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Abstract

We study the forces driving dollar funding stress under adverse market conditions for EMEAP economies. We find that the response of dollar funding conditions to changes in macro-financial variables differs significantly between orderly and turbulent markets. In orderly markets, idiosyncratic dollar strength, and its volatility and market expectations, are key factors affecting the stress for the economy. Monetary policy divergence, which to a large extent reflects the position of the economy relative to the US in the economic cycle, also plays an important role in the short-term funding market. In turbulent markets, the effect of these variables except the volatility of dollar strength against individual currencies, which retains a strong influence, diminishes or even vanishes. Instead, the credit worthiness of the government and corporate sectors, which is found to have little impact under normal market conditions, emerges as a major stress determinant, and becomes increasingly influential as adversity intensifies.

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I. INTRODUCTION

During the Covid-19 pandemic, social distancing measures have been an inevitable policy response in practically all countries in combating the spread of the virus. In cities and countries where the spread takes hold, the authorities have been left with no alternative but to enforce lockdowns, forcing all social activities to a standstill and paralysing the economy. As a result, the world has slipped rapidly into an economic abyss which will almost certainly be the deepest since the Great Depression in the 1930s.[1]

In view of the sharply deteriorating economic outlook for the US and globally, the Federal Reserve eased monetary policy aggressively and took extraordinary steps to cushion the economy and provide sufficient liquidity for US financial institutions and corporations.[2] Given the unrivalled role the US dollar plays in facilitating international finance and trade, the availability and adequacy of dollar funding are equally important for financial institutions and corporations outside the US to weather the global health crisis. However, the actions of the Federal Reserve did not help them initially. Shortly after the announcement on 11 March 2020 by the World Health Organization (WTO) that the outbreak had evolved into a pandemic, a severe shortage of US dollars quickly developed internationally, imposing significant dollar funding stress on the global economy (Avdjiev et al, 2020).

The dust appears to have settled after the Federal Reserve reinvigorated its existing swap line arrangements with major central banks and introduced new ones with the central banks of some emerging markets.[3] However, uncertainty still looms large given that safe and effective vaccines are unlikely to be available for some time yet. Adding to the uncertainty is the recent sharp escalation of the US-China tensions over a wide range of geopolitical issues. Could this lead to a potential reduction in US dollar supply globally or to some economies? Are we already in the

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[1] The latest IMF projection for global growth for 2020 is -4.9 percent as a consequence of what is referred to as the Great Lockdown (https://blogs.imf.org/2020/06/24/reopening-from-the-great-lockdown-uneven-and-uncertain-recovery/).

[2] The Federal Open Market Committee decided to lower the target range for the federal funds rate by 1/2 percentage point to 1 to 1-1/4 percent on 3 March 2020 (https://www.federalreserve.gov/newsevents/pressreleases/monetary20200303a.htm) and by 1 full percentage point to 0 to 1/4 percent on 15 March 2020 (https://www.federalreserve.gov/newsevents/pressreleases/monetary20200315a.htm).

[3] According to the Board of Governors of the Federal Reserve System (2020), the Bank of Canada, the Bank of England, the Bank of Japan, the European Central Bank, the Federal Reserve, and the Swiss National Bank have taken coordinated action to enhance the provision of liquidity via the standing U.S. dollar liquidity swap line arrangements. In addition, the Federal Reserve has established temporary dollar liquidity swap lines with nine additional foreign central banks.

run-up to more significant global financial turmoil than in March when the WTO declared a pandemic? There seems to be a pressing need for policy makers to understand better the driving forces behind dollar funding stress so that they can be more prepared when the next crisis hits. This is particularly true for Asia, given the region's considerably larger share of economic activity accounted for by global supply chains, and its traditionally stronger demand for dollar funding and higher funding cost sensitivity (Hong et al, 2019).

Research on the driving forces behind dollar funding stress is not new. However, much of it is focused on explaining what causes or sustains it, in particular why the phenomenon has persisted for years after the 2007/08 global financial crisis and the European debt crisis (Baba & Packer, 2009a; Ivashina et al, 2015; Borio et al, 2016; Du et al, 2019; Sushko et al, 2017; Cerutti et al, 2019). No study has so far attempted to identify the forces in crisis times. This paper contributes to the literature as a first attempt to study the dynamics of these forces under extreme market situations, focusing on eight EMEAP economies.[4] We first examine the normal market relationship between dollar funding stress and a number of potentially determining factors, leveraging on the findings of previous studies. We then estimate the distressed market relationship between them to uncover any behavioural changes.

Interestingly, we find that bilateral dollar strength, rather than the strength of the dollar globally, plays a much more important role in determining dollar funding stress for the economies in the region, a result that is in contrast with Avdjiev et al (2019) which finds that idiosyncratic currency strength plays, if any, a passive role. We also find that currency volatility and expectations, which reflect risks pertaining to dollar strength on a bilateral basis, contribute to the stress. However, these drivers, except currency volatility, are left on the back burner by the dollar lender in extending credit in financial turmoil, especially under the most extreme scenario. Instead, the credit risk of the government and corporate sectors, which has little impact on both the short and long-term stress during normal market times, emerges as a primary consideration for the dollar lender in turbulent markets. This suggests that borrowers from economies with a weaker fiscal position or higher corporate debt may face greater challenges in dollar funding markets in crisis times.

The rest of the paper is organised as follows. In the next section we explain and define what we mean by dollar funding stress. Section 3 discusses the

[4] EMEAP stands for the Executives' Meeting of East Asia-Pacific Central Banks, a forum launched in 1991 to strengthen the cooperative relationship among central banks in the East Asia and Pacific region.

potential factors driving dollar funding stress. In Section 4 we set out the model, its specifications and the data used for estimation. Section 5 presents and discusses our results. Section 6 concludes the paper with a brief discussion of the policy implications.

II. WHAT IS DOLLAR FUNDING STRESS?

Cost of USD borrowing *per se* should not be taken to mean or reflect dollar funding stress. Otherwise, most funding markets would have registered a reduction, rather than an increase, in the stress at the peak of the outbreak earlier this year. For example, the three-month USD Libor, the cost of borrowing in the interbank money market, in fact fell substantially but the fall was mainly attributed to the large reductions in the target Fed funds rate by the Federal Reserve in March 2020.[5] It is also debatable to label larger spreads of the Libor over its respective overnight indexed swap (OIS) rate as evidence for higher dollar funding stress. As OIS is practically risk-free, the Libor-OIS spread reflects mostly the premium the lender charges for lending on an uncollateralised basis.[6] Other things being equal, this premium would thus increase as the economic environment deteriorates and *vice versa*. True, when the premium increases, it pushes up the Libor, the total cost of USD borrowing. However, a higher cost resulting from a larger premium to compensate the lender for taking a higher risk is not what the stress refers to here.

Dollar funding stress refers to what is above and beyond the cost of borrowing in the Libor market. The interest rates that matter to the borrower are the ones at which he can borrow. The well-known problem with the Libor market is that it is not a market that is always accessible to all.[7] For those shut out of the interbank money market in times of financial turbulence, the Libor is simply irrelevant. Under these circumstances, it is the market they turn to which matters. And the most popular alternative for them is probably the cross-currency swap market, in which they could swap their domestic currency for US dollars, i.e., effectively borrowing US dollars by pledging another currency as collateral.

The more stressful the situation is, more financial institutions and

[5] The Libor, the London interbank offered rate, remains the most popular benchmark cost of borrowing in the interbank money market despite its widely known problems (King and Lewis, 2020).

[6] A Libor transaction is one in which a party lends to another without any collateral, but an OIS, an interest rate swap between a fixed rate and a pre-determined floating daily overnight rate, is a transaction that does not involve lending or exchange of principals.

[7] This may be best exemplified by the difficulties experienced by European financial institutions during the 2007/08 global financial crisis (Baba and Packer, 2009a).

corporations would be forced to resort to the market for USD funding. Other things being equal, this would push up the cost of USD borrowing in the cross-currency swap market. Theoretically, the costs of borrowing should equalise across markets under covered interest parity. Any difference in the borrowing cost between the Libor and cross-currency swap markets cannot sustain even for minute periods of time as traders and other market participants would arbitrage it away. However, following the 2007/08 global financial crisis, the pressure has grown so much that the cost of borrowing US dollars in the cross-currency swap market now often exceeds that in the interbank money market, making possible material violations to the parity condition.

The resulting deviation, which often occurs in favour of the US dollar, is widely interpreted as an indication of how much the market is under stress in its hunger for US dollars.[8] The level of stress can thus be measured by the deviation, that is, the extent to which the cost of USD borrowing in the cross-currency swap market exceeds the cost of USD borrowing in the interbank money market. For short-term dollar funding, the dollar funding stress can be measured by the FX swap basis, which is the difference between the USD Libor and the implied USD interest rate in the FX swap transaction. For long-term dollar funding, it can be gauged directly by the basis traded in the cross-currency basis swap (CCBS) market.[9] The more negative the FX swap or CCBS basis, the greater is the USD shortage and the higher is the dollar funding stress.

In March, the three-month FX swap basis increased 100 basis points for the Japanese yen, 54 for the euro, 63 for the British pound and 91 for the Swiss franc within one week following the WHO announcement, while the five-year CCBS basis widened 13 basis points for the Japanese yen, 4 for the euro, 5 for the British pound and 6 for the Swiss franc. In emerging Asia, economies also took a similar beating, reaching levels unseen in recent years (Figures 1 and 2). The same week saw, for instance, the three-month FX swap basis rise 266 basis points for the Singapore dollar, 9 for the Hong Kong dollar and 161 for the Korean won, whereas there was a widening of the basis by 17, 10 and 72 basis points respectively for these currencies in the CCBS market.

[8] There are, however, competing theories arguing that when counterparty credit risks are present (which is the case after the global financial crisis, as can be seen from the Libor-OIS spread for most currencies), the deviation merely reflects that interest rates for unsecured lending/borrowing are no longer appropriate for pricing the secured transactions in cross-currency swap markets (Wong and Zhang, 2018).

[9] In both cases, the counterparty credit risk involved in the transaction is minimal as the USD borrowing party needs to pledge another currency as collateral. At the same time, the funding liquidity risks of the two parties are swapped, where the USD lending party takes the funding liquidity risk of USD while the USD borrowing party takes the funding liquidity risk of the other currency.

Figure 1 3-month FX Swap Bases of EMEAP Currencies, Jan 2017 - May 2020

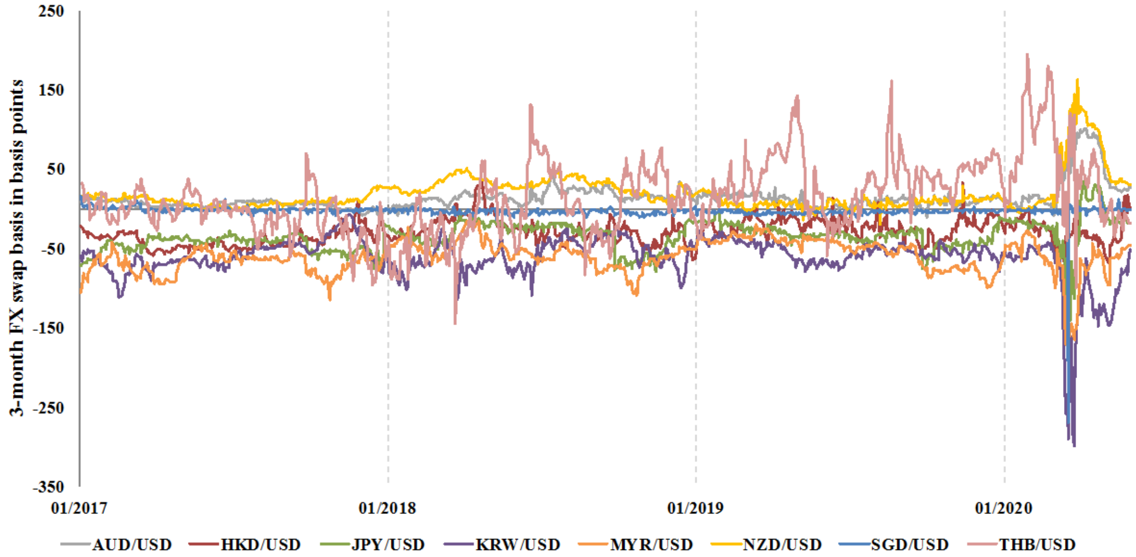
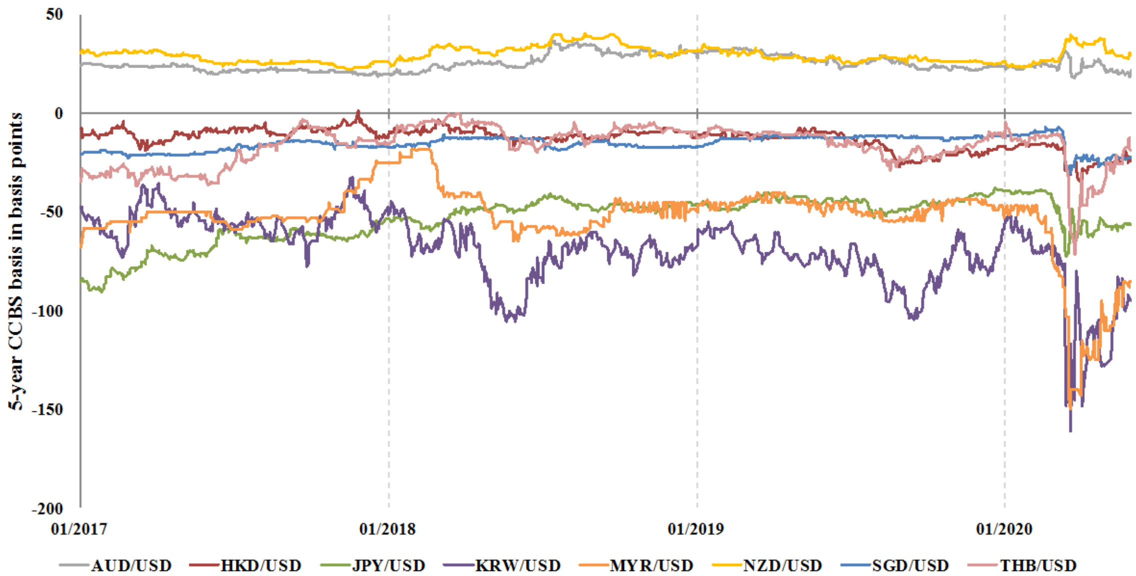


Figure 2 5-year CCBS Bases of EMEAP Currencies, Jan 2017 - May 2020



III. POTENTIAL DRIVING FORCES OF DOLLAR FUNDING STRESS

Cross-currency bases for most currencies vis-à-vis the US dollar are in favour of the lender of US dollars. It is common to see, for example, in CCBS transactions, that the dollar-lending party is the one that receives the basis, a premium over the Libor. There are only a few exceptions where the deviations are instead in favour of the foreign currency lender, e.g., the Australian dollar and the New Zealand dollar.[10] Apart from these rare cases, therefore, the fact that the higher implied dollar interest rates compared to the Libor in cross currency swap transactions are generally taken as a sign of global shortage of US dollars and, hence, also the amount of stress associated with the shortage.

Since the covered interest parity condition broke down following the onset of the global financial crisis in 2007/08, a large volume of literature has surfaced, offering a wide range of explanations and theories about the phenomenon. This study is not another attempt to add more explanations or theories to the debate or argue which explanation or theory is more credible. Instead, we wish to take into account the existing explanations and theories and adopt a more pragmatic approach to tackling the question by examining the potential driving forces empirically. Consequently, we consider the candidates for which data, especially daily data, are available.[11] We have identified the following list of variables and discuss each of them briefly below.

Global dollar strength. Avdjiev et al (2019) find the global strength of the US dollar to be an important driving force behind the currency swap bases for major currencies, as the effect of a stronger dollar feeds through to the shadow price of cross-border bank leverage for non-US financial institutions. This study employs the same proxy they use for global dollar strength, the broad dollar index vis-à-vis the currencies of a large group of US trading partners compiled by the Federal Reserve Board.

Idiosyncratic dollar strength. By the same token, the strength of the dollar vis-à-vis the currency concerned may arguably be a more relevant shadow price for the financial institutions in the economy concerned. Idiosyncratic dollar strength here refers to the strength of the dollar against the currency not

[10] In addition, there are a small number of other currencies such as the British pound whose cross-currency bases occasionally reverse themselves although they are on balance in favour of the dollar.

[11] As a result, institutional factors that may aggravate or contain the stress such as central bank swap lines are not considered, although the effect of these factors can filter through to some of the macro-financial variables in the list below (Bahaj and Reis, 2018).

attributable to the global strength of the dollar. It is represented by the residual obtained by regressing the bilateral exchange rate of each of the currencies vis-à-vis the US dollar (indexed to share the same base with the broader dollar index) on the broad dollar index.[12]

Currency volatility. If dollar strength affects the shadow price of cross-border bank leverage, the risk to its stability would naturally be a source of concern. Consequently, other things being equal, higher currency volatility may result in a higher price premium to pay for the certainty of the cost of dollar funding.

Currency expectation. Similarly, the expected appreciation (or depreciation) of the exchange rate of the US dollar vis-à-vis the currency concerned is also likely to play a role. The risk reversal of the currency, which is the price difference between the call and put currency options, is used to proxy currency expectation.[13]

FX market liquidity. Arai et al (2016) argue that regulatory reforms make global banks less reluctant to engage in market making and arbitrage trading in the FX swap market, while Krohn and Sushko (2020) find that deterioration in dollar funding is linked to a reduction in market liquidity in the spot FX market. It is thus reasonable to consider bid-ask spreads in both the spot and forward markets as potential candidates.

Financial market volatility. Stock market volatility is often regarded as a signal of global banks' leverage cycle that drives cross-border fund flows and hence global liquidity conditions (Borio and Disyatat, 2011; Forbes and Warnock, 2012; Obstfeld, 2012a, 2012b; Bruno and Shin, 2015; Rey, 2015). We adopt the widely used forward-looking S&P 500 volatility measure as a gauge of market risk or "fear" to capture the impact of market sentiment on dollar funding conditions (Whaley, 2000; Giot, 2005).

[12] We have also used the bilateral exchange rate instead of the idiosyncratic dollar strength in our estimation. The results, which can be available upon request, are similar.

[13] The price of an option reflects the market expectation of the likelihood of an adverse outturn happening. A call option gives the right to buy the asset at a certain price and a put option offers the right to sell. Hence, the buyer of a call bets on the asset to rise above the strike price within a certain period, while the seller thinks it may not and accepts a payment for taking the risk. A put option works exactly the other way round. However, the prices of the call and the put are not necessarily the same as there may be heavier betting for a rise in the asset than for a fall, or the other way round. Hence, the price difference can measure how asymmetric the market is in expecting a rise and a fall in the asset. See Wong and Fong (2018) for a more detailed discussion.

Interest differential. Arai et al (2016) observe that corporate borrowers tend to arbitrage any interest differential by issuing bonds denominated in currencies with a lower yield to hedge their proceeds back via FX swaps, thus putting upward pressure on the higher-yielding currency in the cross-currency swap market. Du et al (2018) also find that cross-currency bases tend to be positively correlated with the level of nominal interest rates and increase with interest rate shocks.

Monetary policy divergence. A larger "interest margin" or steeper yield curve for a currency is more conducive to funding investment denominated in the currency by other currencies (with a small "interest margin" or a flatter yield curve) through the cross currency swap market, causing a greater demand for the currency and pushing its basis up (Iida, et al, 2018). Therefore, as the yield curve is essentially a function of monetary policy, term spread differential, reflecting the monetary policy divergence between two countries, can affect funding pressure in the swap market (Borio, et al, 2015).

Credit spread. Last, but not least, counterparty credit risk is often cited as a prominent reason for the emergence and persistence of cross-currency bases in crisis periods (Baba and Packer, 2009b; Coffey et al, 2009; Ivashina et al, 2015; Wong and Zhang, 2018). The credit spread of the sovereign and corporate USD bonds of the economy (over US Treasuries) is used to account for the credit risk of the non-US borrowers in the region.[14]

IV. MODEL SPECIFICATION AND DATA

In light of the potential driving forces identified above, our baseline regression model is specified as follows:

$$\begin{aligned} y_{it} = \alpha_i &+ \beta_1 DollarG_t + \beta_2 DollarI_{it} + \beta_3 VOL_{it} + \beta_4 RiskRev_{it} \\ &+ \beta_5 BASprd_{it} + \beta_6 BASprd3M_{it} + \beta_7 VIX_t \\ &+ \beta_8 IntDiff_{it} + \beta_9 TermSprd_{it} + \beta_{10} CreditSprd_{it} \end{aligned}$$

where

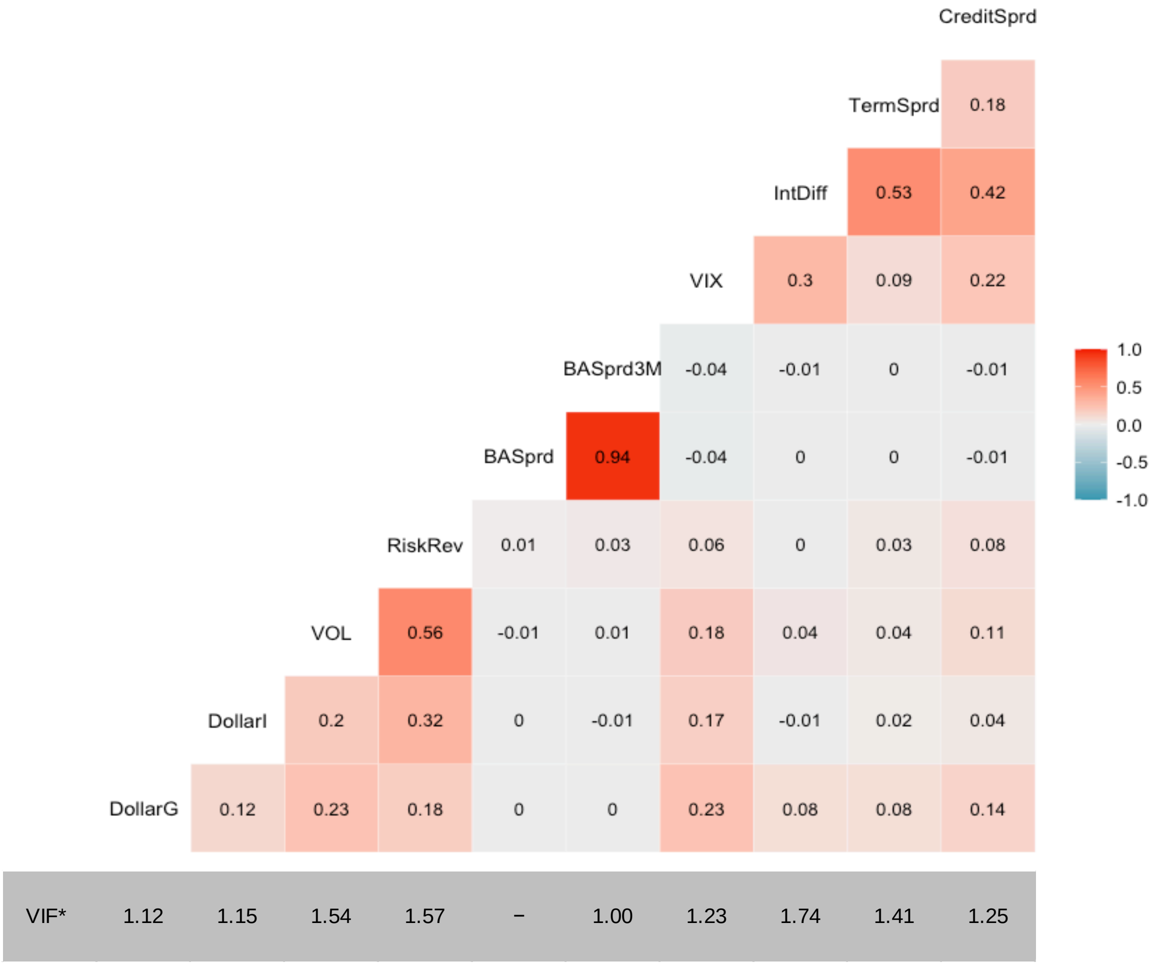
[14] We assume that the difference between the true credit risk and the credit risk as implied by credit spread, if any, is largely stable (due for example to stable investor preferences towards taking the credit risk of holding the bonds) such that the change in credit spread is a reasonable approximation of the change in the true credit risk premium.

y_{it}	denotes the dollar funding stress for economy *i* as represented by the three-month FX swap or five-year CCBS basis of currency *i* vis-à-vis the US dollar;
α_i	is the fixed effect of currency *i*;
$DollarG_t$	stands for the US trade-weighted broad dollar index compiled by the Federal Reserve Board;
$DollarI_{it}$	is the residual obtained by regressing the exchange rate of currency *i* vis-à-vis the US dollar on $DollarG_t$;
VOL_{it}	represents the three-month 25-delta FX call option implied volatility of the exchange rate of currency *i* vis-à-vis the US dollar;
$RiskRev_{it}$	denotes the three-month 25-delta FX option risk reversal of the exchange rate of currency *i* vis-à-vis the US dollar;
$BASprd_{it}$	represents the bid-ask spread of the spot exchange rate of currency *i* vis-à-vis the US dollar;
$BASprd3M_{it}$	denotes the bid-ask spread of the three-month forward exchange rate of currency *i* vis-à-vis the US dollar;
VIX_t	is the 30-day forward-looking Volatility Index compiled by the Chicago Board Options Exchange;
$IntDiff_{it}$	represents the spread of the ten-year government bond yield of currency *i* over the ten-year US Treasury bond yield;
$TermSprd_{it}$	measures the ten-year over two-year spread differential between currency *i* government bond and US Treasury markets; and
$CreditSprd_{it}$	represents the JP Morgan global aggregate bond credit spread index, which measures the spread of US dollar denominated sovereign and corporate bond yields of economy *i* over US treasury yields.

For simplicity, the three-month and five-year funding markets are chosen to represent the short and long-term markets, respectively. All data are daily, covering the period from January 2007 to May 2020. There are eleven EMEAP economies, but data availability allows us to cover only eight of them, namely, Australia, Hong Kong, Japan, Korea, Malaysia, New Zealand, Singapore and Thailand. The sources and statistical characteristics of the data are summarised in Appendix A.

Before estimating the model, we test the data for multicollinearity between the independent variables, as it could compromise the efficiency of the estimation. Figure 3 shows the correlation matrix of the independent variables. The correlation coefficient between *BASprd* and *BASprd3M* is 0.94, which indicates almost perfect positive correlation, but this should not be surprising (Krohn and Sushko, 2020). In view of this, we need to drop one of them. We remove *BASprd* given the intuition that dollar funding in the cross-currency swap market is probably associated more with the liquidity in the forward market than in the spot market, but it does not really matter which one we retain given such a high correlation. The correlation coefficients of 0.56 between *VOL* and *RiskRev* and 0.53 between *IntDiff* and *TermSprd* are less than desired but acceptable in view of their variance inflation factors (VIF).[15] The bottom row in the figure shows that the VIF, a test of multicollinearity, for each remaining independent variable is way below five.

Figure 3 Correlation Matrix and Variance Inflation Factors of Explanatory Variables



*The variance inflation factor (VIF) is estimated after *BASprd* is removed.

[15] The VIF is a measure of how much the variance (i.e., the standard error squared) of the estimated coefficient is inflated due to the existence of correlation among the independent variables in the regression. Specifically, the VIF for the *jth* independent variable is the reciprocal of $(1-R_j^2)$, where R_j^2 is the R^2 value obtained by regressing the *jth* independent variable on the remaining independent variables. A VIF of one means that there is no correlation between the *jth* independent variable and the remaining independent variables, since the variance of b_j is not inflated at all. As a rule of thumb, a VIF greater than five indicates a problem of multicollinearity (Craney and Surles, 2007).

V. EMPIRICAL RESULTS

To examine the effect of the potential candidates on dollar funding stress, we first estimate their normal market relationship in both the short and long-term funding markets by regular linear regressions. We then move on to assess their distressed market relationship, employing the technique of quantile regression.

A. RELATIONSHIP IN NORMAL MARKETS

Tables 1 and 2 present six sets of results for the short and long-term dollar funding stress respectively under normal market conditions. In each of the tables, the second column lists the expected signs for the variables for ease of reference. The next six columns present the estimates obtained from: (i) simple pooled regression; (ii) simple pooled regression with a lagged term of the dependent variable for correcting the first-order serial correlation; (iii) panel regression with currency fixed effects and a lagged term of the dependent variable for correcting the first-order serial correlation; (iv) panel regression with currency random effects and a lagged term of the dependent variable for correcting the first-order serial correlation; (v) pooled regression with the Newey-West (1987) robust covariance matric estimator to obtain the heteroskedasticity and autocorrelation corrected (HAC) standard errors; and (vi) pooled regression with the Driscoll-Kraay (1998) method to correct both cross-sectional and serial correlation to obtain the spatial correlation consistent (SCC) standard errors.

When the simple pooled regression model is estimated, diagnostic tests suggest the presence of potential serial correlation and cross-sectional correlation problems in both the short-term and long-term dollar funding stress equations. We thus re-estimate the pooled model, and the panel models, with a lagged term. The fixed effects model assumes that currency-specific effects are correlated with the independent variables (i.e., a group-specific fixed quantity), while the random effects model assumes currency-specific effects are uncorrelated (i.e., a random sample from the population). However, we find that both the fixed effects and random effects are insignificant, suggesting that a simple pooled model is perhaps a better choice.[16] Indeed, as can be seen, there is practically no difference in the estimates between the models with and without currency-specific effects. When more sophisticated techniques are employed to correct for heteroskedasticity, and higher-order and cross-sectional autocorrelation, the results are of similar flavour with some variables

[16] The pooled regression model does not consider heterogeneity across groups or time.

losing their statistical significance to different extent.

Table 1 Short-term Dollar Funding Stress: Currency-specific Effects & Pooled Panel Data Regressions, January 2007 - May 2020

	Expected Sign	Pooled	Pooled	Fixed	Random	HAC	SCC
(Intercept)		-0.030	-0.032		-0.032	-0.030	-0.030
		(0.094)	(0.093)		(0.093)	(0.074)	(0.026)
lag(FXSwap)			**-0.129** ***	**-0.129** ***	**-0.129** ***		
			(0.006)	(0.006)	(0.006)		
DollarG	–	**1.413** ***	**1.500** ***	**1.500** ***	**1.500** ***	**1.413** *	1.413
		(0.282)	(0.280)	(0.280)	(0.280)	(0.661)	(1.310)
DollarI	–	**0.591** **	**0.683** ***	**0.683** ***	**0.683** ***	0.591	0.591
		(0.180)	(0.179)	(0.179)	(0.179)	(0.442)	(0.386)
VOL	–	**-2.908** ***	**-2.843** ***	**-2.844** ***	**-2.843** ***	**-2.908** **	**-2.908** **
		(0.269)	(0.267)	(0.267)	(0.267)	(0.978)	(1.042)
RiskRev	–	**-6.703** ***	**-7.173** ***	**-7.172** ***	**-7.173** ***	-6.703	**-6.703** ***
		(0.621)	(0.616)	(0.616)	(0.616)	(3.433)	(1.189)
BASprd3M	–	0.004	0.001	0.001	0.001	0.004	0.004
		(0.005)	(0.005)	(0.005)	(0.005)	(0.013)	(0.017)
VIX	–	-0.025	-0.034	-0.034	-0.034	-0.025	-0.025
		(0.052)	(0.052)	(0.052)	(0.052)	(0.150)	(0.036)
IntDiff	+	1.287	2.247	2.246	2.247	1.287	1.287
		(1.763)	(1.749)	(1.749)	(1.749)	(3.110)	(2.669)
TermSprd	+	**10.510** ***	**10.269** ***	**10.271** ***	**10.269** ***	**10.510** *	**10.510** **
		(2.039)	(2.022)	(2.022)	(2.022)	(4.251)	(3.512)
CreditSprd	–	0.017	0.019	0.019	0.019	0.017	0.017
		(0.022)	(0.022)	(0.022)	(0.022)	(0.056)	(0.017)
R^2		0.019	0.036	0.036	0.036		
Adj. R^2		0.019	0.036	0.035	0.036		
Num. obs.		27,628	27,620	27,620	27,620		
Adequacy test		DW = 2.261; Pesaran CD test: p-value < 0.001		F-test: p-value = 0.999	Breusch-Pagan LM test: p-value = 0.062		

Notes:
1. The third and fourth columns present the results of the pooled regression model without and with the lagged dependent variable respectively. A Durbin–Watson statistic of 2.261 indicates the presence of negative serial correlations. A Pesaran (2004) cross-sectional dependence test yielding a p-value of less than 0.001 rejects the null hypothesis that the residuals are not correlated across the currencies.
2. The fifth and sixth columns present the results of the fixed effects and random effects regression models. An F-test yielding a p-value of 0.999 fails to reject the null hypothesis that the fixed effects are insignificant, while a Breusch-Pagan (1980) Lagrange multiplier test yielding a p-value of 0.062 cannot reject the null hypothesis that the variances of the random effects are zero.
3. In the seventh column, the Newey-West (1987) robust covariance matrix estimator is used to correct for serial correlation to obtain the heteroskedasticity and autocorrelation corrected (HAC) standard errors.
4. In the eighth column, the Driscoll-Kraay (1998) method is used to correct both cross-sectional and serial correlation to obtain the spatial correlation consistent (SCC) standard errors.
5. ***, ** and * denote that the estimated coefficient is statistically significant at 0.1%, 1% and 5% respectively.

Table 2 Long-term Dollar Funding Stress: Currency-specific Effects & Pooled Panel Data Regressions, January 2007 - May 2020

	Expected Sign	Pooled	Pooled	Fixed	Random	HAC	SCC
(Intercept)		-0.008	-0.009		-0.009	-0.008	**-0.008** ***
		(0.022)	(0.022)		(0.022)	(0.020)	(0.001)
lag(CCBS)			**-0.077** ***	**-0.077** ***	**-0.077** ***		
			(0.006)	(0.006)	(0.006)		
DollarG	–	-0.051	-0.053	-0.053	-0.053	-0.051	-0.051
		(0.067)	(0.067)	(0.067)	(0.067)	(0.109)	(0.055)
DollarI	–	**-0.193** ***	**-0.169** ***	**-0.169** ***	**-0.169** ***	-0.193	**-0.193** **
		(0.043)	(0.043)	(0.043)	(0.043)	(0.101)	(0.066)
VOL	–	**-1.406** ***	**-1.374** ***	**-1.374** ***	**-1.374** ***	**-1.406** ***	**-1.406** ***
		(0.064)	(0.064)	(0.064)	(0.064)	(0.300)	(0.292)
RiskRev	–	**-0.907** ***	**-0.956** ***	**-0.956** ***	**-0.956** ***	-0.907	**-0.907** ***
		(0.147)	(0.147)	(0.147)	(0.147)	(0.620)	(0.101)
BASprd3M	–	-0.002	**-0.002** *	**-0.002** *	**-0.002** *	-0.002	-0.002
		(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)
VIX	–	**0.054** ***	**0.054** ***	**0.054** ***	**0.054** ***	0.054	0.054
		(0.012)	(0.012)	(0.012)	(0.012)	(0.028)	(0.036)
IntDiff	+	**-2.534** ***	**-2.476** ***	**-2.475** ***	**-2.476** ***	**-2.534** **	**-2.534** *
		(0.418)	(0.417)	(0.417)	(0.417)	(0.804)	(1.196)
TermSprd	+	0.723	0.689	0.688	0.689	0.723	0.723
		(0.484)	(0.482)	(0.482)	(0.482)	(0.950)	(0.708)
CreditSprd	–	0.000	0.000	0.000	0.000	0.000	0.000
		(0.005)	(0.005)	(0.005)	(0.005)	(0.010)	(0.002)
R^2		0.040	0.046	0.046	0.046		
Adj. R^2		0.040	0.046	0.046	0.046		
Num. obs.		27,628	27,627	27,627	27,627		
Adequacy test		DW = 2.165; Pesaran CD tes t: p-value < 0.001		F-test: p-value = 1	Breusch-Pagan LM test: p-value = 0.051		

Notes:
1. The third and fourth columns present the results of the pooled regression model without and with the lagged dependent variable respectively. A Durbin–Watson statistic of 2.165 indicates the presence of negative serial correlations. A Pesaran (2004) cross-sectional dependence test yielding a p-value less than 0.001 rejects the null hypothesis that the residuals are not correlated across the currencies.
2. The fifth and sixth columns present the results of the fixed effects and random effects regression models. An F-test yielding a p-value of 1 fails to reject the null hypothesis that the fixed effects are insignificant, while a Breusch-Pagan (1980) Lagrange multiplier test yielding a p-value of 0.051 cannot reject the null hypothesis that the variances of the random effects are zero.
3. In the seventh column, the Newey-West (1987) robust covariance matrix estimator is used to correct for serial correlation to obtain the heteroskedasticity and autocorrelation corrected (HAC) standard errors.
4. In the eighth column, the Driscoll-Kraay (1998) method is used to correct both cross-sectional and serial correlation to obtain the spatial correlation consistent (SCC) standard errors.
5. ***, ** and * denote that the estimated coefficient is statistically significant at 0.1%, 1% and 5% respectively.

Looking at the overall picture, most striking to us is the coefficient of *DollarG*, which is found to have the wrong sign in the short-term stress equation in the simple pooled and panel regressions. However, the standard errors are probably compressed in the presence of heteroskedasticity and cross-currency correlation, causing the dubious result that a strong dollar globally would help contain dollar funding stress. Indeed, when the model is re-estimated under HAC, the coefficient becomes much less significant. And when the model is re-estimated under SCC, it becomes insignificant. The coefficient of *DollarG* for long-term stress is insignificant across different models and estimation techniques. Interestingly, while the coefficient of *DollarI*, which measures dollar strength vis-à-vis the currency concerned that is not attributable to the global dollar strength, shares the problem of having the wrong sign in the short-term stress equation, it is generally found to be significant and carries a negative sign as expected for long-term stress. Overall, it seems to be idiosyncratic, rather than global, dollar strength that causes dollar funding stress to the economy, a result that is at odds with that of Avdjiev et al (2019). The finding therefore appears to suggest that if dollar strength plays any role in determining dollar funding stress for an economy, it would be dollar strength vis-à-vis the currency concerned, rather than dollar strength on a global basis. It seems that it makes more sense than otherwise, the funding stress is largely an adversity suffered by non-US financial institutions. From their perspective, when the US dollar is weak against other major currencies, these borrowers are still likely to find it more difficult and costly to obtain dollar funding if their own currency is even weaker. For example, a larger amount of their own currency would be required as collateral for the same amount of dollar funding. We find that the risks pertaining to the stability of dollar strength vis-à-vis individual currencies are also important, as evidenced by the highly significant and negative coefficients of *VOL* and *RiskRev* in both the short and long-term stress equations. This shows that dollar funding stress in general tends to be associated with a volatile exchange rate and a dollar appreciation risk.

Turning to the variables other than those related to dollar strength, the effect of market liquidity is found to be insignificant. General financial market volatility as proxied by *VIX* is also found to have little effect on short-term dollar funding stress; it positively impacts long-term dollar funding stress, but the impact becomes insignificant when it is estimated under HAC and SCC. Long-term interest differential as represented by *IntDiff* supposedly has a positive influence on dollar funding stress but is found to have no impact on the short-term stress. Like Avdjiev et al (2019), we find that it has a negative influence on long-term stress. *TermSprd*, which denotes the relative stance of monetary policy of the economy vis-à-vis the US, is found to have a significant positive impact on the short-term stress as expected, though little impact on the long-term stress. Finally, *CreditSprd* is found to have little influence on both.

B. RELATIONSHIP IN EXTREME MARKETS

The results of the panel and pooled regressions, which are essentially least-squares-based, represent only the relationship between dollar funding stress and the various driving forces in normal market situations. It is the average, or the conditional mean to be exact, relationship over a long period of time, thirteen and a half years in the present study. While it is useful to know the long-term driving forces behind what seems to be an intriguing global phenomenon, policymakers would probably find it more useful to understand the dynamics underpinning the phenomenon in times of market stress. This is exactly what we are trying to do with the aid of quantile regression.

The distinct advantage of quantile regression is that it can enable us to evaluate the relationship between the dependent and independent variables across different quantiles of the conditional distribution of the dependent variable (see Appendix B). As such, this makes it possible to estimate the response of dollar funding stress to any potential factor during extreme scenarios. In this study, the extremity of the scenarios is defined by dollar funding stress set progressively at the 25%, 20%, 10% and 5% quantiles of its conditional distribution given that the greater the dollar funding stress, the more negative (or the less positive) is the FX swap or CCBS basis.

The results of the quantile regressions are presented in a progressive manner in Tables 3 and 4. As can be seen, compared with the least squares estimates, the results of the quantile regressions apparently seem to be more clear-cut, especially when we move along the extremity scale. In the most extreme situation, no estimate which is found to be significant carries a wrong sign. There are three points we wish to highlight.

Firstly, dollar strength, regardless of whether it is global or idiosyncratic, seems to be irrelevant for the determination of short-term dollar funding stress, especially at the lower quantiles, i.e., more adverse scenarios. For long-term dollar funding stress, however, unlike in the orderly market, both *DollarG* and *DollarI* are factors not to be ignored in the quantile regressions: their coefficients are found to be negative and statistically significant. This means that as the market becomes turbulent, a stronger dollar, both in terms of its strength vis-à-vis the currency concerned or globally, inflicts more stress on the borrower in the region. However, as we move towards the most extreme market, it too vanishes in statistical significance.

Table 3 Short-term Dollar Funding Stress: Quantile Regressions January 2007 - May 2020

	Expected Sign	Quantile 25%	20%	10%	5%
(Intercept)		**-2.288** ***	**-3.240** ***	**-6.852** ***	**-11.895** ***
		(0.043)	(0.057)	(0.112)	(0.253)
lag(FXSwap)		**-0.052** ***	**-0.050** ***	**-0.048** ***	**-0.042** **
		(0.002)	(0.003)	(0.006)	(0.014)
DollarG	–	**0.231** *	0.150	**0.750** *	0.360
		(0.115)	(0.156)	(0.308)	(0.715)
DollarI	–	**-0.158** *	-0.170	-0.156	0.352
		(0.063)	(0.100)	(0.189)	(0.435)
VOL	–	**-1.521** ***	**-1.708** ***	**-2.615** ***	**-3.721** ***
		(0.057)	(0.114)	(0.242)	(0.724)
RiskRev	–	-0.528	-0.421	**-1.529** *	-2.960
		(0.289)	(0.291)	(0.734)	(1.912)
BASprd3M	–	**0.005** *	0.004	0.001	-0.003
		(0.002)	(0.002)	(0.005)	(0.009)
VIX	–	0.009	0.027	0.077	0.171
		(0.011)	(0.027)	(0.058)	(0.108)
IntDiff	+	**2.967** ***	**3.248** ***	**4.275** *	**9.394** *
		(0.756)	(0.974)	(1.965)	(4.639)
TermSprd	+	-0.078	0.203	1.633	3.367
		(0.971)	(1.188)	(2.451)	(5.797)
CreditSprd	–	**-0.045** ***	**-0.056** ***	**-0.129** ***	**-0.180** ***
		(0.009)	(0.012)	(0.017)	(0.054)
Num. obs.		27,627	27,627	27,627	27,627

***, ** and * denote that the estimated coefficient is statistically significant at 0.1%, 1% and 5% respectively.

Table 4 Long-term Dollar Funding Stress: Quantile Regressions January 2007 - May 2020

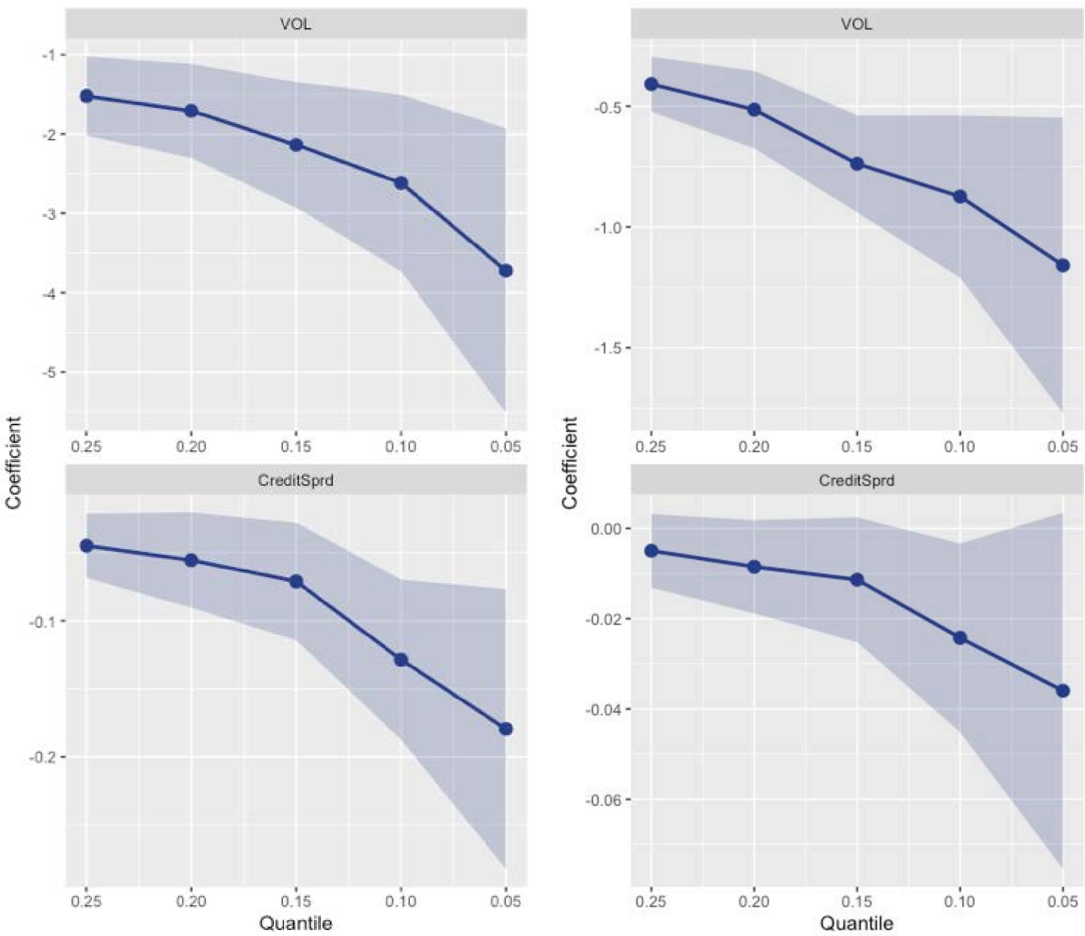
	Expected Sign	Quantile			
		25%	**20%**	**10%**	**5%**
(Intercept)		**-0.470** ***	**-0.776** ***	**-1.997** ***	**-3.790** ***
		-0.012	-0.020	-0.038	-0.090
lag(CCBS)		**-0.050** ***	**-0.063** ***	**-0.068** ***	**-0.061** **
		(0.003)	(0.004)	(0.008)	(0.020)
DollarG	–	**-0.058** *	**-0.108** *	**-0.208** *	-0.478
		(0.026)	(0.050)	(0.105)	(0.265)
DollarI	–	**-0.054** **	**-0.084** **	**-0.157** *	-0.311
		(0.018)	(0.030)	(0.068)	(0.162)
VOL	–	**-0.408** ***	**-0.514** ***	**-0.874** ***	**-1.159** ***
		(0.026)	(0.053)	(0.086)	(0.230)
RiskRev	–	**-0.421** ***	**-0.439** **	**-0.891** **	-0.989
		(0.074)	(0.146)	(0.293)	(0.616)
BASprd3M	–	-0.001	-0.001	-0.001	-0.001
		(0.001)	(0.001)	(0.002)	(0.003)
VIX	–	**0.012** *	**0.020** *	**0.035** *	0.049
		(0.006)	(0.008)	(0.015)	(0.044)
IntDiff	+	-0.292	**-0.818** ***	**-1.955** **	-1.708
		(0.154)	(0.237)	(0.724)	(1.683)
TermSprd	+	0.151	0.155	1.041	1.478
		(0.134)	(0.086)	(0.906)	(2.271)
CreditSprd	–	**-0.005** *	**-0.009** *	**-0.024** **	**-0.036** *
		(0.002)	(0.004)	(0.009)	(0.016)
Num. obs.		27,627	27,627	27,627	27,627

***, ** and * denote that the estimated coefficient is statistically significant at 0.1%, 1% and 5% respectively.

Second, *VOL*, the volatility of the dollar strength vis-à-vis individual currencies, continues to play a critical role in determining dollar funding stress in both the short and long-term markets under extreme scenarios. In addition, the coefficient becomes more negative as we move towards a lower quantile in the estimation, meaning that the more volatile the market condition, the larger is the impact on the stress. Figure 4 provides a graphical exposition of the results of the various quantiles to clearly illustrate how the response changes as the market conditions worsen. However, exchange rate expectations play a much smaller role in stressful situations compared to normal market times. *RiskRev*, which can be interpreted as the expected dollar strength vis-à-vis the local currency, is found to have no impact on the short-term stress. It maintains its impact on the long-term stress initially as we move from the simple pooled regression to the quantile regressions, but the impact also disappears when we reach the lowest quantile in the estimation.

Figure 4 Response Sensitivity at Various Quantiles

3-month FX swap basis ***5-year CCBS basis***



The blue shaded area represents the 95% confidence interval.

Finally, the coefficients of *BASprd3M* and *VIX* continue to be found to be statistically insignificant, suggesting that market liquidity and financial market volatility generally do not contribute to dollar funding stress regardless of market conditions. Interestingly, *IntDiff* which is found to have no impact on short-term stress now shows up with a significant and increasing impact alongside the degree of market extremity. It has little impact on long-term stress, however, in the most extreme scenario. On the contrary, *TermSprd*, which impacts short-term stress significantly in the normal market, is found to have little influence over both the short and long-term funding stress in the extreme scenarios, meaning that relative monetary conditions are only an important driver in the long run but not at critical moments. Most interesting to us is *CreditSprd*, a variable that is found to have no effect on the short or long-term stress at all during normal times, shows up as an important factor affecting dollar funding stress in both the short and long-term markets as market conditions deteriorate. This means counterparty risk is an important element from the perspective of the dollar lending party as reflected by the steeper compensation it demands from the borrower in turbulent times as compared to what would normally be required in a quiet market.

VI. CONCLUDING REMARKS

Overall, the results of our estimation suggest that macro-financial variables tend to behave quite differently in terms of how they impact dollar funding stress in the EMEAP economies, as compared to what is found by previous studies. To some extent, this may be attributed to the fact that most previous studies are centred on the most advanced economies, while the economies under study here are a much more diverse group. The results also highlight the importance of differentiating the response of the stress between normal and extreme market circumstances for policymaking and market surveillance.

Recent studies have identified global dollar strength as probably the single most important factor that drives dollar funding stress. We find that it generally plays little role in determining both the short and long-term stress faced by EMEAP dollar borrowers in normal markets. It adds to the long-term borrowing stress when turbulence increases but the effect also dissipates under the most adverse circumstances. On the contrary, idiosyncratic dollar strength can create long-term dollar funding pressure during normal market times and when market conditions become turbulent. Only in the most extreme market does its effect recede. However, uncertainty about dollar strength against individual currencies is found to be much more important both in orderly markets and in times of crisis. Currency expectations also play a role but again only during normal market times: if the US dollar is expected to appreciate vis-à-vis the currency concerned, dollar funding stress increases for the respective economy.

Our findings suggest that credit risk which does not impact dollar funding stress in normal markets is an important consideration for the dollar lender in extending credit in turbulent times. This means that under stressful scenarios economies that suffer a sharper deterioration in the credit outlook for their government, banks and corporations (due possibly to a larger public debt or heavy borrowing) are likely to experience tighter funding conditions.

These results provide food for thought for policymakers in the region. For example, instead of monitoring the global dollar strength as suggested in the literature, they should perhaps focus more on their own currency movement, volatility and the market expectations about it. And if they are concerned with potential financial contagion from their neighbours, they might also wish to keep a close eye on those who have a larger public debt or heavier corporate borrowing, which could render these economies more susceptible to a major credit risk reappraisal in times of crisis.

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APPENDIX A SOURCES AND DESCRIPTIVE STATISTICS OF THE DATA

Table A1 Sources of the Data

Variable	Description	Source
FXSwap	3-month FX swap basis of foreign curency vs US dollar	Bloomberg, RBNZ
CCBS	5-year CCBS of foeign currency vs US dollar	Bloomberg
DollarG	Federal Reserve Board US trade-weighted broad dollar index	FRB of St. Louis
DollarI	Residual from regressing *DollarG* on bilateral exchange rate	Authors' estimation
VOL	3-month 25-delta FX call option-implied volatility	JP Morgan database
RiskRev	3-month 25-delta FX option risk reversal	JP Morgan database
BASprd	Bid-ask spread of spot exchange rate	Bloomberg
BASprd3M	Bid-ask spread of 3-month forward exchange rate	Bloomberg
VIX	CBOE Volatility Index	Bloomberg
IntDiff	Yield spread of 10-year foreign govt over 10-year US Treasury	Bloomberg
TermSprd	10-year over 2-year spread differential (foreign govt over US Treasury)	Bloomberg
CreditSprd	JP Morgan global aggregate bond credit spread index	JP Morgan database

Table A2 Descriptive Statistics of the Data

	Min	Median	Mean	Max	S.D.	Num. Obs.
			FXSwap			
AUD/USD	130.35	9.89	11.45	241.21	15.07	3,324
HKD/USD	81.82	-16.76	-17.18	58.37	14.67	3,261
JPY/USD	255.69	-25.76	-28.58	66.31	20.42	3,389
KRW/USD	1195.47	-61.83	-99.71	14.68	127.28	3,243
MYR/USD	338.24	-43.50	-51.53	23.36	42.14	3,104
NZD/USD	54.43	15.64	18.84	162.50	15.61	3,324
SGD/USD	269.17	-0.51	1.94	159.46	14.61	3,293
THB/USD	260.26	17.31	86.21	1245.17	200.88	3,211
			CCBS			
AUD/USD	-50.00	23.13	21.27	48.00	9.60	3,498
HKD/USD	-63.00	-9.00	-8.86	20.50	12.60	3,490
JPY/USD	-102.50	-49.84	-49.39	34.00	25.82	3,498
KRW/USD	-324.00	-75.25	-94.02	5.50	52.71	3,351
MYR/USD	-240.00	-80.00	-86.77	-3.00	42.56	3,294
NZD/USD	-5.50	27.00	25.41	52.30	11.95	3,495
SGD/USD	-69.00	-19.44	-21.10	2.50	12.68	3,491
THB/USD	-205.00	-20.00	-32.56	6.00	35.14	3,444
			DollarG			
All currencies	85.49	96.17	100.94	126.47	10.58	3,358

Table A2 Descriptive Statistics of the Data (Cont'd.)

	Min	Median	Mean	Max	S.D.	Num. Obs.
			DollarI			
USD/AUD	-10.78	-0.68	0.00	32.10	6.47	3,498
USD/HKD	-0.67	-0.13	0.00	0.84	0.38	3,498
USD/JPY	-16.80	-0.83	0.00	23.02	9.18	3,498
USD/KRW	-18.05	-0.44	0.00	44.47	8.90	3,498
USD/MYR	-6.93	-0.99	0.00	11.03	3.59	3,498
USD/NZD	-12.95	-1.14	0.00	41.16	8.37	3,498
USD/SGD	-7.34	-1.21	0.00	12.19	4.77	3,498
USD/THB	-9.18	-0.19	0.00	8.49	4.12	3,498
			VOL			
USD/AUD	5.70	10.44	10.93	32.37	3.92	3,353
USD/HKD	0.28	0.75	0.90	5.46	0.58	3,353
USD/JPY	4.44	9.66	9.77	24.47	2.68	3,353
USD/KRW	3.54	11.05	12.60	68.31	7.78	3,353
USD/MYR	2.78	8.59	8.83	20.27	3.43	3,353
USD/NZD	6.35	11.33	11.79	28.34	3.68	3,353
USD/SGD	2.90	6.42	6.65	17.89	2.42	3,353
USD/THB	3.80	6.90	7.58	14.86	2.43	3,353
			RiskRev			
USD/AUD	0.11	1.66	1.93	8.25	1.27	3,353
USD/HKD	-1.30	-0.40	-0.34	2.13	0.42	3,241
USD/JPY	-10.08	-1.23	-1.48	1.50	1.62	3,353
USD/KRW	-0.63	2.05	2.63	27.00	2.58	3,353
USD/MYR	-0.85	1.43	1.44	5.61	1.00	3,353
USD/NZD	0.14	1.66	1.93	8.00	1.23	3,353
USD/SGD	-0.68	0.93	0.91	4.47	0.69	3,353
USD/THB	0.27	1.11	1.19	4.63	0.60	3,353
			VIX			
All currencies	9.14	16.66	19.69	82.69	9.83	3,375
			BASprd			
USD/AUD	-77.66	2.24	3.78	151.14	7.38	3,499
USD/HKD	0.13	0.64	1.18	35.35	1.75	3,499
USD/JPY	-1.84	1.16	2.19	60.32	3.29	3,499
USD/KRW	0.09	17.19	16.49	336.26	22.52	3,499
USD/MYR	0.32	11.24	11.47	324.86	11.58	3,489
USD/NZD	-1.53	4.16	6.58	473.35	12.92	3,499
USD/SGD	0.65	3.81	5.76	214.43	9.29	3,499
USD/THB	-647.95	7.44	15.56	448.33	28.67	3,498
			BASprd3M			
USD/AUD	-72.60	2.48	4.16	168.38	8.10	3,499
USD/HKD	0.13	1.29	1.91	36.66	2.01	3,499
USD/JPY	-1.57	1.33	2.09	60.78	3.47	3,499
USD/KRW	1.59	50.08	64.62	652.57	62.27	3,444
USD/MYR	0.58	12.53	13.03	324.52	11.28	3,298
USD/NZD	-1.07	4.98	7.47	477.36	13.41	3,499
USD/SGD	0.23	5.15	7.52	215.21	10.12	3,499
USD/THB	-548.91	15.98	25.59	451.12	32.11	3,498

Table A2 Descriptive Statistics of the Data (Cont'd.)

	Min	Median	Mean	Max	S.D.	Num. Obs.
			IntDiff			
AUD/USD	-0.86	1.21	1.07	2.77	0.93	3,461
HKD/USD	-2.05	-0.62	-0.63	0.40	0.28	3,443
JPY/USD	-3.36	-2.01	-1.99	-0.56	0.59	3,473
KRW/USD	-0.65	0.81	0.82	2.93	0.82	3,458
MYR/USD	-1.77	1.37	1.18	2.82	0.80	3,466
NZD/USD	-0.67	1.69	1.38	3.14	0.94	3,459
SGD/USD	-2.36	-0.38	-0.44	0.78	0.55	3,416
THB/USD	-1.29	0.47	0.56	2.17	0.66	3,474
			TermSprd			
AUD/USD	-2.51	-0.81	-0.77	0.47	0.72	3,262
HKD/USD	-1.71	-0.43	-0.40	0.51	0.33	2,876
JPY/USD	-2.02	-0.90	-0.84	1.11	0.66	3,160
KRW/USD	-2.20	-1.01	-0.85	1.06	0.72	3,097
MYR/USD	-2.07	-0.78	-0.71	0.45	0.69	3,183
NZD/USD	-4.94	-0.64	-0.85	0.78	1.17	3,253
SGD/USD	-1.15	-0.10	-0.16	1.20	0.33	3,220
THB/USD	-2.52	-0.42	-0.48	1.15	0.76	3,117
			CreditSprd			
AUD	27.96	146.06	166.01	470.00	70.39	3,353
HKD	63.75	244.75	251.01	673.31	83.23	3,353
JPY	50.94	125.57	140.97	347.59	50.15	3,353
KRW	49.71	131.90	172.74	706.27	116.50	3,353
MYR	66.00	160.20	176.40	496.00	66.04	3,353
NZD	61.16	118.24	141.54	408.43	72.54	3,353
SGD	59.32	136.82	152.04	466.11	61.98	3,353
THB	137.00	225.00	272.50	839.00	147.09	3,104

APPENDIX B QUANTILE REGRESSION

An ordinary least squares (OLS) regression estimates the mean response of the dependent variable to the independent variables based on the conditional mean function. Hence, this provides only a general or average view of the relationship between them. However, sometimes we are only interested in the relationship at certain points in the conditional distribution of the dependent variable, rather than at the mean. And in some cases, it is possible that a relationship does not exist at the mean at all but only at the tails of the conditional distribution. Quantile regression is an elegant technique of estimating the conditional median (or other quantiles) of the response variable. This technique is appealing due to its robustness to outliers and especially useful in the analysis of extreme events that lie in the high (or low) conditional quantiles for heavy tailed distributions.

Taking a similar formulation as the classical regression model, the quantile regression model for τth quantile can be written as:

$$Q_\tau\left(y_i \middle| x_1, x_2, \cdots, x_p\right) = \beta_0(\tau) + \beta_1(\tau)x_1 + \beta_2(\tau)x_2 + \cdots + \beta_p(\tau)x_p$$

In contrast to being constants in the OLS regression, the beta coefficients are now functions with a dependency on the quantile level τ. The corresponding conditional quantile of y_i given x_p can be written as $Q_\tau\left(y_i \middle| x_p\right)$ such that the quantile level τ is the probability of y_i equal to or less than its value estimated by the model, i.e., $Pr\left(y_i \le Q_\tau\left(y_i \middle| x_p\right) \middle| x_p\right)$.

Figure B1 presents an example of regression data for which both the mean and the variance of the response Y increase as the predictor X increases. The red dashed line in the middle represents a simple OLS fit. The OLS regression models the conditional mean $E(Y|X)$, but does not capture the conditional variance $Var(Y|X)$. By fitting a series of quantile regression models for a grid of values of τ in the interval (0,1), we can describe the entire conditional distribution of the response. The solid lines in Figure B1 show the fitted quantile regressions for the quantile levels at 1%, 5%, 10%, 25% and 50%. In this particular example, the OLS regression line (the red dashed line) conveys little information about the relationship between X and Y as the fitted regression line has only a slight positive slope and does not describe the increasing dispersion of Y, while the quantile regression lines reveal interesting relationships. As can be seen, the decrease in response Y accelerates along the quantile scale as the predictor X increases, meaning that the relationship becomes more prominent as we move to the lower quantiles. This relationship, which apparently is negative, is not observable at the mean level.

Figure B1 OLS and Quantile Regression Lines