the backbone of the demand for the financial asset. Regardless of the types of the asset, the pricing formula must be satisfied. If there are two classes of assets available, the marginal utilities of holding these assets should be equal on the margin. In this economy, there are two types of assets to be priced: a risk-free bond and a foreign risky bond.

Pricing of Bonds

The portion the trader choose to save in the bank can be viewed as the purchase of a bond with floating rates. For any floating-rate bonds, they are priced at the notional amount. Therefore, the deposit of one unit of the good is priced as 1 at any time. The dividend is then the interest i_t. With these two pieces of information, we can price the bond according to the financial asset pricing formula (3). That is,

$$1 = (1 + i_t)\beta E_t[(\frac{C_{t+1}}{C_t})^{-\gamma}]. \tag{5}$$

Note that we use the fact that $\phi_t = 0$ for the bond's non-marginal trading nature. It is redundant to acquire the floating bond on margin, since what the trader receives as the financial asset is also the same good as the margin requirement he posts. However, Equation (5) is not adequate for the trader because he does not have the same credit level as a risk-free borrower. The trader has either to deposit more to receive the same amount of interests or get the lower, but risk-free deposit rate:

$$\frac{1}{\omega_t} = (1 + i_t)\beta E_t[(\frac{C_{t+1}}{C_t})^{-\gamma}]$$

or

$$1 = (1+i_t^f)\beta E_t[(\frac{C_{t+1}}{C_t})^{-\gamma}],$$

where $\omega_t(\equiv \frac{1+i_t^f}{1+i_t})$ is time-varying and a number less than 1 that denotes the hair-cut the trader has to concede. Defining credit spread between risk-free rate and the rate the trader can get as $CS_t \equiv i_t - i_t^f$, we get

$$CS_t = \frac{1}{\omega_t} - 1. \tag{6}$$

Later in discussion of the supply side, we will have some more assumptions about the deposit.

Foreign Bond as the Financial Asset

We assume the foreign bond is one of the only two financial assets that the trader has access to. Assuming foreign interest rate $i_t^* > i_t$, we specify that the trader acquires one unit of the foreign bond and the payoff of the foreign position next period is

$$p_{t+1}(1+D_{t+1}) = (1+i_t^*)S_{t+1}$$

where S_{t+1} is the exchange rate, defined as the number of the domestic currency per unit of the foreign currency. The definition of the exchange rate is in the international finance convention, in which an increasing number indicates the depreciation of the domestic currency. It is straightforward that the exchange rate is the price of the foreign bond, i.e. $S_t = p_t$.By acquiring the foreign bond on margin, the trader essentially conducts a carry trade. That is, he borrows in the domestic currency, converts the proceeds to the foreign currency, purchases the foreign bond, and sells the foreign bond to get the domestic currency back next period.

Proposition 1 *Deviation from UIP*

We will show here that a carry trade position is valuable ex ante. In other words, deviation from UIP is expected. (to be completed)

Demand for the Foreign Bond

In the economy, only the creditor has the technology to store the domestic good and grow it at the risk-free rate. There is not foreign demand for the domestic good. Therefore, the exchange rate is the exchange values of the foreign bond between the creditor and the trader.

As stated before, the trader will adjust the holding of the risk free deposit and the foreign bond such that marginal utilities are equalized. In this sense, the existence of the risk-free deposit helps determine the demand for the foreign bond. We further assume that the creditor cannot recourse to the trader's other assets[5]. He can confiscate holdings in the trader's account, but no more. Therefore, on the margin, the trader is indifferent between acquiring the financial asset on margin

[5] No-recourse clause is not only required by the Federal governement in the U.S. in the real estate market, but also implicitly practiced in every financial market where there is a margin requirement. Brokers/dealers often use marking-to-market to protect themselves. In FX market, marking-to-market is often conducted more frequently than daily.

or depositing his unconsumed fruit in the bank. In other words, the following two positions must have the same level of marginal utility: depositing $(1-\phi_t)S_t$ in the bank or acquiring one unit of the foreign bond on margin. That is

$$(1-\phi_t)S_t\omega_t(1+i_t)\beta E_t[(\frac{C_{t+1}}{C_t})^{-\gamma}] = \frac{\beta E_t[C_{t+1}{}^{-\gamma}\cdot(1+i_t^*)S_{t+1}]}{C_t^{-\gamma}(1-\phi_t)+(1+i_t)\phi_t\beta E_t C_{t+1}^{-\gamma}}.$$

It implies

$$S_t = \frac{1}{(1-\phi_t)\omega_t(1+i_t)E_t[(\frac{C_{t+1}}{C_t})^{-\gamma}]}\frac{(1+i_t^*)E_t(C_{t+1}{}^{-\gamma}S_{t+1})}{C_t^{-\gamma}(1-\phi_t)+(1+i_t)\phi_t\beta E_t C_{t+1}^{-\gamma}}. \tag{7}$$

Equation (7) is the demand for the foreign bond.

2.2 Clearing the Goods Market

We assume consumption follows a random-walk process with drift to clear the goods market. Specifically, the motion of log consumption can be expressed as

$$\log C_{t+1} = d + \log C_t + u_{t+1}, \tag{8}$$

where the drift term $d \geq 0$ and $u_{t+1} \sim i.i.d.N(o,\sigma^2)$. It implies

$$(\frac{C_{t+1}}{C_t})^{-\gamma} = e^{-\gamma(d+u_{t+1})}.$$

Take expectation to get

$$E_t[(\frac{C_{t+1}}{C_t})^{-\gamma}] = e^{-\gamma d+\gamma^2\sigma^2/2}.$$

Substitute into demand (7) to get the demand function when the goods market clears:

$$S_t = \frac{1}{(1-\phi_t)\omega_t(1+i_t)e^{-\gamma d+\gamma^2\sigma^2/2}}\frac{(1+i_t^*)E_t[e^{-\gamma(d+u_{t+1})}\cdot S_{t+1}]}{(1-\phi_t)+(1+i_t)\phi_t\beta e^{-\gamma d+\gamma^2\sigma^2/2}}. \tag{9}$$

It can be shown that, with certain restrictions on parameters, $\frac{\partial S_t}{\partial \phi_t} < 0$. Intuitively, we can see the result as the following: the more the creditor allows the trader to borrow, the more the quantity of the foreign bond transacted. Since the exchange rate here is simply the relative abundance of the two goods to the trader, higher ϕ_t leads to lower S_t, i.e. domestic appreciation. The transformed demand curve can be best illustrated in Figure 3.

2.3 Risk-Neutral Creditors

The representative creditor, or simply the bank, can be seen as a super bank comprised of a commercial bank sector, a foreign-exchange bank sector, and a central bank sector. He takes deposits from the trader. For simplicity, we assume the trader's deposit earns an interest rate i_t^f, which is also the cost of the bank's funding. It can be seen as the creditor simply passes on the exclusive technology he has to the trader. This assumption eliminates the bank's need to decide whether and by how much he should take deposits from the trader.

The bank is risk neutral. He draws his profits from lending to the trader. Since the trader acquires the foreign bond on margin, the interest accrued on the borrowed amount is the expected profit to the bank. If next period's exchange rate movement is in favor of the trader, the trader will get the gross return on the foreign bond investment, net of payback. The potential cash outflow for the creditor, calculated at time $t+1$ and in terms of the domestic fruit, can be written as

$$S_{t+1} - (1+i_t)\phi_t S_t.$$

Together with the margin requirement the creditor receives from the trader at time t, we derive the potential cash outflow for the creditor as

$$(1-\phi_t)S_t(1+i_t^f) - [S_{t+1} - (1+i_t)\phi_t S_t] = (1 + i_t^f + \phi_t CS_t)S_t - S_{t+1}.$$

Note that collateral earns for the creditor at the risk free rate.

If, however, the trader defaults on his obligation after seeing the adverse movement of the exchange rate, the creditor can confiscate collateral, but cannot reach to the trader's other assets, such as his current and future endowments. Therefore, the creditor is looking at a net gain from trading with the trader by

$$(1-\phi_t)S_t(1+i_t^f).$$

Suppose the level of S_{t+1} that triggers the trader's defaulting is $\overline{S}$. A risk-neutral creditor will equate the potential loss with the potential gain by setting

$$\int_0^{\overline{S}} (1-\phi_t)S_t(1+i_t^f)f(S_{t+1})dS_{t+1} + \int_{\overline{S}}^{\infty} [(1+i_t^f+\phi_t CS_t)S_t - S_{t+1}]f(S_{t+1})dS_{t+1} = 0,$$

where $f(S_{t+1})$ is the unconditional distribution of the time $t+1$ exchange rate. It implies

$$S_t = \frac{\int_{\overline{S}}^{\infty} S_{t+1} f(S_{t+1})dS_{t+1}}{1 + i_t^f + CS_t\phi_t - (1+i_t)\phi_t \int_0^{\overline{S}} f(S_{t+1})dS_{t+1}}. \quad (10)$$

Equation (10) is then the supply of the foreign bond. It can be shown that under certain restrictions, $\frac{\partial S_t}{\partial \phi_t} > 0$.The supply curve is graphed the foreign bond market in Figure 3.

2.4 Clearing the Financial Market

Demand for the foreign bond from the trader equals supply of it from the creditor in equilibrium. Normally, loanable funds are in equilibrium when the interest rate on the funds clears the market. In our model, the supply of the foreign bond is perfectly elastic, i.e. a flat supply curve. The interest rate i_t^* is exogenous. The quantity of the bond flowing from the creditor to the trader is purely determined by the demand for the bond. We have shown that the demand for the foreign bond is endogenously determined by S_{t+1}, ϕ_t, and CS_t. Since the exchange rate in this economy is the relative abundance of the two goods, a higher quantity of the bond changed hand from the creditor to the trader indicates a depreciation of the foreign currency. We can write the demand as

$$S_t^d = g(\phi_t, CS_t, E_t S_{t+1}).$$

On the supply side, the curve is also independent of the interest rates. Since the creditor picks ϕ_t to determine the supply of the foreign bond, we can also write the supply as

$$S_t^s = h(\phi_t, CS_t, E_t S_{t+1}).$$

The market is in equilibrium when

$$S_t^d = S_t^s.$$

Graphically, we show the equilibrium in Figure 3.

3 Results

3.1 Solution

Ideally, we would like to do comparative statics at any given level of CS_t. Since CS_t enters into both supply and demand, it is better to solve for the solution of the system of equations. CS_t is time-varying but exogenous to our model. In many circumstances, the spread is beyond the control of the trader and the creditor. It might seem plausible that the creditor has some control over CS_t, but the customer's relative default-risk level is hardly a factor any bank can unilaterally change. Generally, the credit spread is a system-wide variable that affects every agent in the economy. We assume its logs follow an AR(1) process:

$$CS_t = e_t CS_{t-1}^A, \tag{11}$$

where $|A| < 1$ and $\log e_t = \varepsilon_t$ is a white noise.

(To be completed) Equations (9) (10), and (11) will be log-linearized as the following system of equations.

$$\begin{bmatrix} E_t \widetilde{S}_{t+1} \\ \widetilde{CS}_t \\ \widetilde{\phi}_t \end{bmatrix} = \Gamma \begin{bmatrix} \widetilde{S}_t \\ \widetilde{CS}_{t-1} \\ \widetilde{\phi}_{t-1} \end{bmatrix} + \Xi, \tag{12}$$

where $\widetilde{\cdot}$ denotes the variable's deviation from steady state.

3.2 Equilibrium Dynamics

(To be completed) The system (12) is expected to have a reduced-form solution between exchange rates and the credit spread by eliminating the latent ϕ_t variable. Specifically, we expect to get

$$\Delta\widetilde{S}_{t+1} = \beta_0 + \beta_1\widetilde{CS}_t + u_t, \tag{13}$$

where β_1 is a negative coefficient. Intuitively, as $\widetilde{CS}_t$ reverts to its long-run mean as often happens after a positive shock, the creditor is more willing to lend money to the trader by setting higher $\widetilde{\phi}_t$. Demand for the foreign bond will thus increases and appreciates the foreign currency. In Figure 4, we plot the yen/dollar exchange rate on the same graph as the TED spread's time evolution. The general trend is matching with our reduced-form prediction (13).

In Table 1, we first estimate Equation (13) with different frequencies of yen/dollar exchange rates and the TED spread. We use the difference between 3-month T-bill yields and 3-month LIBOR rates to construct the TED spread and to proxy the credit spread. It can be argued that the interbank rates in London are dubious, but researchers have found that the general trends between the TED spread and other credit spreads are of no significant differences. All regressions have the right signs for coefficient estimates, though they are not statistically significant.

There is, however, an issue with the full-sample regressions. In many of the sub-periods, the interest rates between the U.S. and Japan are not large enough to entice traders to enter the carry trade. Hattori and Shin (2007) show that when Japanese and U.S. interest rates are not significantly different, large investment banks do not have significant amount of interoffice loans from Tokyo to New York. As stated previously, the interoffice loans fall into the category of broadly defined carry trades. We then include a dummy variable to interact with the credit spread. The dummy variable is to separate the sample into periods with high and low interest rate differentials. As is predicted by our model, a decreasing credit spread does depreciate the yen. The coefficients are statistically significant. The results are the most pronounced when the interest rate differentials are largest.

R^2 in Tables 1 and 2 are extremely low. It is not surprising for the limited numbers of explanatory variables included in our regressions. We will add more controls to see if the results stand.

3.3 Impulse Response Function

(To be completed) Figure 4 also shows an interesting pattern that captures the unwinding of the carry trade. Whenever there is large spike in the credit spread, the yen appreciates. We will estimate the system (12) and report the impulse response function to see how exchange rates are affected by credit spread shocks.

3.4 Volatilities of Risk Premium and Excess Return

(To be added) We will also address the volatility issue raised by Fama (1984) with our system of equations.

4 Conclusion

(To be added)

Figure 1: Yen/Dollar Exchange Rate in 2008

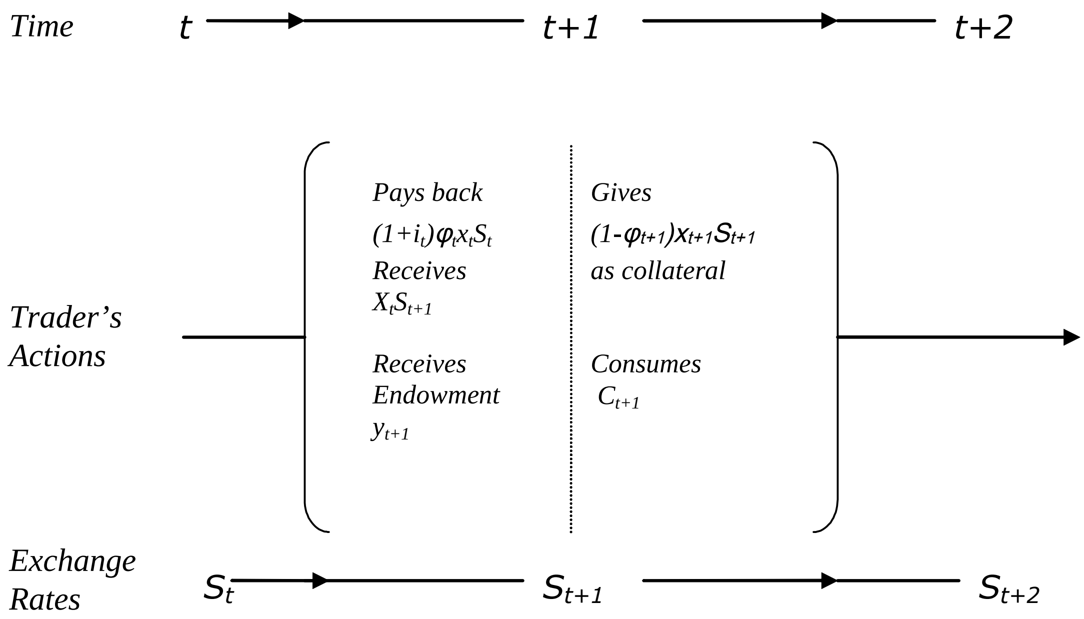

Figure 2 : Trader's Actions at Time $t + 1$

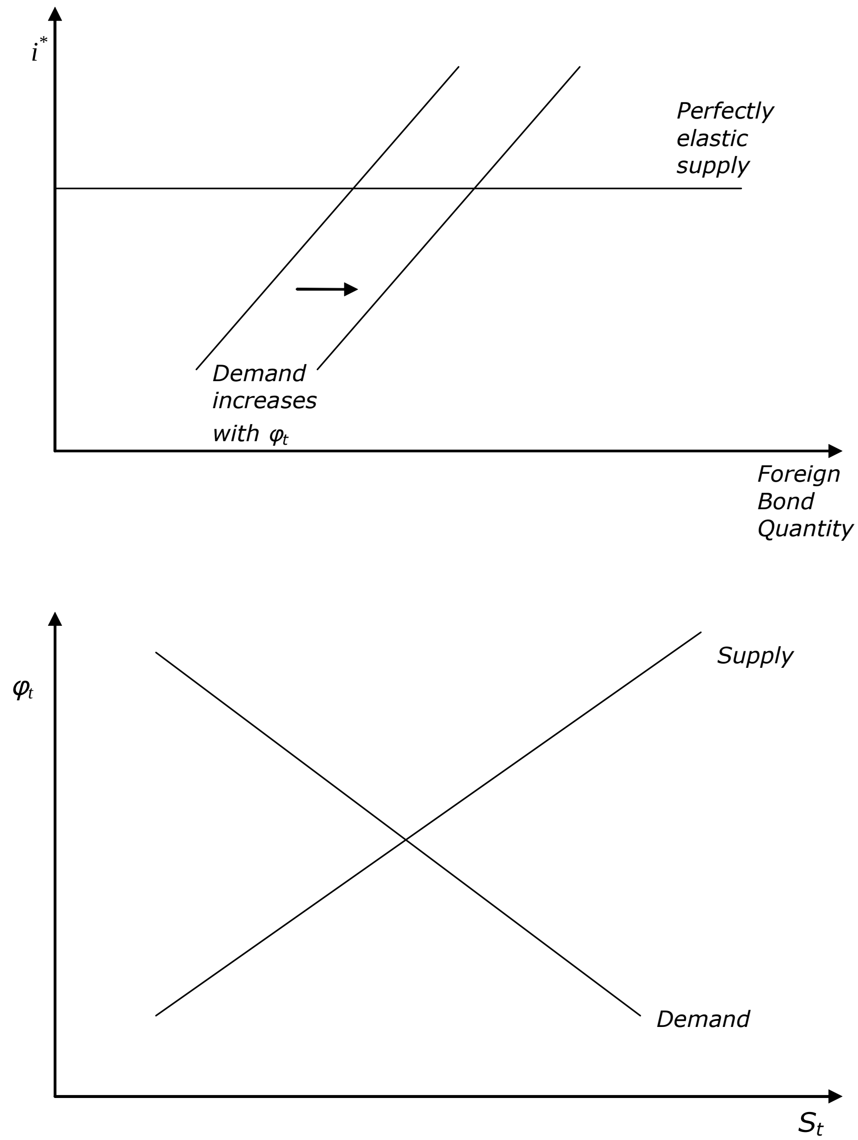

Figure 3 : The Foreign Bond Market

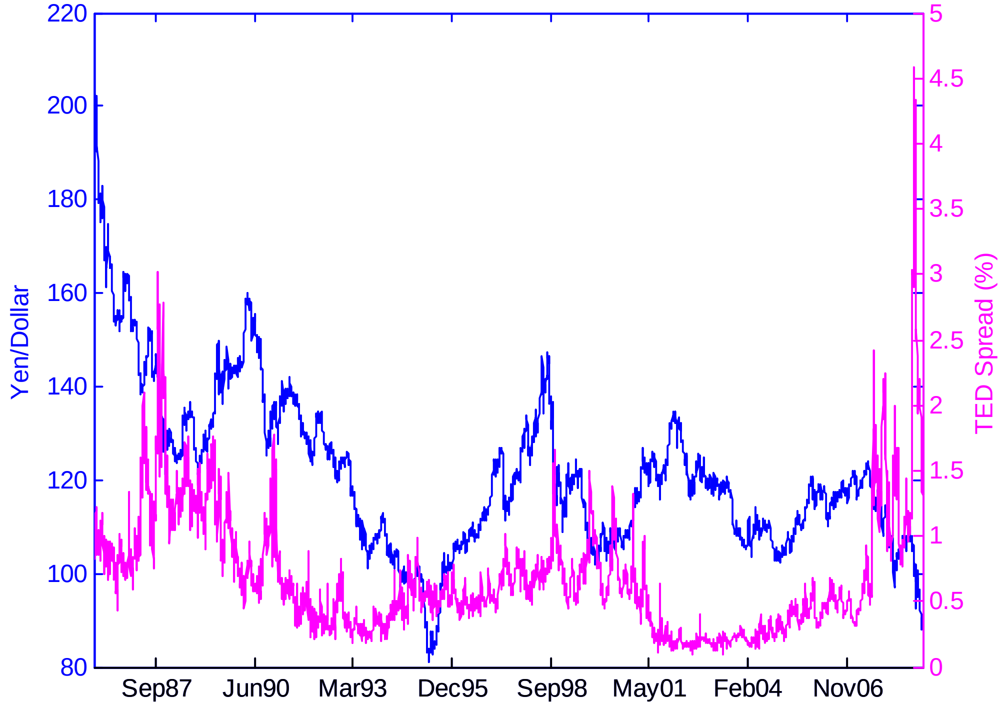

Figure 4: Yen/Dollar Exchange Rate and the TED Spread

Note– TED spread is the difference between 3-month Eurodollar rates and 3-month T-bill rates. Units are in percentage (annualized).

TABLE 1 : EXCHANGE RATE (YEN/DOLLAR) CHANGES ON CREDIT SPREAD

	Daily	Weekly	Monthly
	(1)	(2)	(3)
$\log CS_t$	-0.00024	-0.00115	-0.00064
	(0.00017)	(0.00127)	(0.00540)
Serial (Breusch-Godfrey)	0.24	0.28	0.48
	0.28	0.06	0.54
Heteroskedasticity (Engle)	0.00	0.16	0.12
	0.00	0.30	0.10
R^2	0.00045	0.00102	0.00007
Obs	5644	805	200
Constant	-0.00028*	-0.00109	-0.00278
	(0.00015)	(0.00079)	(0.00321)

Note– The regressed equation is $\log S_{t+1} - \log\ S_t = \beta_0 + \beta_1 \log CS_t + u_t$, where TED spread is the proxy to CS_t. Data start from January 1986 and end in December 2008. Weekly data use daily closes on Monday. If Monday is not a trading day, Tuesday's close is used. We also do a robust check by using other days' closing prices. There is not any discernible difference between them and Monday's. For monthly data, we actually pick Monday's closing prices at an interval of 4 weeks. We report p-values for Breusch-Godfrey LM (Breusch 1978; Godfrey 1978) test for residual autocorrelation: first-order in the top row and fifth-order for daily data and twelfth-order for weekly and monthly in the bottom row. 5th-order is to capture one-week autocorrelation, while 12th-order is to capture quarterly and yearly effects. We also present p-values for Engle ARCH LM (Engle 1982) test for residual heteroskedasticity. Lag selection is similar to Breusch-Godfrey LM tests. The null hypotheses for both tests are no serial or no heteroskedasticity. When there are autocorrelation or heteroskedasticity in residuals, standard errors are adjusted with Newey-West covariance matrix. Standard errors for the estimates are in parentheses. *, **, and *** denote the significance levels at 10%, 5%, and 1%, respectively.

TABLE 2 : EXCHANGE RATE CHANGES ON CREDIT SPREAD—

CARRY TRADE INDICATORS

	Dependent Variable : $\log S_{t+1} - \log S_t$				
	(1)	(2)	(3)	(4)	(5)
$\log CS_t$	-0.00024	0.00002	-0.00009	-0.00012	-0.00017
	(0.00017)	(0.00029)	(0.00017)	(0.00017)	(0.00017)
$\log CS_t \cdot Dummy(i^* - i \geq 1\%)$		-0.00030			
		(0.00028)			
$\log CS_t \cdot Dummy(i^* - i \geq 2\%)$			-0.00049**		
			(0.00022)		
$\log CS_t \cdot Dummy(i^* - i \geq 3\%)$				-0.00057**	
				(0.00024)	
$\log CS_t \cdot Dummy(i^* - i \geq 4\%)$					-0.00078***
					(0.00029)
Serial (Breusch-Godfrey)	0.24	0.25	0.27	0.28	0.28
	0.28	0.28	0.28	0.29	0.29
Heteroskedasticity (Engle)	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00
R^2	0.00045	0.00064	0.0012	0.0014	0.0016
Non-zero dummy/Obs	5644/5644	4720/5644	3479/5644	2915/5644	2228/5644
Constant	-0.00028*	-0.00026*	-0.00030**	-0.00031**	-0.00037**
	(0.00015)	(0.00015)	(0.00015)	(0.00015)	(0.00016)

Note– The regressed equation is $\log S_{t+1} - \log\ S_t = \beta_0 + \beta_1 \log CS_t + \beta_2 (\log CS_t \cdot ID\_Dummy) + u_t$, where ID_Dummy is a dummy variable for various level of interest rate differential between the U.S. and Japan. High levels of interest rate differentials indicate possible carry trade activities. Data are daily. For data and reporting specifications, please see the note in Table 1. *, **, and *** denote the significance levels at 10%, 5%, and 1%, respectively.

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Appendix

A1. Data

Exchange rates and T-bill rates are from St. Louis Fed's Fred2 database. For Eurodollar deposits (LIBOR), we obtain the data from British Bankers' Association.

A2. Why acquiring the foreign asset on margin?

From the trader's perspective, the main benefit of acquiring the financial asset on margin is the no-recourse clause. Downside risk is protected for betting on the price fluctuations of the financial asset. It thus provides an extra incentive for the trader to leverage. Most importantly, we assume this because the creditor sees the interests earned on lending as the only sure profit of accepting the trader's carry trade bet. Without this profit opportunity, the carry trade becomes a pure bet between the trader and the creditor. In this economy, we don't assume asymmetric information. If both the trader and the creditor have the same belief in exchange rate movements, there will not be any transactions. Therefore, we force the trader to acquire the foreign asset on margin. It turns out that the assumption is not far from reality as most FX traders leverage their positions.