Deviations from the Law of One Price across Economies

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Abstract

In a model with agents facing constraints heterogeneous across economies, we provide a novel explanation for an understudied yet economically significant deviation from the Law of One Price across FX forward markets. Specifically, we document a substantial divergence between the exchange rate for locally traded forward contracts and contracts with the same maturity traded outside the jurisdiction of countries during the global financial crisis, and that the magnitudes varied across currencies. The model predicts that (1) the basis increases with the shadow costs of constraints across time and increases with the country-specific FX position limit across countries; (2) the shadow cost of each constraint non-linearly increases as the intermediary sector's relative performance declines below a threshold; and (3) higher shadow cost of the position limit predicts lower future excess return on local-currency denominated assets, as buying local assets relaxes the FX position limit constraint imposed on the intermediaries. We test the model predictions and find consistent evidence in the countries with tight position limits.

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1 Introduction

During the global financial crisis (GFC) of 2007–2009, the difference between the exchange rate for locally traded forward contracts and contracts with the same maturity traded outside the jurisdiction of countries increased significantly across emerging markets (EM) currencies. This is clearly a failure of the Law of One Price (LoOP), as contracts with identical cash flows were traded at different prices. The extent of divergence is staggering; the 10-day moving average of the annualized absolute value of the basis reaches approximately 1,000 basis points (bps) at the six-month horizon for some currencies during the GFC. Despite the astounding magnitude that ranges over five times that of the maximum contemporaneous covered interest rate parity (CIP) deviation, this failure of the LoOP has received surprisingly little attention in the academic literature.

We attempt to explain this failure of the LoOP using an intermediary-based asset pricing model with FX position limit constraint, which is heterogeneous across economies, and margin constraint. We further test empirically the model's predictions to understand the effect of such constraints on asset prices.

Limits on a bank's net open FX position, the difference between its assets and liabilities denominated in foreign currency, are imposed by regulators to prevent banks from taking unmatched currency positions, thereby discouraging them from speculating on exchange rate movements. Such limits are imposed on all banks operating within the jurisdiction of countries and are commonly specified as leverage caps. For instance, banks in Indonesia are not allowed to take net open FX positions of more than 20% of their capital. These regulations are becoming increasingly prevalent. Based on the Annual Report on Exchange Arrangements and Exchange Restrictions by International Monetary Fund (IMF), approximately 77% of countries had limits on the financial sector's open FX positions as of 2018.

The main challenges in identifying the effect of heterogeneous constraints on asset prices are the lack of a valid counterfactual for the outcome in the absence of constraints and the short time-series of the post-crisis period. This paper addresses these challenges by examining a unique setting in the currency markets of EM economies where (1) the markets are segmented by regulation and (2) only the local market participants face the FX position limit. This setting provides a useful laboratory because the market segmentation was enforced prior to the global financial crisis, and the offshore market prices can be considered a counterfactual for the outcomes in the treatment group without the treatment.

The segmentation in EM currency markets is enforced by the regulators to limit the delivery of their home currencies offshore, outside the jurisdiction of countries.[1] The authorities of these countries have been concerned that large offshore markets in their currencies could induce greater volatility in capital flows and exchange rates. Consequently, onshore market participants have limited access to offshore forwards traded outside the jurisdiction of countries with restrictions on currency conversion, and offshore market participants have limited access to the onshore forwards. An offshore forward contract is similar to a regular FX forward contract except that it does not require the physical delivery of currencies at maturity. In the absence of frictions, whenever a price discrepancy between onshore and offshore forward contracts arises, global banks with access to both markets can arbitrage the price gap (basis) away.[2]

We show that two constraints, the FX position limit and margin constraint, can explain why the basis cannot be arbitraged away. To that end, we extend the margin-based asset pricing model of Garleanu and Pedersen (2011). Our model includes three types of agents: EM risk-averse, US risk-averse, and global bank agents. The local risk-averse agents have limited access to non-local assets, while global bank agents have access to all assets. All agents are subject to margin constraints. In addition to the margin constraint, each EM risk-averse agent and global bank faces the EM country-specific FX position limit.

With the model, we first link the shadow cost of the position limit to the interest rate spread. The spread between two EM-currency denominated uncollateralized rates, one traded in the EM ($r^{e₩u}$) and the other traded outside the EM ($r^{0₩u}$), represents the shadow

[1]Appendix E lists relevant regulations in each country in the sample.
[2]Appendix F shows the list of major dealers in the market and the local presence of global banks.

cost of the position limit λ:

$$\lambda = r^{0₩u} - r^{e₩u} \tag{1}$$

Intuitively, because investment in EM currency-denominated uncollateralized rate $r^{e₩u}$ in the EM relaxes the position limit by increasing the bank's capital base while the same instrument traded outside of EM $r^{e\$u}$ does not, the spread captures the marginal utility of relaxing the position limit constraint.

Next, we show how the FX position limit affects the excess returns on different types of assets: USD-denominated and EM currency-denominated assets traded in onshore and offshore locations. Since the assets traded outside of EM, such as US forwards, are not subject to the position limit, their required excess return μ^{0i} when a global bank holds long positions in equilibrium is the same as in the Garleanu and Pedersen (2011) economy:

$$\mu^{0i} - r = \beta^{0i} \times \text{covariance risk premium} + m^{0i} \times \text{margin premium} \tag{2}$$

In contrast, the assets traded in the EM are affected by the position limit, and therefore the position limit premium shows up in the expression for the excess required returns. For instance, suppose that a global bank holds a net long USD position in the EM. Purchase of an EM forward contract, an agreement to receive USD in exchange of EM currency, will further increase its USD exposure and therefore make the position limit more binding. Hence, for EM forward contracts in which the global bank holds long positions, the required excess return includes the position limit premium:

$$\mu^{ef} - r = \beta^{ef} \times \text{covariance risk premium} + m^{ef} \times \text{margin premium} + \pi^{e} \times \text{position limit premium} \tag{3}$$

where π^e denotes country-specific position limit.

It follows that the basis is linearly related to the two terms: the product of the margin and the shadow cost of the margin requirement and the product of the position limit and the shadow cost of position limit. The basis widens when the position limit is tighter, required margin is higher, or shadow prices of the two constraints increase.

The model offers additional predictions that can be tested. First, when global banks' aggregate consumption share is sufficiently low, the shadow cost of margin constraint increases non-linearly as the consumption share of global banks falls. Second, the shadow cost of position limit constraint has non-linear relation with global banks' consumption relative to EM's consumption. The relation depends on (1) whether USD-denominated assets are riskier than local currency-denominated assets in the EM, and (2) the global banks' aggregate net USD position in each EM. Third, higher basis predicts lower future excess return on EM assets because buying local currency-denominated assets relaxes position limit constraint by increasing the global banks' capital base in the EM.

We empirically test these predictions for five EM countries with similar settings in which markets are segmented, and position limits are imposed only on the local market participants. The data on daily exchange rates and interest rates are obtained from Bloomberg, and historical position limits data are obtained from central banks. Based on the empirical tests, we find evidence consistent with model implications in the countries with tight position limits.

Related Literature

This paper relates to three strands of literature. First, this paper fits into the literature that studies the impact of frictions in financial intermediation on asset prices. He and Krishnamurthy (2012), He and Krishnamurthy (2013), Brunnermeier and Sannikov (2014), and Moreira and Savov (2017) provide models of intermediary-based asset pricing. On the empirical side, Adrian et al. (2014) and He et al. (2017) show that the shocks to the equity capital ratio of financial intermediaries explain the cross-sectional variation in expected returns. Gabaix et al. (2007) study the pricing of prepayment risks in mortgage-backed security (MBS) markets and find evidence that the marginal investor in the MBS market is a specialized arbitrageur that trades exclusively in the MBS market. Koijen and Yogo (2015) study life insurers and the pricing of insurance policies, and show that insurers sold policies at prices below actuarial fair value because sales of such policies increase regulatory capital in the short-run. Siriwardane (2018) shows that capital shocks at protection sellers impact pricing in the credit default swap market. We add to this literature by showing how foreign exchange position limit constraint imposed on global banks affects asset prices. Since onshore and offshore markets are segmented by regulation and the foreign exchange position limits are imposed only on the onshore market participants, it is an excellent setting to test whether a constraint on intermediaries affects asset prices without making assumptions on which class of agents are constrained.

Second, the onshore-offshore forward rate basis is related to the empirical literature studying frictions in the interest rate market and FX swap market. Klinger and Sundaresan (2018) and Jermann (2018) examine the disparity between the interest rate swap rate and the yield of a Treasury bond with dealer banks' balance sheet constraints combined with the demand of underfunded pension plans and with the regulation-induced cost of holding Treasuries, respectively. Coffey et al. (2009), Mancini-Griffoli and Ranaldo (2011), Ivashina et al. (2015), and Du et al. (2018) study the covered interest rate parity (CIP) violations during the financial crisis. This paper shows that the onshore-offshore forward rate basis is driven not only by funding distress but also by position limit, which has not yet been carefully studied as a friction in the FX derivative markets.

Third, there is a literature that studies the relation between onshore and offshore foreign exchange forward markets. Ma et al. (2004) and Santaella (2015) provide overviews of NDF markets in Asia and Latin America. McCauley et al. (2014) document that the basis widens sharply in stressed market conditions, including the global financial crises. Wang (2015) finds that the CIP deviations observed in the onshore forward market were primarily caused by conversion restriction in the spot market, while offshore forwards reflect the market's expectation of the future spot rate. Some papers analyze the two-way influence between onshore and offshore forwards of a single currency. (Misra and Behera (2006), Kim and Song (2010) Behera (2011), Cadarajat and Lubis (2012) and Goyal et al. (2013)). However, none of these papers presents a model that links the basis to position limits.

This paper is organized as follows: section 2 provides motivating evidence, section 3 presents a model linking the basis to the margin requirement and position limits, section 4 contains model predictions and section 5 includes empirical results of testing the predictions. Section 6 concludes.

2 Motivating Evidence

We motivate our model by presenting some stylized facts based on daily EM forward and US forward rates for five currencies, Indonesian Rupiah (IDR), Indian Rupee (INR), Korean Won (KRW), New Taiwan Dollar (TWD) and Thailand Baht (THB), from 2000 January to 2018 July. The exact starting date is different for each country based on data availability. The data source is Bloomberg.

1. Basis, defined as log EM forward less log US forward, deviated significantly from zero during the financial crisis for all currencies except Korean Won. Figure 1 shows this graphically, and the first row of Table 1 reports the difference in mean basis during the crisis (2007-2009) and the rest of the period.

2. The magnitude of the deviation during the crisis roughly aligns with the tightness of capital-based position caps. The second row in Table 1 shows position limit in 2018 (as a percentage of bank capital) imposed by each local central bank. The position limit is relatively tight in Thailand, India, and Indonesia, compared to Korea. In Taiwan, each bank is allowed to determine its own positions; however, they are subject to the approval of central bank. Figure 2 presents time-series of position limits for the sample currencies. Overall, the position limits do not vary over time for each country.

3. Since EM forwards are deliverable contracts while US forwards are non-deliverable, it is natural to ask whether this difference affects the basis. Although we do not test this formally, we provide a suggestive evidence that the delivery requirement has insignificant effect on the basis. The evidence is from the time-series variation in Thailand Baht basis. The EM forward and US forward are both deliverable contracts for THB. Had the basis been mainly driven by the cost of funding deliverable contracts, THB would not have shown any significant spike during the financial crisis. However, the basis surged by 1%[3] during the crisis. Figure 3 also shows that there was a significantly negative basis during the crisis.

4. The bases for longer-term contracts tend to be less volatile than the bases for shorter-term contracts. For instance, 6-month contracts are less volatile than 1-month contracts. (Figure 13-17)

5. The volatility of basis is higher during the financial crisis (2007-2009) for all currencies, and Indonesia had the most volatile basis among the sample countries. (Table 2)

3 Model

3.1 Model Illustration

For illustration, we show a simplified version of the model to demonstrate the roles of position limit and the margin constraint. Consider two countries– an EM onshore market and an offshore "US" market – and a global bank operating in the two countries with the following balance sheets:

[3]compared to non-crisis excluding the time period when unremunerated reserve requirement (URR) was imposed. BoT enacted an URR regime effective 12/18/2006- 03/02-2008 to slow speculative capital inflows. BoT applied 30% reserve requirement on investments into Thailand and restricted the movements of THB from onshore to offshore.

EM Branch (e)		US Branch (0)	
Assets:	Liabilities:	Assets:	Liabilities:
$\theta^{e\$}$	$\eta^{e\$u}(< 0)$	$\theta^{0\$}$	$\eta^{0\$u}(< 0)$
$\theta^{e\text{₩}}$			$\eta^{0\$c}(< 0)$
	Capital in EM		Capital in US
EM forward (θ^{ef})		US forward (θ^{0f})	

θ and η are portfolio weights in risky assets and risk-less assets respectively, and the portfolio weights sum to 1:

$$\theta^{e\$} + \theta^{e\text{₩}} + \eta^{e\$u} + \theta^{0\$} + \eta^{0\$u} + \eta^{0\$c} = 1$$

A long position in an asset makes it "asset" and a short position in an asset makes it "liability". In the model, the sign of the position is not restricted for any asset. Assets are characterized by trading location, denominated currency, and collateralization in case of risk-less assets. Trading locations 0 denotes US and e denotes EM. \$ denotes USD-denominated assets and ₩[4] denotes EM currency-denominated assets. u denotes uncollateralized loans and c denotes collateralized loans.

Suppose that each country has risk-averse agents who have access to only the assets that are traded in his country; global bank has access to all of the assets traded in both locations, and has log utility. Then, the global bank's portfolio allocation problem is:

$$\max_{\theta^i, \eta^i} \; r^{0\$c} + \eta^{0\$u}(r^{0\$u} - r) + \eta^{e\$u}(r^{e\$u} - r) + \sum_{i \in \{e\$,\, e\text{₩},\, e^{0\$}\}} \theta^i(\mu^i - r) - \frac{1}{2}\sum_{i,j} \theta^i \theta^j \sigma^i (\sigma^j)^T$$

subject to (1) FX position limit constraint and (2) margin constraint.

1. The FX position limit is modeled as:

$$\frac{|\theta^{e\$} + \theta^{ef} + \eta^{e\$u}|}{\theta^{e\$} + \theta^{e\text{₩}} + \eta^{e\$u}} \leq \frac{1}{\pi} \quad (e.g. = 20\%)$$

The ratio of net USD position to capital **in EM** should not exceed $1/\pi$.

[4] Korean Won

(a) How does this constraint affect asset prices? Suppose that the global bank has long USD position: $\theta^{e\$} + \theta^{ef} + \eta^{e\$u} > 0$. There are three ways for global bank to relax the constraint.

i. First, global bank can buy more EM-currency denominated asset $e₩$ to increase its capital in the EM (denominator effect). Because investment in EM-currency denominated asset in EM ($e₩$) relaxes the constraint while the same asset traded in the US (0₩) does not, the expected return on $e₩$ is lower than 0₩ in equilibrium.

ii. Second, global bank can sell EM forwards ef, contracts to receive USD in the future, to reduce the USD exposure (numerator effect). Since the *sale* of the EM forward relaxes the constraint while the sale of US forward does not, the expected return on ef is higher than $0f$.

iii. Third, global bank can sell USD-denominated assets in EM $e\$$. Whether the expected return on $e\$$ earns premium or discount compared to 0\$ depends on π.

The size of premium due to position limit depends on how tight the position limit (π) is and the marginal utility of relaxing the position limit constraint.

(b) When does this constraint bind more for global bank? Suppose for a moment that USD-denominated asset ($e\$$) is riskier than EM currency- denominated asset ($e₩$) in EM. Since global bank is more risk tolerant, he is more heavily invested in the riskier $e\$$. Therefore, following a series of bad shocks in EM, global bank loses more and risk-averse agent becomes a larger part of the market. As a result, premium on $e\$$ rises by more than $e₩$ to induce risk-averse agents to hold more $e\$$ for markets to clear. This is when the position limit constraint binds more (less) if global bank holds net long (short) USD position in EM.

2. Following Garleanu and Pedersen (2011), the margin constraint is modeled as:

$$\underbrace{\sum_{i \in \{e\$, e₩, 0\$\}} m^i |\theta^i|}_{\text{Margin for risky assets positions}} + \underbrace{\eta^{0\$u} + \eta^{e\$u}}_{\text{uncollateralized USD loans}} \leq \overbrace{1}^{100\% \text{ of wealth}}$$

The capital uses in margin for positions in risky assets and riskless uncollateralized USD loans must be less than 100% of his wealth.

3.2 Full Model

We extend the continuous-time model of Garleanu and Pedersen (2011) with multiple EM economies and the US. Trading locations are again denoted by L: $L = 0$ for US and $L > 0$ for EM. We denote USD-denominated assets with \$ and EM currency-denominated assets with ₩[5].

Risky Assets

Each country has a continuum of assets and each asset i pays a dividend δ_t^i at time t and is available in a net supply of 1. The dividend of each security i follows:

$$d\delta_t^i = \delta_t^i \left(\mu_t^{\delta^i} dt + \sigma_t^{\delta^i} dw_t \right)$$

There are two types of assets in each EM country: USD-denominated assets and EM currency-denominated assets. In each EM e, there are two consumption goods, \$-denominated and ₩-denominated :

$$dC_t^{e\$} = \mu^{C^{e\$}} C_t^{e\$} dt + \sigma^{C^{e\$}} C_t^{e\$} dw_t$$

$$dC_t^{e₩} = \mu^{C^{e₩}} C_t^{e₩} dt + \sigma^{C^{e₩}} C_t^{e₩} dw_t$$

[5] Korean Won

There is a single consumption good in the US:

$$dC_t^0 = \mu^{C^0} C_t^0 dt + \sigma^{C^0} C_t^0 dw_t$$

Appealing informally to the Law of Large Numbers, $E[\delta_t^{e\$}|C_t^{e\$}] = C_t^{e\$}$, $E[\delta_t^{e₩}|C_t^{e₩}] = C_t^{e₩}$ for each EM e and $E[\delta_t^0|C_t^0] = C_t^0$.

Each asset requires asset-specific margin $m^i \in [0, 1]$, a fraction of the investment that must be financed by an agent's own capital.

Money-Market Assets

There are two riskless money-market assets in the US, collateralized loans (r) and uncollateralized loans ($r^{0\$u}$). There is only one riskless money-market asset in each EM country, uncollateralized USD-denominated loans ($r^{e\$u}$). This assumption is based on the fact that collateralized loan markets are not well developed in many EM economies. In addition, there are uncollateralized loans denominated in EM currencies, traded in the EM and in the US. These assets are riskless in each denominating EM currency, but are *risky* in USD.

Derivatives

In addition to these underlying assets, there are derivatives in net zero supply. A type of derivatives in particular interest is FX forwards, contracts to receive USD in exchange of pre-specified amount of other currencies in a pre-specified future date. US forwards are denoted $0f$ and EM forwards are ef. We assume that margins required for derivatives are lower than those for underlying assets.

Agents

There are three types of agents: EM risk-averse ea, global bank b, and US risk-averse $0a$. The local risk-averse agents can trade only the local assets. Global bank has access to all markets by having branches in the EM countries and in the US. Each agent $g \in \{ea, b, 0a\}$ maximizes his utility for consumption

$$E_t \int_0^\infty e^{-\rho s} u^g(C_s) ds$$

where $u^a(C) = \frac{1}{1-\gamma^a} C^{1-\gamma^a}$ with $\gamma^a > 1$, and $u^b(C) = \log(C)$ with $\gamma^b = 1$.

Each agent chooses his consumption C_t^g, portfolio weight θ_t^i for each asset i, and the proportion $\eta_t^{L\$u}$ invested in each riskless USD-denominated uncollateralized loan in each location L. The rest of his wealth is invested in riskless collateralized loans. The wealth W_t evolves as the following:

$$dW_t = \left(W_t \left(r_t + \sum_L \eta_t^{L\$u} (r_t^{L\$u} - r_t) \right) \right) dt + W_t \sum_i \theta_t^i \sigma_t^i dw_t$$

where the last term is summation over all risky assets and derivatives. Without loss of generality, returns on assets that are denominated in non-USD are converted back to USD.

Margin Constraint

Each agent can tie up his capital in margin for positions in risky assets and riskless uncollateralized USD loans ($\eta^{L\$u}$). These capital uses must be less than 100% of the wealth:

$$\underbrace{\sum_i m^i |\theta^i|}_{\text{Capital in Margin}} + \underbrace{\sum_L \eta^{L\$u}}_{\text{Investment in riskless uncollateralized loans}} \leq \underbrace{1}_{\text{Wealth}} \tag{4}$$

Again, the first term is summation over all risky assets and derivatives.

The relevant state variable for margin constraint is b's consumption as a fraction of the sum of the total global consumption:

$$\frac{C^b}{C^0 + \sum_{L \geq 1} (C^{L\$} + C^{L₩})}$$

This is direct extension of Garleanu and Pedersen (2011). Since global bank b is less risk averse, he invests more in the risky assets and therefore loses more following a series of bad shocks in $C^{e\$}$, $C^{e₩}$ for some EM e or C^0. As the risk-averse agent (ea and $0a$) becomes a larger part of the market, the market price of risk increases to induce them to hold enough of the risky assets for market to clear. This is when global bank's leverage rises and its margin constraint becomes more binding. The relation between the shadow cost of funding ψ and the state variable is non-linear as plotted in Figure 4.

FX Position Limit Constraint

In addition to the margin constraint, each EM risk-averse agent and global bank faces EM country-specific position limit. EM branch's foreign exchange net exposure, the difference between assets and liabilities in foreign currencies, cannot exceed $1/\pi$ (e.g. $1/5$=20% for Indonesia) of the branch's capital:

$$\underbrace{\left|\sum_i \theta^{e\$i} + \theta^{ef} + \eta^{e\$u}\right|}_{\text{Net USD Exposure in EM}} \leq \overbrace{\frac{1}{\pi}}^{\substack{\text{higher } \pi = \\ \text{tighter constraint}}} \underbrace{\left(\sum_i \theta^{e\$i} + \sum_i \theta^{e₩i} + \eta^{e\$u}\right)}_{\text{Capital in EM}} \tag{5}$$

As π increases position limit becomes more stringent.

The relevant state variable for position limit constraint of EM e is the b's consumption as a fraction of the EM's total consumption plus b's consumption:

$$\frac{C^b}{C^{e\$} + C^{e₩} + C^b}$$

Suppose that asset $e\$$ have higher volatility than $e₩$. When global bank's consumption C^b declines more than the EM's total consumption, $C^{e\$} + C^{e₩}$, risk-averse agents become a larger part of $e\$$ market and $e₩$ market, and risk premium for $e\$$ rises by more than the risk premium for $e₩$ assets to induce ea to hold more $e\$$ assets and more $e₩$ assets for markets to clear. In this case, if b is net long (short) USD in the EM: $\sum_j \theta^{e\$j} + \theta^{ef} + \eta^e > (<) 0$, his position limit is more (less) binding. A series of bad shocks in C^0 will make $0a$ become a larger part of 0\$ market and therefore the risk premium on 0\$ would increase. However, since positions in 0\$ are not subject to the position limit, bad shocks in C^0 will not affect the position limit constraint, assuming that C^0 and $C^{e\$}$ or $C^{e₩}$ are independent.

Equilibrium

An equilibrium for the economy is a set of prices, agent decisions for consumptions and asset positions such that (1) given prices, each agent maximizes his utility subject to constraints and (2) markets clear.

3.3 Asset Prices

Consider the optimization problem of global bank. The logarithmic utility for consumption implies that the problem can be reduced to mean-variance optimization:

$$\max_{\Theta, \{\eta^{L\$u}\}} \quad r + \sum_L \left(\eta^{L\$u} (r^{L\$u} - r) \right) + \Theta'(\mu - r) - \frac{1}{2} \Theta' \Sigma \Theta$$

subject to the margin constraint (4) and position limit constraint (5). Θ denotes positions in risky assets, and Σ denotes variance-covariance matrix of risky assets.

Interest Rates

Attaching Lagrange multiplier ψ to the margin constraint, the first-order condition with respect to the weight in the US uncollateralized loan, $\eta^{0\$u}$ is:

$$\psi_t = r_t^{0\$u} - r_t \tag{6}$$

This is the result of Garleanu and Pedersen (2011). Intuitively, global bank is willing to borrow at higher rate on uncollateralized loan because uncollateralized loan relaxes the margin constraint while collateralized loan requires capital. Therefore, the interest-rate differential between uncollateralized and collateralized loan captures the global bank's shadow cost of funding.

The expression for shadow cost of position limit constraint depends on global bank's net USD exposure in EM branch. First, suppose that EM branch is net USD long: $\sum_i \theta^{e\$i} + \theta^{ef} + \eta^{e\$u} > 0$. Attaching Lagrange multiplier λ to the position limit constraint, the shadow cost of position limit constraint is:

$$\lambda_t = \frac{r_t^{0\$u} - r_t^{e\$u}}{1 - \pi_t} \geq 0 \tag{7}$$

Since the position limit constraint becomes:

$$\sum_i \theta^{e\$i} + \theta^{ef} + \eta^{e\$u} \leq \frac{1}{\pi}\left(\sum_i \theta^{e\$i} + \sum_i \theta^{e₩i} + \eta^{e\$u}\right)$$
$$\sum_i \theta^{e\$i} + \theta^{ef} \leq \frac{1}{\pi}\left(\sum_i \theta^{e\$i} + \sum_i \theta^{e₩i}\right) + \eta^{e\$u}\left(\frac{1}{\pi} - 1\right)$$

if $\pi > 1$, then constraint becomes looser as $\eta^{e\$u}$ decreases. As EM \$ denominated collateralized loans loosen the position limit, while USD-denominated uncollateralized loans do not, $r_t^{0\$u} \leq r_t^{e\$u}$. On the other hand, if $\pi < 1$, constraint becomes tighter as η^c decreases. Because USD-denominated collateralized loans in the EM tighten the position limit, whereas USD denominated uncollateralized loans do not, $r_t^{0\$u} \geq r_t^{e\$u}$.

Now suppose that global banks are net short USD in EM. The shadow cost of position limit constraint is:

$$\lambda_t = \frac{r_t^{0\$u} - r_t^{e\$u}}{1 + \pi_t} \geq 0 \tag{8}$$

Constraint becomes tighter as $\eta^{e\$u}$ decreases:

$$-\left(\sum_i \theta^{e\$i} + \theta^{ef} + \eta^{e\$u}\right) \leq \frac{1}{\pi}\left(\sum_i \theta^{e\$i} + \sum_i \theta^{e₩i} + \eta^{e\$u}\right)$$
$$-\left(\sum_i \theta^{e\$i} + \theta^{ef}\right) \leq \frac{1}{\pi}\left(\sum_i \theta^{e\$i} + \sum_i \theta^{e₩i}\right) + \eta^{e\$u}\left(\frac{1}{\pi}+1\right)$$

The USD-denominated collateralized loans in the EM tighten the position limit, while uncollateralized loans in the US do not; therefore, $r_t^{0\$u} \geq r_t^{e\$u}$.

Risky Assets

Global bank's first-order conditions with respect to the risky asset positions Θ depends on the net USD exposure of global bank in the EM. First, suppose that global bank is net USD **long** in the EM. Then the expected excess returns on the risky assets are as following.

$$\mu^{0\$i} - r = \begin{cases} \beta^{0\$i} + \psi m^{0\$i} & \text{if } \theta^{0\$i} > 0 \\ \beta^{0\$i} - \psi m^{0\$i} & \text{if } \theta^{0\$i} < 0 \end{cases} \tag{9}$$

$$\mu^{0₩i} - r = \begin{cases} \beta^{0₩i} + \psi m^{0₩i} & \text{if } \theta^{0₩i} > 0 \\ \beta^{0₩i} - \psi m^{0₩i} & \text{if } \theta^{0₩i} < 0 \end{cases} \tag{10}$$

$$\mu^{0f} = \begin{cases} \beta^{0f} + \psi m^{0f} & \text{if } \theta^{0f} > 0 \\ \beta^{0f} - \psi m^{0f} & \text{if } \theta^{0f} < 0 \end{cases} \tag{11}$$

where $\beta_t^{C^b,i} = \text{Cov}_t\left(\frac{dC^b}{C^b}, \frac{dP^i}{P^i}\right)$ denotes the conditional covariance between global bank's consumption growth and the return on security i. The expected excess returns on the assets that are traded in the US depends on $\beta^{C^b,i}$, the asset-specific margin and the shadow cost of funding ψ, as in Garleanu and Pedersen (2011) economy. The sign of the margin premium depends on whether global bank is long or short the security because both long and short positions require margin.

In contrast, the assets traded in the EM are affected by position limits, and therefore the shadow cost of the position limit constraint λ shows up in the first-order conditions:

$$\mu^{e\$i} - r = \begin{cases} \beta^{e\$i} + \psi m^{e\$i} - \lambda(1-\pi) & \text{if } \theta^{e\$i} > 0 \\ \beta^{e\$i} - \psi m^{e\$i} - \lambda(1-\pi) & \text{if } \theta^{e\$i} < 0 \end{cases} \tag{12}$$

$$\mu^{e₩i} - r = \begin{cases} \beta^{e₩i} + \psi m^{e₩i} - \lambda & \text{if } \theta^{e₩i} > 0 \\ \beta^{e₩i} - \psi m^{e₩i} - \lambda & \text{if } \theta^{e₩i} < 0 \end{cases} \tag{13}$$

$$\mu^{ef} = \begin{cases} \beta^{ef} + \psi m^{ef} + \lambda\pi & \text{if } \theta^{ef} > 0 \\ \beta^{ef} - \psi m^{ef} + \lambda\pi & \text{if } \theta^{ef} < 0 \end{cases} \tag{14}$$

Intuitively, purchase of EM asset relaxes the position limit constraint and therefore its expected excess return is lower by λ compared to the expected excess return when position limit is not imposed. The last term in equation (13) represents this. Because global bank is already net long USD in the EM, purchase of forward contracts to receive USD makes the constraint even tighter. Hence, EM forwards earn premium of $\lambda\pi$, the last term of equation (14). The purchase of USD-denominated asset has two effects. On the one hand, it increases its capital in the EM, which relaxes the constraint. On the other hand, it increases its USD exposure, which makes the constraint more stringent. The expected excess return on USD-denominated assets traded in EM is discounted by λ due to the former effect and it earns premium of $\lambda\pi$ due to the latter effect. In sum, if $\pi > 1$, the last term in equation (12) is positive; the expected excess return on USD denominated asset earns premium of $\lambda(\pi - 1)$.

Suppose now that EM branch is net USD **short**. The global bank's first-order conditions with respect to the positions of risky assets traded in the US are the same as the case when the global bank is net USD long in the EM and the equations (9)-(11) remain the same. This is simply because they are not subject to the position limit. The expected excess returns on the EM currency-denominated assets also do not depend on the net USD position of global bank in the EM, because EM currency-denominated assets always relaxes the position limit constraint by increasing the bank's capital base in the EM. Therefore, equation (13) also remains the same. However, when global bank is net short USD, the purchase of EM forward relaxes the position limit constraint and therefore its expected excess return is discounted by $\lambda\pi$:

$$\mu^{ef} = \begin{cases} \beta^{ef} + \psi m^{ef} - \lambda\pi & \text{if } \theta^{ef} > 0 \\ \beta^{ef} - \psi m^{ef} - \lambda\pi & \text{if } \theta^{ef} < 0 \end{cases} \tag{15}$$

By similar argument, the purchase of USD denominated asset unambiguously relaxes the position limit, and thus its expected excess return is discounted by $\lambda(1+\pi)$:

$$\mu^{e\$i} - r = \begin{cases} \beta^{e\$i} + \psi m^{e\$i} - \lambda(1+\pi) & \text{if long} \\ \beta^{e\$i} - \psi m^{e\$i} - \lambda(1+\pi) & \text{if short} \end{cases} \tag{16}$$

EM Currency-denominated Money Market Assets

Since global bank is interested in USD returns, the EM currency-denominated money market assets are risky. Because uncollateralized loans can be thought of as risky assets with margin of

$$m = \begin{cases} 1 & \text{if long} \\ -1 & \text{if short} \end{cases}$$

first-order conditions on the positions in EM currency-denominated uncollateralized loans give:

$$\begin{aligned} \mu^{0₩u} - r &= \beta^{0₩u} + \psi \\ \mu^{e₩u} - r &= \beta^{e₩u} + \psi - \lambda \\ \Rightarrow \mu^{0₩u} - \mu^{e₩u} &= (r^{0₩u\, in₩} - s) - (r^{e₩u\, in₩} - s) \\ &= r^{0₩u\, in₩} - r^{e₩u\, in₩} \approx \lambda \end{aligned} \tag{17}$$

where s is expected instantaneous return on spot exchange rate (defined as the value of 1 USD in terms of EM currencies). The equation (17) expresses the shadow cost of position limit in terms of observable quantities. In words, because investment in EM currency denominated rates $e₩u$ relaxes the position limit by increasing the bank's capital base, $e₩u$ earns premium of λ compared to $0₩u$ traded in the US. This equation is used for empirical test of the model predictions.

4 Predictions

1. **Basis**. Define basis as: $basis = \mu^{0f} - \mu^{ef}$. A basis arises when all agents are constrained by one or more constraints: margin constraint and position limit constraint for all agents, and access constraint for risk-averse agents. Such a situation arises when b is constrained by both position limit constraint and margin constraint, ea is constrained by his limited ability to hold $0f$ and $0a$ is constrained by his limited ability to hold ef. The basis depends on global bank's net USD position in the EM as well as its positions in US forward and EM forward. First, suppose that b is net long USD in its EM branch.

(A) If global bank is long both US forward and EM forward, the basis is:

$$basis = \left(\beta^{0f} - \beta^{ef}\right) + \psi\left(m^{0f} - m^{ef}\right) - \lambda\pi \tag{18}$$

(B) If global bank is short US forward and long EM forward, the basis is:

$$basis = \left(\beta^{0f} - \beta^{ef}\right) - \psi(m^{0f} + m^{cf}) - \lambda\pi \tag{19}$$

(C) If global bank is short both US forward and EM forward, the basis is:

$$basis = \left(\beta^{0f} - \beta^{ef}\right) + \psi\left(-m^{0f} + m^{cf}\right) - \lambda\pi \tag{20}$$

(D) If global bank is long US forward and short EM forward, the basis is:

$$basis = \left(\beta^{0f} - \beta^{ef}\right) + \psi(m^{0f} + m^{cf}) - \lambda\pi \tag{21}$$

Analogously, there are four expressions for basis depending on b's positions in the forwards when b is net short USD in its EM branch. The margin effects remain the same as the case when b is net long USD. However, sign on $\lambda\pi$ is positive in this case because long position in EM forward relaxes the position limit constraint if b is net short USD in its EM branch.

(A) If global bank is long both US forward and EM forward, the basis is:

$$basis = \left(\beta^{0f} - \beta^{ef}\right) + \psi\left(m^{0f} - m^{ef}\right) + \lambda\pi \tag{22}$$

(B) If global bank is short US forward and long EM forward, the basis is:

$$basis = \left(\beta^{0f} - \beta^{ef}\right) - \psi(m^{0f} + m^{cf}) + \lambda\pi \tag{23}$$

(C) If global bank is short both US forward and EM forward, the basis is:

$$basis = \left(\beta^{0f} - \beta^{ef}\right) + \psi\left(-m^{0f} + m^{cf}\right) + \lambda\pi \tag{24}$$

(D) If global bank is long US forward and short EM forward, the basis is:

$$basis = \left(\beta^{0f} - \beta^{ef}\right) + \psi(m^{0f} + m^{cf}) + \lambda\pi \tag{25}$$

In any case, the $|basis|$ increases in $|\lambda\pi|$, after controlling for the margin effect.

Due to limited data availability, this prediction is not directly testable.[6]

On the other hand, the following predictions are testable.

2. **Shadow Cost of Margin Constraint (ψ)**: When global bank's consumption share is low enough, the shadow cost of margin constraint ψ increases non-linearly as the consumption share of global bank falls. See Figure 4 based on Garleanu and Pedersen (2011)'s calibration.

3. **Shadow Cost of Position Limit (λ)**: The shadow cost of position limit constraint has non-linear relation with global bank's consumption relative to EM's ($\frac{C^b}{(C^b+C^{EM})}$). The relation depends on (1) whether $e\$$ are riskier than $e₩$, and (2) global bank's net USD position in each EM. See Figure 5 and 6.

4. **Return predictability**: Regardless of global bank's net USD position in EM, buying EM denominated EM asset relaxes position limit constraint by increasing the bank's capital base:

$$\mu^{e₩i} - r = \begin{cases} \beta^{e₩i} + \psi m^{e₩i} - \lambda & \text{if long} \\ \beta^{e₩i} - \psi m^{e₩i} - \lambda & \text{if short} \end{cases}$$

[6]See Appendix for the detailed data availability.

5 Empirical Tests

5.1 Data

We focus on six countries with similar market settings where markets are segmented and position limits are imposed only on the local market participants. We use the following data sources:

Spot, Forward Exchange Rates, TED Spread. We obtain daily spot exchange rate, forward exchange rate with different tenors (1-month, 3-month, 6-month and 1-year), and TED spread, 3-month Libor rate less 3-month T-bill interest rate, from Bloomberg. The sample period is 2003 - 2018 June, which is the longest overlapping period. For Thailand, we exclude the period when URR was implemented, as the basis was significantly wider during this period.

Position Limits. Historical position limits are obtained from each central bank.[7]

US Firm Data. Market equity and dividend data are obtained from CRSP.

EM Market Data. Each EM's stock and bond data are from Bloomberg.

5.2 Shadow Cost of Margin Constraint and Performance of Global Banks Relative to the World

Performance of Global Banks

As discussed in the full model section, the relevant state variable for margin constraint is b's consumption as a fraction of the sum of the total global consumption. We use market equity of firms as a proxy for consumption. To construct the global bank's consumption share, We use Fama French's 49 industry definition and MSCI ACWI index[8]. Figure 7 plots the proxy for consumption share of global bank with varying definition of global banks.

[7]Bank Indonesia, Reserve Bank of India, Bank of Korea, Central Bank of the Republic of China, Bank of Thailand

[8]Market capitalization weighted index; it is comprised of stocks from 23 developed countries and 24 emerging markets.

Proxy for Shadow Cost of Margin Constraint

Following Garleanu and Pedersen (2011), we use TED spread, 3-month LIBOR − 3-month US Treasury yield, as a proxy for shadow cost of margin constraint.

Non-linear Relation: Regression Kink Model

Figure 8 is the scatter plot of TED spread and the proxy for global bank's consumption share; it suggests that the shadow cost of margin constraint indeed non-linearly increases as the global bank's consumption share falls. To formally test the non-linear relation, we estimate parameters in the following specification on monthly basis:

$$TED_t = b_1(w_t^b - k)_- + b_2(w_t^b - k)_+ + a_1 + \varepsilon_t$$

Table 3 shows that both slopes b_1 and b_2 are significant and negative, which is not entirely in line with the model prediction of $b_1 < 0$ and $b_2 = 0$. However, b_1 is steeper than b_2, and testing for a threshold effect, the two slopes are significantly different with p-value of 8% (Table 4). Figure 9 shows the fitted line with kink.

5.3 Shadow Cost of Position Limit Constraint and Performance of Global Banks Relative to the EM

Performance of Global Banks

The relevant state variable for position limit constraint of EM e is the b's consumption as a fraction of the EM's total consumption plus b's consumption. Again, we use global bank's market equity as a proxy for global banks' consumption, and each EM's market capitalization of equity index as a proxy for EM's consumption.

Proxy for Shadow Cost of Position Limit Constraint

To obtain a proxy for the shadow cost of position limit constraint ($\hat{\lambda}$), we first assume that the margins required for both EM forwards and US forwards are negligible. This assumption considerably simplifies the expression for basis; the basis expression is reduced to the following two cases:

$$Basis = \begin{cases} -\lambda\pi & \text{if net USD long} \\ \lambda\pi & \text{if net USD short} \end{cases}$$

from equations (18) - (25). In practice, the required margins are small (however non-zero) compared to equities, and we proceed with the simplifying assumption to test the model predictions. Figure 10 plots the constructed proxy for the position limit constraint for each country. Specifically, daily shadow cost of position limit is calculated as:

$$\hat{\lambda}_t = |Basis_t|/\pi_t \tag{26}$$

where $Basis_t = -\frac{1}{n}\ln(USFwd_{t,t+n}) + \frac{1}{n}\ln(EMFwd_{t,t+n})$. We use 6-month tenor ($n = 0.5$ year), because contracts with shorter tenor such as 1-week or 1-month are noisy and contracts with longer tenor such as 1-year and longer are not actively traded. To obtain monthly basis, we average daily basis for each calendar month. Since Taiwan implicitly regulates the positions by requiring banks to get approval of their internal position limit, we do not observe π for Taiwan.

Non-linear Relation

Figure 11 include scatter plots of the constructed proxy for λ and the global bank's consumption relative to each EM's consumption on monthly basis. Unreported analysis shows that linear regression coefficient is significantly negative only for Indonesia. This could be consistent with the model, if the true threshold lies outside of observed range. Overall, none of the rest of the three countries shows strong result consistent with the model.

5.4 Return Predictability

To test[9] whether high λ predicts lower future return on EM assets, we regress quarterly excess return (including the change in exchange rate) on each EM's stock index and government bond. The latter is same as currency risk premium if government bond is risk-free.

EM Stock Returns (in USD)

$$xr_{t,t+1} = \alpha + \beta\hat{\lambda}_t + \varepsilon_{t+1}$$

where $xr_{t,t+1}$ is return on a 1$ worth of investment in the EM's stock market (EM currency-denominated) converted back to USD for each quarter, in excess of US risk-free rate for the same period. The explanatory variable is lagged $\hat{\lambda}$ (average of daily $|Basis_t|/\pi_t$ for the previous month). Table 5 reports regression results for each country. The reported standard errors are Newey-West corrected. As the model predicts, the coefficients are negative and significant for Indonesia, India, and Thailand, where the position limits are relatively tight. This result remains similar for Indonesia and India when lagged TED spread is included as regressor (Table 6). Korea's result is inconsistent with the model, potentially due to lower degree of segmentation[10], other regulations and structural factors that are not modeled.

EM Currency Risk Premium

$$xr_{t,t+1} = \alpha + \beta\hat{\lambda}_t + \varepsilon_{t+1}$$

where $xr_{t,t+1}$ is return on a 1$ worth of investment in the EM's 3-month government bond (EM currency-denominated) converted back to USD for each quarter, in excess of US risk-free rate for the same period. This return is EM currency risk premium if EM government

[9] Sample period is short, 61 quarters, for return predictability analysis.

[10] In Korea's case, local market participants are allowed to trade US forwards to some extent (subject to a certain limit).

bond is risk-free. Table 7 reports regression results for each country. For Indonesia, the coefficient is significantly negative, consistent with the model. The results are overall weaker when TED spread is included in the regression, and the result for Korea is inconsistent with the model (Table 8). Again, this could be due to high degree of segmentation and other factors that are not modeled.

6 Conclusion

This paper explores the mispricing of FX forward contracts traded locally and the contracts traded outside of a country's jurisdiction for countries with FX position limits. With an intermediary asset pricing model, we show how the onshore and offshore FX forward contracts can be mispriced when the position limits bind for global banks. The main model prediction is that the basis is the sum of $|$position limit $\times$ its shadow cost$|$ and $|$required margin $\times$ its shadow cost$|$. Furthermore, the model implicates return predictability that high basis would predict the lower future excess returns on EM assets. The rationale behind this hypothesis is that when global banks allocate more capital to an EM economy and invest in the local-currency denominated assets, global banks' position limit constraint is relaxed. The model predictions are tested empirically, and we find evidence consistent with model implications, particularly in the countries with tight position limits.

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Tables

Table 1: Size of bases and Position Limits in 2018

The first row is the difference in basis during the crisis and basis outside of the crisis. The second row is position limit expressed as % of bank capital.

	KRW	TWD	INR	THB	IDR
Basis during crisis - Basis during the rest	0%	-0.59%	0.52%	0.67%	0.74%
Position limit[11] as % of bank capital	50%	*	25%	15%	20%

*each authorized bank is allowed to determine its own positions subject to the approval of the central bank.

Table 2: Difference in Mean Basis for Each Country

Mean and standard deviation of daily basis (6-month tenor) during the crisis (2007-2009) and non-crisis (2001-2006 and 2010-2018) are reported for each country. For Thailand, URR period is excluded.

IDR

	Crisis		Non-Crisis		Diff	
	mean	sd	mean	sd	b	t
basis_6m	-0.011	0.051	-0.003	0.026	0.0074***	(3.790)
Observations	715		3455		4170	

THB

	Crisis		Non-Crisis		Diff	
	mean	sd	mean	sd	b	t
basis_6m	-0.014	0.014	-0.007	0.012	0.0067***	(9.700)
Observations	422		3790		4212	

INR

	Crisis		Non-Crisis		Diff	
	mean	sd	mean	sd	b	t
basis_6m	-0.007	0.029	-0.002	0.014	0.0052***	(4.764)
Observations	737		3981		4718	

TWD

	Crisis		Non-Crisis		Diff	
	mean	sd	mean	sd	b	t
basis_6m	0.008	0.021	0.002	0.014	-0.0059***	(-7.428)
Observations	739		3931		4670	

KRW

	Crisis		Non-Crisis		Diff	
	mean	sd	mean	sd	b	t
basis_6m	-0.001	0.009	-0.001	0.005	0.0002	(0.668)
Observations	747		3802		4549	

Table 3: Regression Kink Model Estimates

TED is TED spread, difference between 3-month LIBOR and 3-month US Treasury yield. w^b is the proxy for global bank's consumption share.

$$TED_t = b_1(w_t^b - k)_- + b_2(w_t^b - k)_+ + a_1 + \varepsilon_t$$

	Est	SE	Pval	CI_L	CI_R
b1	-0.21	0.06	0.03	-0.35	-0.08
b2	-0.04	0.02	0.06	-0.07	-0.01
a1	0.01	0.00	0.00	0.00	0.01
k	0.17	0.01	0.00	0.15	0.18

Table 4: Testing for Threshold Effect

Testing whether the two slopes b_1 and b_2 are significantly different.

$$TED_t = b_1(w_t^b - k)_- + b_2(w_t^b - k)_+ + a_1 + \varepsilon_t$$

	FStat	Pval	CritVal	Level
1	5.25	0.08	4.89	0.90

Table 5: Stock Index Return Predictability with the Shadow Cost of Position Limit (λ)

$$xr_{t,t+1} = \alpha + \beta\hat{\lambda}_t + \varepsilon_{t+1}$$

$xr_{t,t+1}$ is quarterly excess stock market index return and $\hat{\lambda}_t$ is the measure of the shadow cost of position limit from Equation 26.

	IDR	INR	THB	KRW
Lambda Lag	-10.00***	-20.59**	-36.78***	4.695***
	(-5.55)	(-2.68)	(-4.27)	(5.91)
Constant	0.0702**	0.0646**	0.0606**	0.00729
	(3.39)	(2.91)	(3.18)	(0.65)
Observations	61	61	54	61
Adjusted R^2	0.14	0.06	0.07	0.03

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 6: Stock Index Return Predictability with the Shadow Cost of Position Limit (λ) and the Shadow Cost of Margin Constraint (ψ)

$$xr_{t,t+1} = \alpha + \beta^{\lambda}\hat{\lambda}_t + \beta^{\psi}\hat{\psi}_t + \varepsilon_{t+1}$$

$xr_{t,t+1}$ is quarterly excess stock market index return, $\hat{\lambda}_t$ is the measure of the shadow cost of position limit from Equation 26, and $\hat{\psi}_t$ is TED spread, a measure of the shadow cost of margin constraint.

	IDR	INR	THB	KRW
Lambda Lag	-8.349**	-17.08*	-12.93	5.147***
	(-3.00)	(-2.57)	(-0.48)	(3.61)
Ted3M Lag	-5.617	-4.174	-14.70	-10.94***
	(-1.38)	(-1.57)	(-1.95)	(-3.64)
Constant	0.0891**	0.0775**	0.0927***	0.0540**
	(3.30)	(3.41)	(4.73)	(3.00)
Observations	61	61	54	61
Adjusted R^2	0.15	0.05	0.13	0.17

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 7: Carry Trade Return Predictability with the Shadow Cost of Position Limit (λ)

$$xr_{t,t+1} = \alpha + \beta\hat{\lambda}_t + \varepsilon_{t+1}$$

$xr_{t,t+1}$ is quarterly currency risk premium and $\hat{\lambda}_t$ is the measure of the shadow cost of position limit from Equation 26.

	IDR	INR	THB	KRW
Lambda Lag	-3.654***	-1.016	-6.797*	1.098
	(-4.07)	(-0.94)	(-2.44)	(1.67)
Constant	0.0121	0.00118	0.00604	-0.00445
	(1.72)	(0.22)	(1.07)	(-0.52)
Observations	61	61	54	61
Adjusted R^2	0.17	-0.01	0.04	-0.00

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 8: Carry Trade Return Predictability with the Shadow Cost of Position Limit (λ) and the Shadow Cost of Margin Constraint (ψ)

$$xr_{t,t+1} = \alpha + \beta^{\lambda}\hat{\lambda}_t + \beta^{\psi}\hat{\psi}_t + \varepsilon_{t+1}$$

$xr_{t,t+1}$ is quarterly currency risk premium, $\hat{\lambda}_t$ is the measure of the shadow cost of position limit from Equation 26, and $\hat{\psi}_t$ is TED spread, a measure of the shadow cost of margin constraint.

	IDR	INR	THB	KRW
Lambda Lag	-2.972*	1.320	-4.900	1.300**
	(-2.06)	(1.24)	(-0.88)	(3.22)
Ted3M Lag	-2.316*	-2.776***	-1.170	-4.891***
	(-2.03)	(-4.39)	(-0.90)	(-7.77)
Constant	0.0198*	0.00977	0.00859*	0.0164**
	(2.45)	(2.00)	(2.18)	(2.78)
Observations	61	61	54	61
Adjusted R^2	0.19	0.05	0.03	0.16

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Figures

Figure 1: Time Series of 6M Basis

Time series of basis, difference between log of EM 6M forward rate and log of US 6M forward rate, for each country.

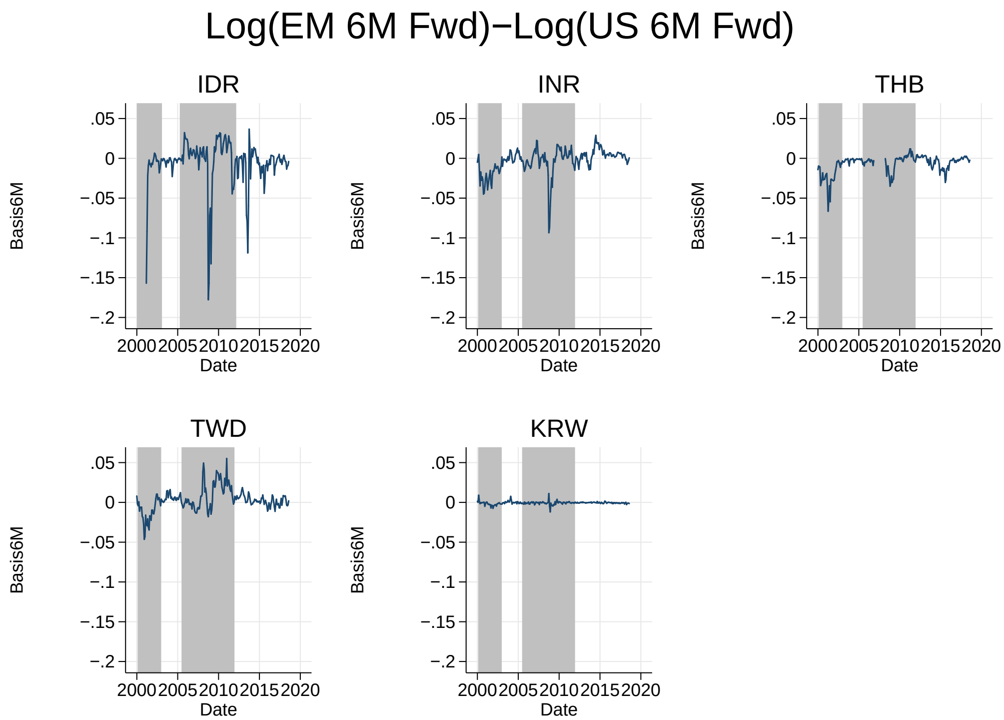


Figure 2: Position Limits

Historical position limits ($1/\pi$) for each country. Higher PL indicates tighter position limit. In Taiwan, each authorized bank is allowed to determine its own positions subject to the approval of the central bank. Therefore, explicit position limits are not observed for Taiwan.

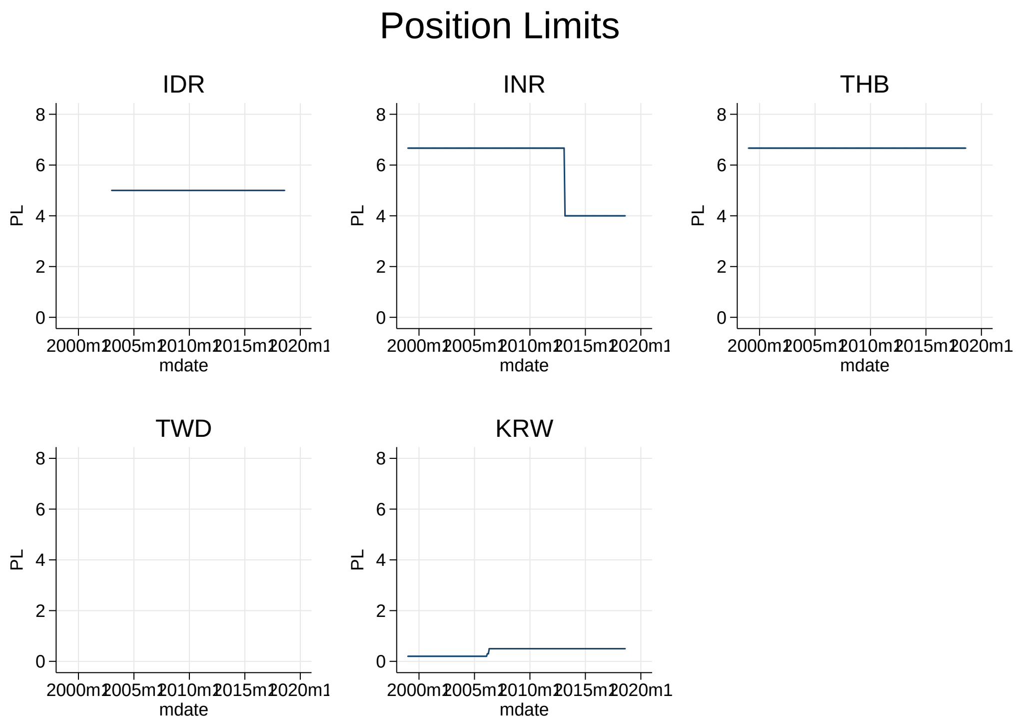


Figure 3: Thailand Baht Basis

Time series of basis for Thailand Baht. Blue area indicates the period when unremunerated reserve requirement was applied.

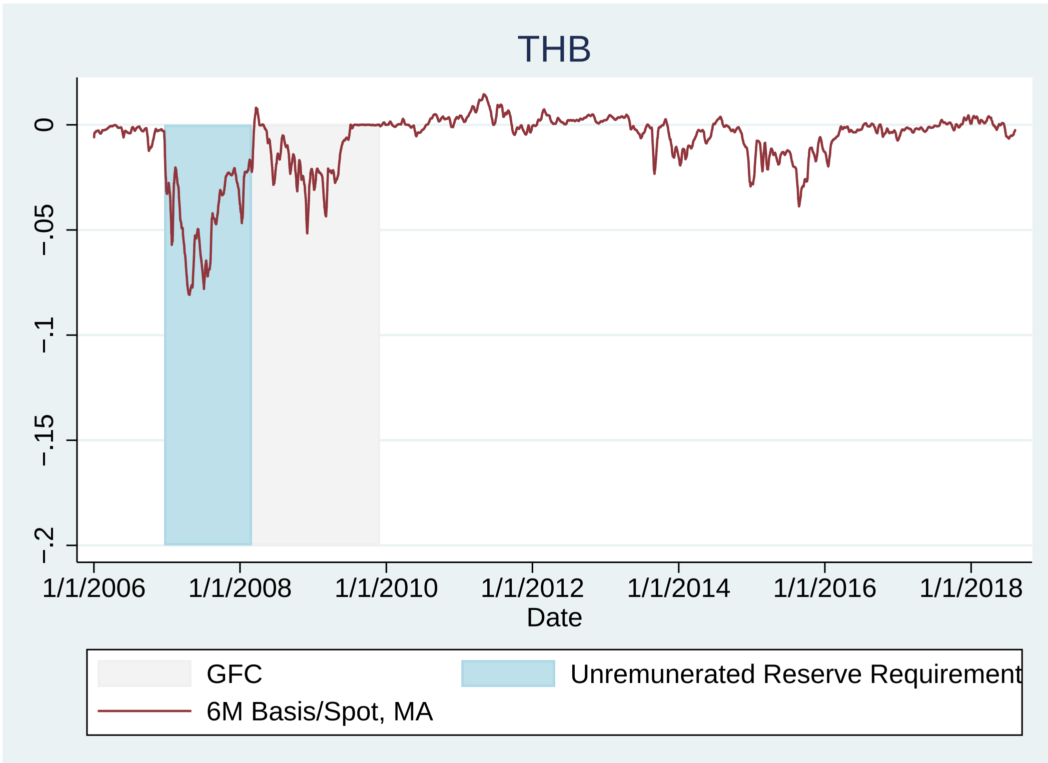


Figure 4: Model Prediction about Margin Constraint

Model prediction of non-linear relation between the shadow dost of margin constraint (ψ) and the performance of global banks relative to the world (c^b). This plot is generated based on Garleanu and Pedersen (2011)'s calibrated model. When global banks are poor enough, their margin constraint binds more and the shadow cost of margin constraint (ψ) rises.

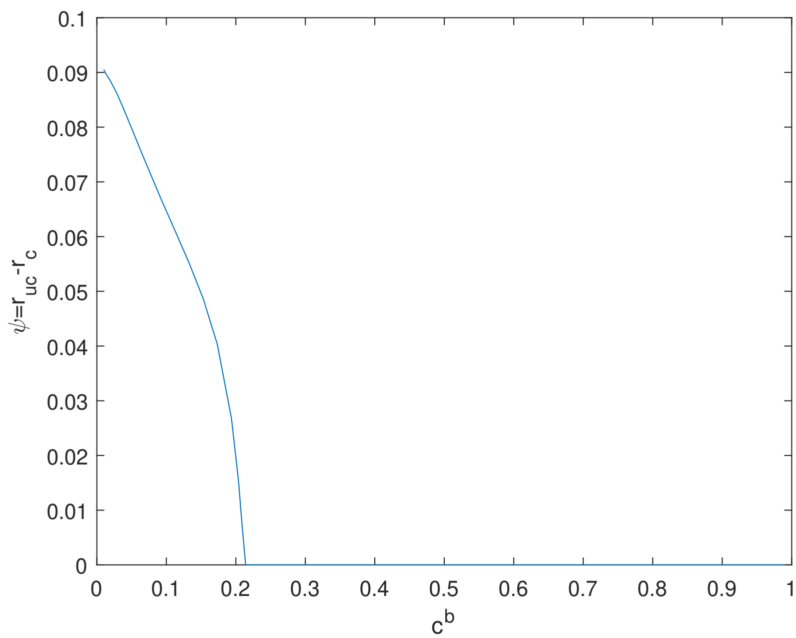
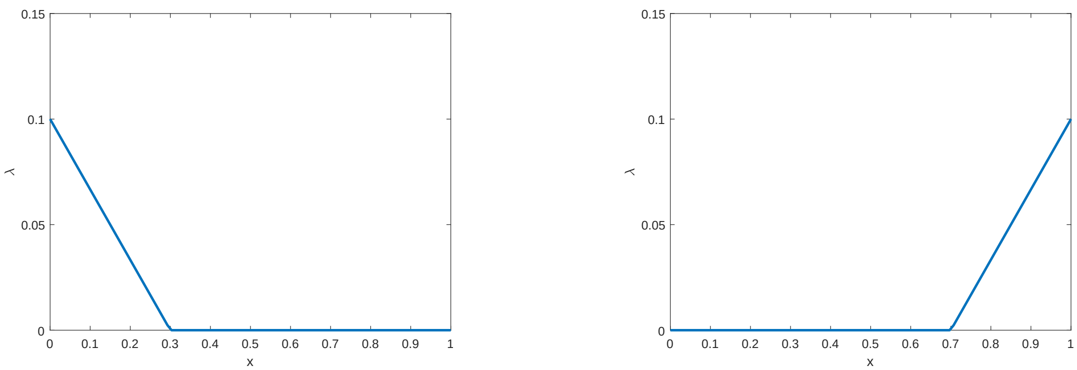


Figure 5: Model Prediction about FX Position Limit Constraint when \$ assets are *more* volatile than ₩ assets in EM.

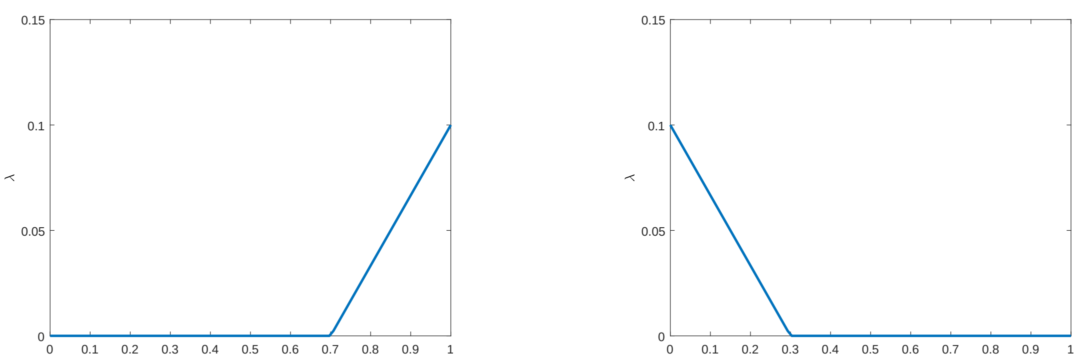
Since global bank is more risk tolerant, he is more heavily invested in the riskier asset $e\$$ than e₩. Following a series of bad shocks, global bank loses more and risk-averse agent becomes a larger part of the market. As a result, premium on $e\$$ rises by more than e₩ to induce risk-averse agents to hold more $e\$$ for markets to clear. This is when position limit constraint binds more (higher λ) if global bank holds net long USD position in the EM. Therefore, as global bank's relative performance (x) decreases, shadow cost of position limit (λ) increases non-linearly. (Panel a).



(a) Net Long USD in EM

(b) Net Short USD in EM

Figure 6: Model Prediction about FX Position Limit Constraint when \$ assets are *less* volatile than ₩ assets in EM.



(a) Net Long USD in EM

(b) Net Short USD in EM

Figure 7: Proxy for Global Banks' Performance

Time series of global banks' performance measure: $c^b = \frac{ME^b}{ME^a + ME^b}$. For the numerator, Fama French's 49 industry definition is used to classify firms. For the denominator, MSCI's global equity (ACWI) index is used.

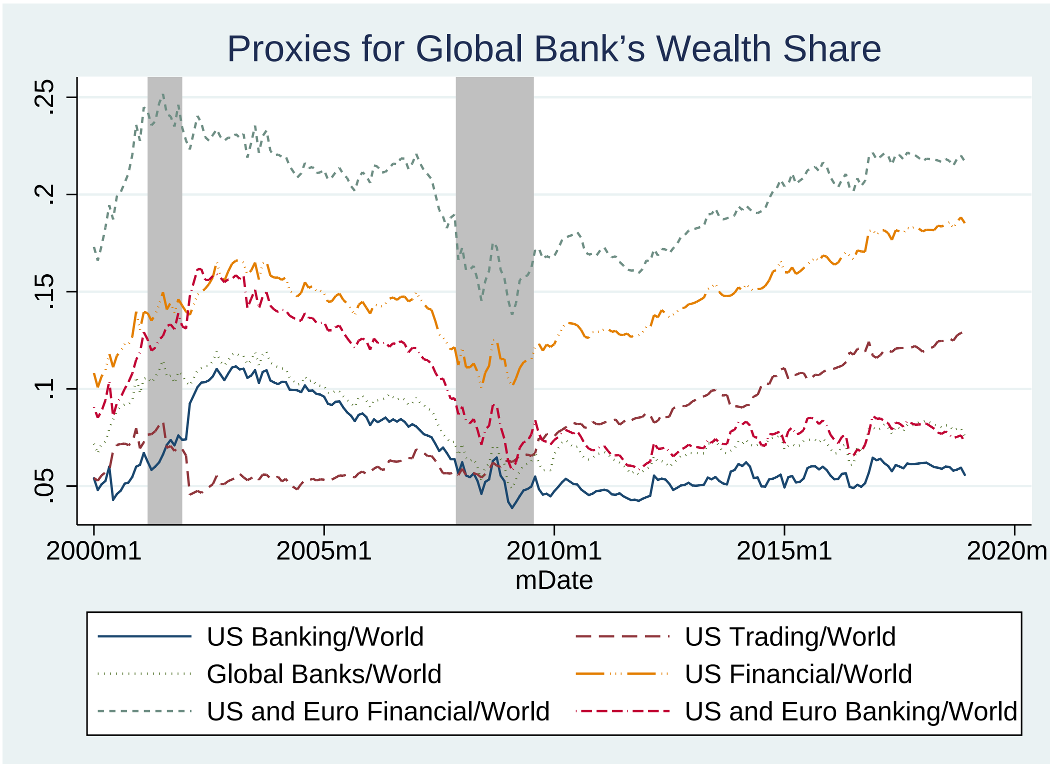
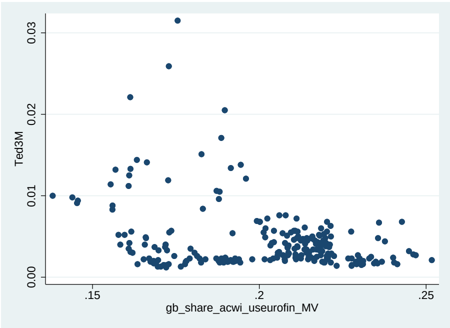
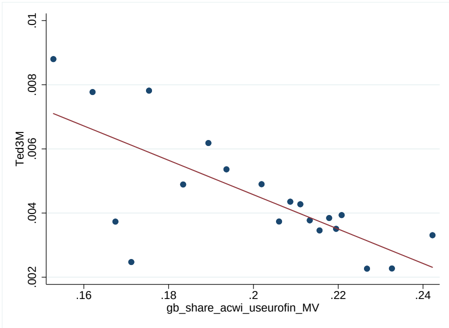


Figure 8: TED Spread vs. Global Bank's Consumption Share



(a) Scatter Plot



(b) Binned Scatter

Figure 9: TED Spread vs. Global Bank's Consumption Share (Fitted)

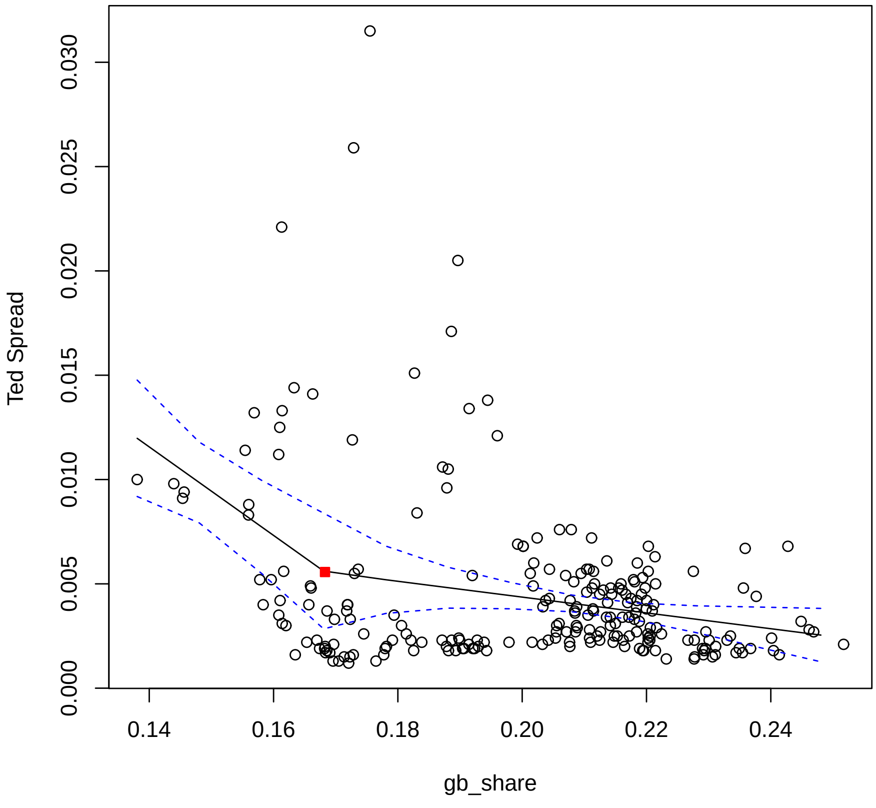


Figure 10: Proxy for the Shadow Cost of Position Limit ($\hat{\lambda}$)

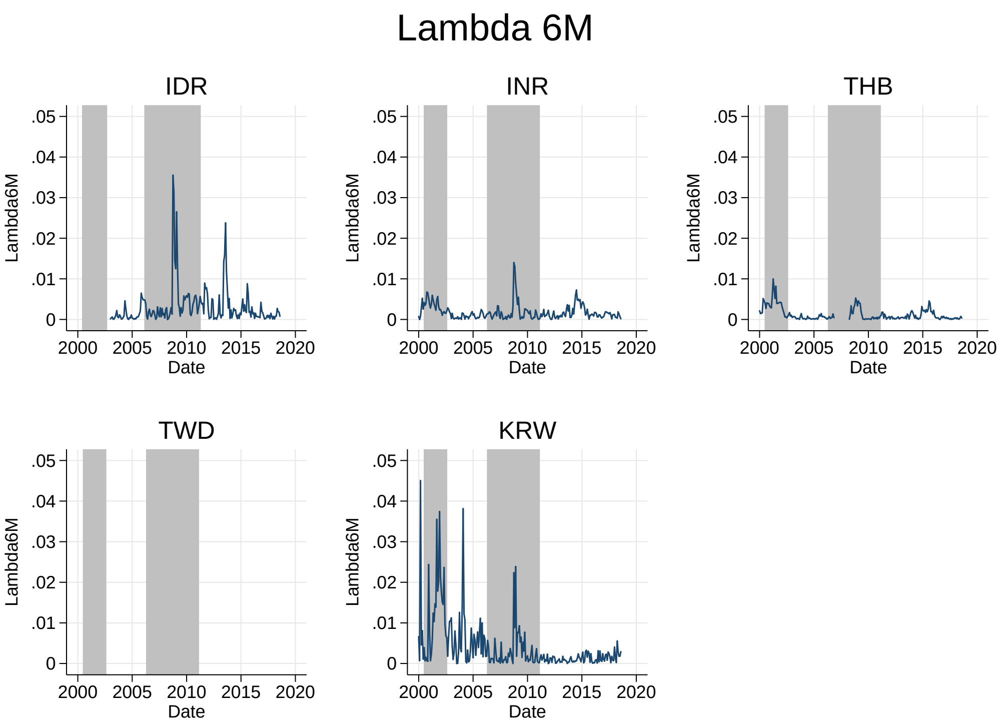
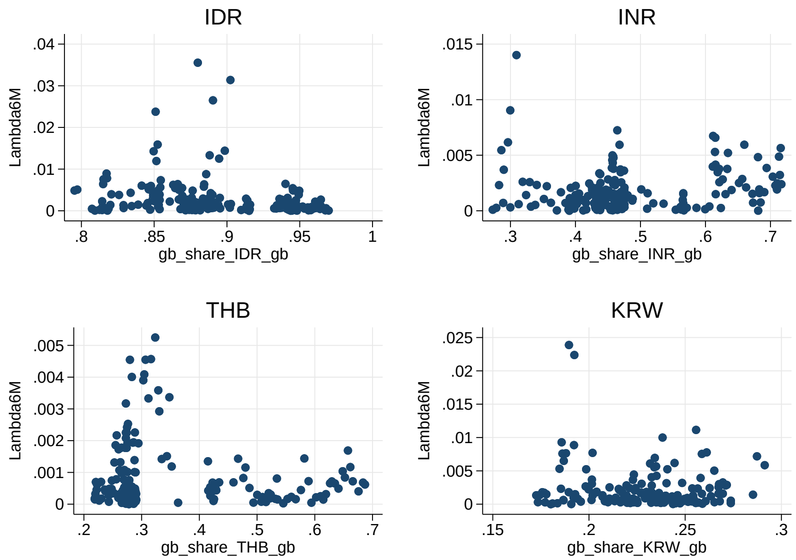


Figure 11: Proxy for Shadow Cost of Position Limit ($\hat{\lambda}$) vs. Global Banks' Performance Relative to EM



A Bases Summary Statistics

Table 9: Indonesia

	IDR			
	Basis1M	Basis3M	Basis6M	Basis12M
N	210.0000	210.0000	210.0000	210.0000
Mean	-0.0161	-0.0087	-0.0055	-0.0026
SD	0.0806	0.0435	0.0295	0.0171
Min	-0.6746	-0.3115	-0.1777	-0.0982
Max	0.3121	0.0865	0.0367	0.0275
AC	0.4831	0.6164	0.7154	0.7181

Table 10: India

	INR			
	Basis1M	Basis3M	Basis6M	Basis12M
N	223.0000	223.0000	223.0000	223.0000
Mean	-0.0048	-0.0034	-0.0029	-0.0025
SD	0.0255	0.0204	0.0158	0.0119
Min	-0.2191	-0.1577	-0.0934	-0.0593
Max	0.0488	0.0380	0.0290	0.0188
AC	0.6108	0.7843	0.8619	0.9014

Table 11: Korea

	KRW			
	Basis1M	Basis3M	Basis6M	Basis12M
N	224.0000	224.0000	224.0000	224.0000
Mean	-0.0028	-0.0010	-0.0007	-0.0005
SD	0.0093	0.0034	0.0020	0.0012
Min	-0.0444	-0.0195	-0.0119	-0.0090
Max	0.0544	0.0172	0.0112	0.0046
AC	0.3850	0.3773	0.3334	0.4150

Table 12: Taiwan

	TWD			
	Basis1M	Basis3M	Basis6M	Basis12M
N	224.0000	224.0000	224.0000	224.0000
Mean	0.0052	0.0047	0.0031	0.0008
SD	0.0249	0.0180	0.0142	0.0108
Min	-0.1126	-0.0603	-0.0464	-0.0312
Max	0.1758	0.0940	0.0552	0.0344
AC	0.5631	0.8012	0.8683	0.9121

Table 13: Thailand

	THB			
	Basis1M	Basis3M	Basis6M	Basis12M
N	224.0000	224.0000	224.0000	224.0000
Mean	0.0349	0.0049	-0.0016	-0.0039
SD	0.1922	0.0583	0.0284	0.0152
Min	-0.2302	-0.1043	-0.0665	-0.0529
Max	1.2056	0.3755	0.1769	0.0837
AC	0.9046	0.8871	0.8760	0.8793

Table 14: Thailand (Excluding URR Period)

	THB			
	Basis1M	Basis3M	Basis6M	Basis12M
N	208.0000	208.0000	208.0000	208.0000
Mean	-0.0093	-0.0079	-0.0073	-0.0064
SD	0.0156	0.0135	0.0116	0.0098
Min	-0.0953	-0.0867	-0.0665	-0.0529
Max	0.0136	0.0142	0.0119	0.0116
AC	0.6489	0.8202	0.8758	0.9141

B 6M Bases Correlation Across Countries

	Corr				
	IDR	INR	KRW	TWD	THB
IDR	1.0000	0.0000	0.0000	0.0000	0.0000
INR	0.6408	1.0000	0.0000	0.0000	0.0000
KRW	0.0151	0.2334	1.0000	0.0000	0.0000
TWD	0.5253	0.6390	0.2832	1.0000	0.0000
THB	0.4079	0.4735	0.2217	0.6420	1.0000

C Other Proxies for Shadow Cost of Margin Constraint

Figure 12: TED Spread and Libor-Repo Spread

The correlation between the two spreads is 0.8456.

psi_m-eps-converted-to.pdf

Alternatively, Libor3M - Repo3M, IOER - Repo1W, IOER - OIS1W, and tenor basis swap 5 year are considered. Here are summary statistics of spreads and the correlation:

Table 15: Summary Statistics of Spreads

	Spreads				
	TED3M	Libor-Repo3M	IOER-Repo1W	IOER-OIS1W	TenorBasisSwap5Y
N	390.0000	326.0000	117.0000	117.0000	252.0000
Mean	0.0058	0.0026	0.0008	0.0011	0.0006
SD	0.0044	0.0029	0.0009	0.0005	0.0005
Min	0.0012	-0.0005	-0.0022	0.0002	-0.0000
Max	0.0315	0.0310	0.0045	0.0045	0.0019
AC	0.8612	0.7532	0.5809	0.3769	0.9617

Table 16: Correlation of Spreads

Corr	TED3M	Libor-Repo3M	IOER-Repo1W	IOER-OIS1W	TenorBasisSwap5Y
TED3M	1.0000	0.0000	0.0000	0.0000	0.0000
Libor-Repo3M	0.8456	1.0000	0.0000	0.0000	0.0000
IOER-Repo1W	0.0637	0.0966	1.0000	0.0000	0.0000
IOER-OIS1W	0.0438	-0.0223	0.6785	1.0000	0.0000
TenorBasisSwap5Y	-0.1238	-0.0227	-0.2861	-0.0721	1.0000

D Term Structure of Bases

Annualized daily basis (10-day moving average) for 1M and 6M contracts.

Figure 13: Indonesia

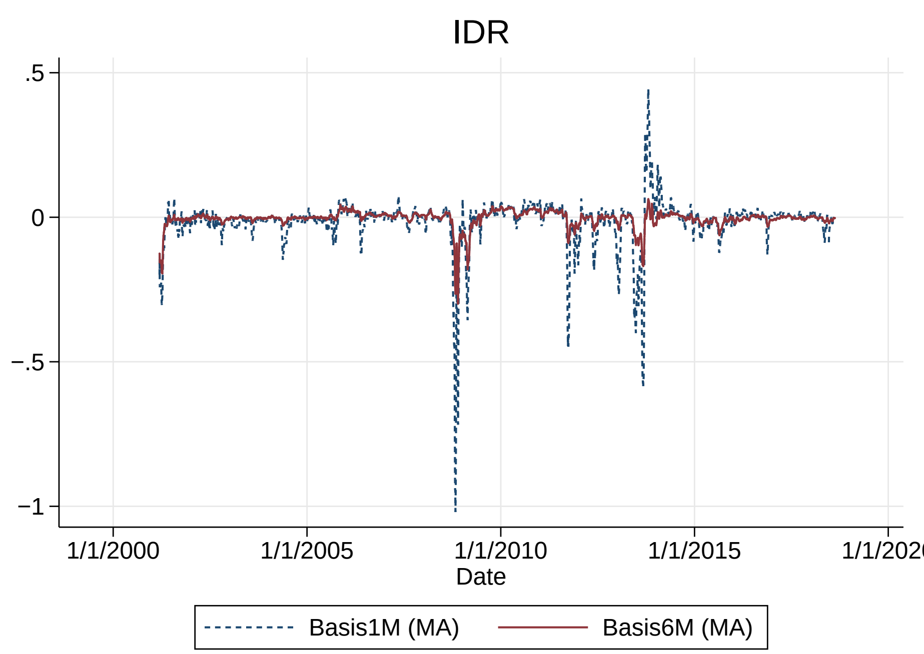


Figure 14: Thailand

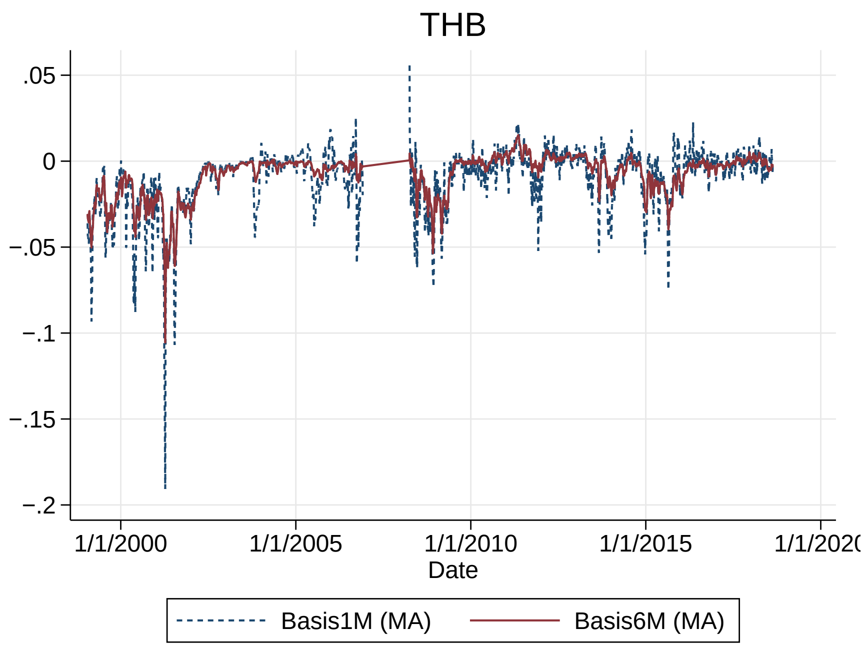


Figure 15: India

Figure 16: Taiwan

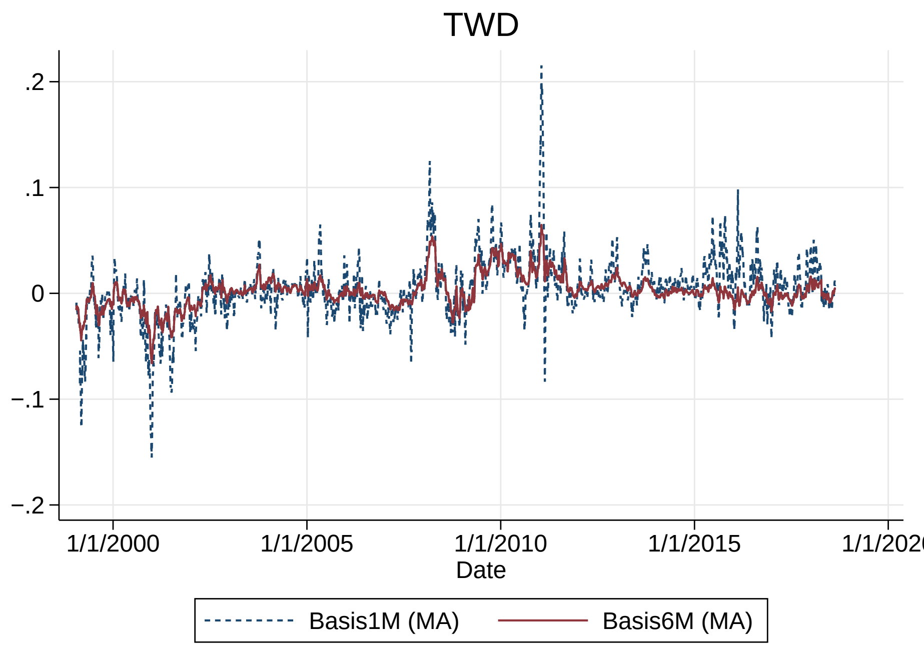
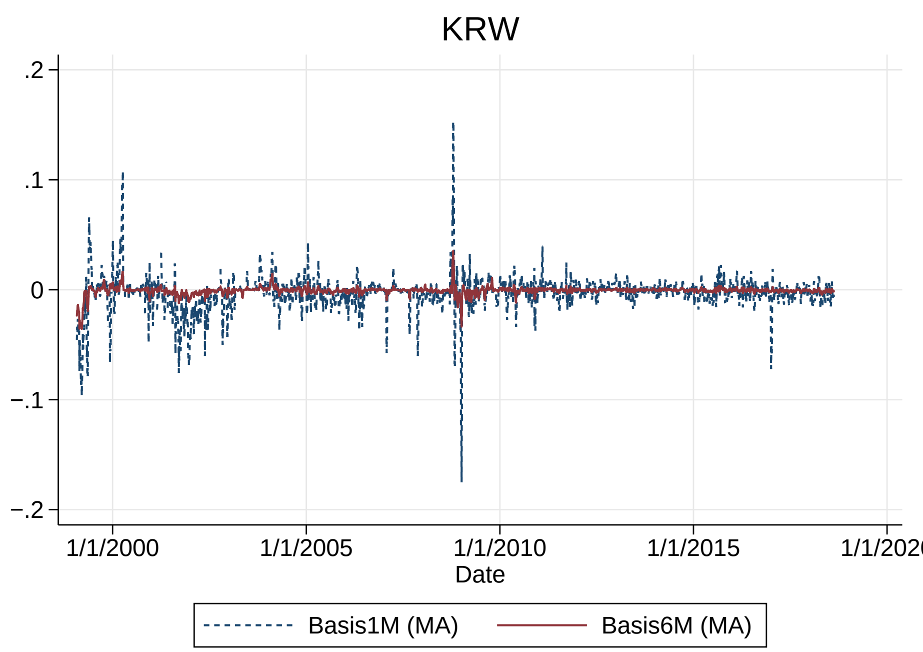


Figure 17: Korea



E Regulations

- Korean Won (KRW)
  - Not deliverable, Convertible on current account but with limited convertibility on capital account.
  - Resident Participation in NDF: Allowed for limited size (since April 1999)
  - Non-resident Participation in DF: Not allowed
  - NOP Limit: 15% → 20% in 1999, → 30% in 2006 March 22, → 50% in 2006 May 22.
  - Derivatives Position Limit: Effective July 1, 2016, the limits on banks' foreign exchange derivatives contracts were increased to 40% from 30% of bank capital (for domestic banks) and to 200% from 150% (for foreign bank branches).

- Indian Rupee (INR)
  - Not deliverable, Convertible on current account but with limited convertibility on capital account.
  - Resident Participation in NDF: Not allowed
  - Non-resident Participation in DF: Allowed only for hedging real (trade and investment) transactions.
  - NOP Limit: NOP should not exceed 25 percent of the total capital (Tier I and Tier II capital) of the bank. (RBI Circular 2013). Net Overnight Open Position Limits (NOOPL) were reduced[12] in December 2011 and relaxed in 2013.

- Indonesian Rupiah (IDR)
  - Not deliverable, Convertible on current account but with limited convertibility on capital account.
  - Resident Participation in NDF: Not allowed. [13]
  - Non-resident Participation in DF: Allowed but limited. [14]
  - NOP Limit: Banks in Indoensia can have maximum NOP of 20 percent of their capital.

[12] by 50-70% (not official)

[13] On 19 Jan 2001, BI prohibited onshore banks from lending or transferring IDR to offshore accounts, effectively making IDR non-deliverable offshore.

[14] For instance in 2012, permitted upto USD 1 million per counterparty without documentation.

- New Taiwan Dollar (TWD)
  - Convertible on current account but with limited convertibility on capital account.
  - Resident Participation in NDF: Not allowed. Initially in 1995, the CBC set up a firewall to limit the NDF trading position of authorized banks to one third of their total foreign exchange position. However, in 1998, CBC announced that only the authorized banks could carry out NDF trades with other authorized counterparts and their overseas branches or headquarters. [15]
  - Non-resident Participation in DF: Not allowed
  - NOP Limit: From July 1, 1996 onwards, each authorized bank has been allowed to determine its own overbought and oversold positions subject to the approval of the Bank.[16] The CBC requires authorized foreign exchange banks to follow the sum of position limits for NDF and foreign exchange options such that the combined amount may not exceed one-fifth of the total position limit. [17]

- Thailand Baht (THB)
  - Convertible on the current account, deliverable offshore with some restrictions on capital account.
  - BoT enacted an URR (unremunerated reserve requirement) regime in December 2006 (effective 18 December 2006) to slow speculative capital inflows. BoT applied 30% reserve requirement on investments into Thailand and restricted the movements of THB from onshore to offshore. This regime was dismantled in February 2008, effective 03 March 2008. [18]
  - Resident participation in offshore DF: Residents can sell/buy THB (and buy/sell USD) from offshore, but not the other way. The size of such transaction is limited to 300 million THB per day per bank (group).
  - Non-resident participation in onshore DF: Non-residents can buy/sell THB from onshore, but not the other way. The size of such transaction is limited to 300mio THB per day per bank (group). Non-residents can access the onshore forward market to hedge equity and other investments with valid documentation.

[15] https://www.cbc.gov.tw/public/Attachment/562515465471.PDF
[16] https://www.cbc.gov.tw/ct.asp?xItem=857&CtNode=481&mp=2
[17] https://www.cbc.gov.tw/public/Attachment/5101911345971.pdf
[18] https://www.bot.or.th/thai/pressandspeeches/press/news2551/n0951e.pdf

– NOP Limit: Financial Institutions are required to maintain net open positions in each currency of no more than 15 percent and an aggregate position of no more than 20 percent of total capital at the end of the day.

F Global Banks

Global banks (FX dealers) with both onshore and offshore presences are well positioned for the arbitrage trades. Table 17 lists the top 10 FX dealers in Asia region. The combined market shares of these banks is 76%.

Table 18 shows the local presence of large global banks. The values (1 or 0) indicate whether the bank has onshore presence (either as a subsidiary or branch with FX forward dealing license). Due to local market closings, Singapore or Hong Kong is the offshore center that is useful for executing the arbitrage trades. The data sources are SNL and the websites of local central banks.

Table 17: Top 10 Liquidity Provider in Asia (by Euromoney)

2018	2017	Liquidity Provider	Asia Regional Market Share
1	3	JPMorgan	17%
2	2	Bank of America Merrill Lynch	10%
3	4	UBS	8%
4	1	Citi	7%
5	10	Goldman Sahcs	7%
6	7	Deutsche Bank	7%
7	31	XTX Markets	6%
8	8	HSBC	5%
9	6	Standard Chartered	5%
10	5	Barclays	4%

https://www.euromoney.com/article/b18c1skvsyyk47/fx-survey-2018-market-share-by-region#APAC2

Table 18: Local Presence of Global Banks

Bank Name	Hong Kong	Singapore	Korea	Indonesia	India	Philippines	Thailand	Taiwan	Malaysia	Total Assets	Ultimate Parent Country
Mitsubishi UFJ Financial Group	1	1	1	1	1	1	1	1	1	2722	Japan
JPMorgan Chase Co.	1	1	1	1	1	1	1	1	1	2533	USA
HSBC Holdings Plc	1	1	1	1	1	1	1	1	1	2521	United Kingdom
BNP Paribas SA	1	1	1	1	1	0	1	1	1	2353	France
Bank of America Corp.	1	1	1	1	1	1	1	1	1	2281	USA
Citigroup Inc	1	1	1	1	1	1	1	1	1	1842	USA
Mizuho Financial Group	1	1	1	1	1	1	1	1	1	1799	Japan
Deutsche bank AG	1	1	1	1	1	1	1	1	1	1770	Germany
Sumitomo Mitsui Financial Group Inc.	1	1	1	1	1	1	1	1	1	1660	Japan
Barclays Plc	1	1	1	0	1	0	0	1	0	1532	United Kingdom
Societe Generale	1	1	1	0	1	0	0	0	0	1531	France
ING Groep NV	1	1	1	1	0	1	0	1	1	1016	Netherlands
Royal Bank of Canada	1	1	1	0	0	0	0	0	0	940	Canada
UBS Group	1	1	1	0	0	0	0	1	0	939	Switzerland
Goldman Sachs Group Inc	1	1	1	0	0	0	0	0	1	917	USA
Morgan Stanley	1	1	1	1	0	0	0	1	0	851	USA
Credit Suisse Group AG	1	1	1	0	1	0	0	0	1	817	Switzerland
Bank of Nova Scotia	1	1	1	0	1	0	0	1	1	710	Canada
Australia and New Zealand Banking Group Ltd.	1	1	1	1	1	1	1	1	0	703	Australia
Standard Chartered	1	1	1	1	1	1	1	1	1	663	United Kingdom
Bank of New York Mellon Corporation	1	1	1	0	0	0	0	1	0	371	USA
Nomura holdings	1	1	1	0	1	0	1	1	1	365	Japan
DBS Group Holdings	1	1	1	1	1	0	0	1	0	333	Singapore
State Street Corporation	1	1	1	0	0	0	0	1	1	242	USA