Heavy Tails and Currency Crises

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The paper in a nutshell

- Theory:

  I. Financial (FX) returns/underlying fundamentals nonnormally distributed ("heavy tails")

  II. Fundamentals' tail properties determine currency crisis spillover potential

  $\Rightarrow$**fat (thin) tailed** fundamentals imply **strong (weak)** spillover potential

  $\Rightarrow$ integrated risk management: risks strongly comove if common risk drivers fat tailed

- Empirics: exploit extreme value theory to calculate joint financial (FX) crash probability

  (=**"systemic" risk**)

- "Currency" interchangeable with "financial" everywhere

Rest of agenda

- Monetary model of the exchange rate
- What is a "crisis"?
- "Thin" tails vs. "heavy" tails?
- Indicator of systemic currency risk (joint probability)
- Relation between FX volatility (scales) and systemic currency risk indicator
- Estimation results for three currency blocks
- Conclusions

FX monetary model revisited...

- Frenkel's (1976) monetary model of the (nominal bilateral) spot rate:

$$\begin{aligned} s_{j0} &= \left(m_j - \phi y_j + \lambda R_j\right) - (m_0 - \phi y_0 + \lambda R_0) \\ &= g_j - g_0, \quad j = 1, \cdots, n \\ &\Rightarrow \Delta s_{j0} = \Delta g_j - \Delta g_0 = X_j + X_0 \end{aligned}$$

- **Common factor** X_0 induces FX cross sectional dependence

- All upcoming results also hold for general common factor models

- But do tail events like *crises* also tend to coincide?

  $\Rightarrow$ yes if X_0 is nonnormally distributed

Financial crisis literature

- View 1: inherent malfunctioning of financial institutions/markets (sunspots)

  - Diamond/Dybvig (1983): bank runs as selffulfilling and thus random events

  - Osbtfeld (1986): currency crises resulting from multiple equilibria

- View 2: fundamental-based crises

  - Gorton (1988): US banking panics related to business cycle downturns

  - Krugman (1999): unsustainably large budget deficits can lead to currency attacks

- This paper: extent of crisis spillover depends on *tail properties* of fundamentals ($\approx$view 2)

What is a “crisis”?

- Operational definition: financial return (currency, bank stock) exceeds a certain barrier or threshold ($X > s$)

- s determined by excess probability $p \equiv P\left\{\Delta s_{j0} > s\right\}$ chosen by e.g. risk manager

- If $p = 5\%, 1\%$ than s is traditional VaR number as requested by the BIS

- For (rare) systemic events: go beyond s ($p << 5, 1\%$)

- This paper: asymptotic spillover measure (s finite or $s \rightarrow \infty$ renders same outcome)

Thin vs. heavy tails

- Reconsider monetary model for currency pair (1,2) with numeraire currency 0:

$$\Delta s_{10} = X_1 + X_0 \text{ and } \Delta s_{20} = X_2 + X_0$$

- Fundamentals (X_0, X_1, X_2) and thus $(\Delta s_{10}, \Delta s_{20})$ are found to be **fat tailed**

- Other example: banks

  $\Rightarrow$ X_0 may reflect exposure to 3rd bank (via interbank market), CDO exposure etc.

- Thin tails (e.g. normal df)

$$P\{X_i > s\} \approx a_i e^{-s}$$

- Fat (heavy) tails

$$P\{X_i > s\} \approx a_i s^{-\alpha}$$

Thin vs. heavy tails: empirical evidence

- Example: Thai Baht experienced largest one-day depreciation $+7.06\%$ relative to US$ during Asian crisis

- *Unconditional* likelihood of this event **under normality**?

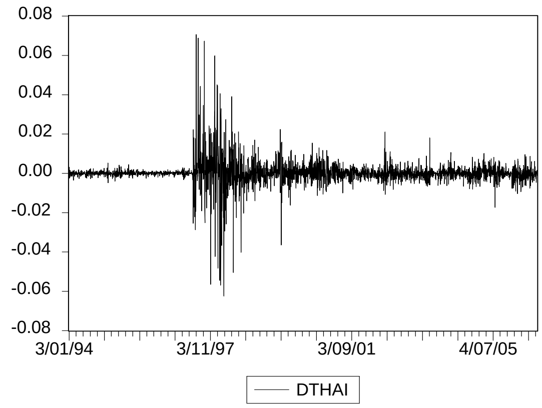
$$\begin{aligned} \mu &= 0.011\%;\ \sigma = 0.62\% \\ P\{X < -7.06\%\} &= P\left\{\frac{X-\mu}{\sigma} < \frac{-7.06\% - \mu}{\sigma}\right\} \\ &= 1.5 \times 10^{-34} \end{aligned}$$

- Expected waiting time in days/years for a crash of this magnitude?

$$\begin{aligned} E(days) &= 6.43 \times 10^{33} \\ E(years) &= 2.47 \times 10^{31} \end{aligned}$$

Fat vs. thin tails: empirical evidence (3)

- Redraw n=3,313 data pairs from $(\Delta Thai/US\$) \sim N(\mu, \sigma)$ and compare with original time series



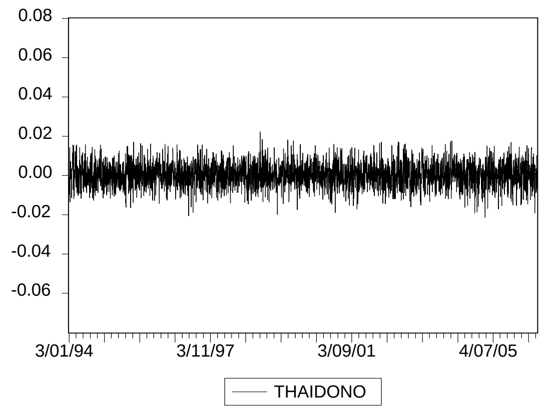


Figure 1: Thai Bath : real and simulated (normal) series

Normality and extremes?

- Alan Greenspan at first "Risk Measurement and Systemic Risk" conference in Washington (DC), 1995:

"From the point of view of the **risk manager**, *inappropriate use of the normal distribution can lead to an understatement of risk. From the* **central bank**'*s corner, the consequences are even more serious because we often need to concentrate on the left tail of the distribution in formulating lender-of-last-resort policies. Improving the characterization of extreme values is of paramount concern"*

Systemic currency risk measure

- The paper sofar: fundamentals, FX returns fat tailed

  $=$ currency crises strike **more often** than expected under normal df

- Implications for currency crises **to spread**?

Systemic currency risk measure (2)

- *Expected number* of joint crashes given at least one crash in the system

$$E\{\kappa|\kappa \geq 1\} = \frac{P\{\Delta s_{10} > s\} + P\{\Delta s_{20} > s\}}{1 - P\{\Delta s_{10} < s,\, \Delta s_{20} < s\}}$$

$$= P\{\kappa = 2|\kappa \geq 1\} + 1$$

κ = number of crashes

s = large VaR quantile

- Each currency can play role of "crashing asset"

- $1 \leq E \leq 2$; generalizable to N assets

- $E = 1$ implies absence of systemic risk

- $E > 1$ provided FX fundamentals, returns non-normally distributed

Systemic currency risk with heavy tailed FX fundamentals

- Systemic currency risk in terms of fundamentals:

$$E\{\kappa\,|\kappa \geq 1\} =$$

$$\frac{P\{\Delta s_{10} > s\} + P\{\Delta s_{20} > s\}}{1 - P\{\Delta s_{10} \leq s, \Delta s_{20} \leq s\}}$$

$$= \frac{P\{X_0 + X_1 > s\} + P\{X_0 + X_2 > s\}}{1 - P\{X_0 + X_1 \leq s, X_0 + X_2 \leq s\}}$$

- Remember nonnormality of the fundamentals:

$$P\{X_i > s\} \approx a_i s^{-\alpha}$$

- It can be easily shown (without proof) that

$$\begin{aligned} E\{\kappa\,|\kappa \geq 1\} &= \frac{(2a_0 + a_1 + a_2)\, s^{-\alpha}}{a_0 s^{-\alpha} + a_1 s^{-\alpha} + a_2 s^{-\alpha}} \\ &= \frac{2a_0 + a_1 + a_2}{a_0 + a_1 + a_2} > 1 \end{aligned}$$

"Tail dependence"

Systemic currency risk with fat tailed fundamentals (2)

- Comparable result for any common factor model of financial assets

  - see e.g. APT (Ross (1976))

  - Trade linkages as transmitters of shocks between countries (Forbes and Chinn (2003))

- Volatility of common factors relative to other factor's volatility determines level of systemic risk

- Case I: high degree of economic integration

  $(a_0 \approx a_1 \approx a_2) \Rightarrow E \approx 4/3$

- Case II: base currency relatively more stable

  $(a_0 < a_1 \approx a_2) \Rightarrow E < 4/3$

- Case III: base currency relatively more volatile

  $(a_0 > a_1 \approx a_2) \Rightarrow E > 4/3$

Estimating systemic risk measure

- Impose bivariate normal df for $(JPY/US\$; CHF/US\$$

$$(\Delta s_{10}, \Delta s_{20}) \sim N\,(\mu_1; \mu_2; \sigma_1; \sigma_2; \sigma_{12})$$

- Simulate n=3,313 data pairs using biv. norm.

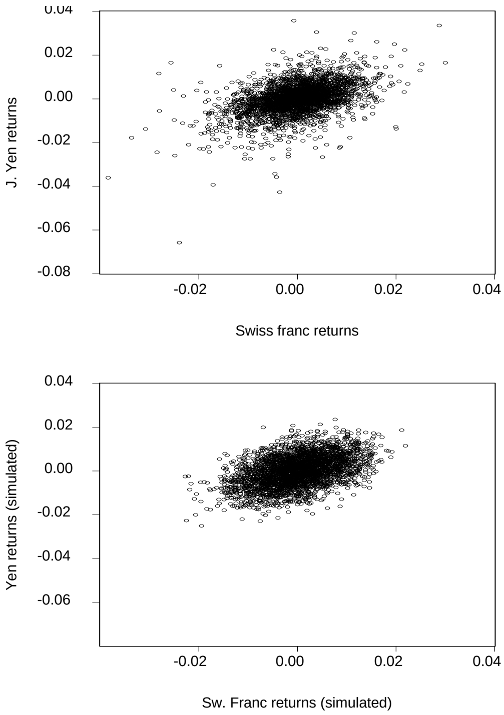


Figure 2: Real and simulated (biv. normal) scatters

Estimating systemic risk measure (2)

- Reduce to *univariate* estimation problem

$$\begin{aligned} E \quad : \quad &= \frac{P\{\Delta s_{10} > s\} + P\{\Delta s_{20} > s\}}{1 - P\{\Delta s_{10} \le s, \Delta_{20} \le s\}} \\ &= \frac{P\{\Delta s_{10} > s\} + P\{\Delta s_{20} > s\}}{1 - P\{\max(\Delta s_{10}, \Delta s_{20}) \le s\}} \\ &= \frac{P\{\Delta s_{10} > s\} + P\{\Delta s_{20} > s\}}{P\{\max(\Delta s_{10}, \Delta s_{20}) > s\}} \end{aligned}$$

- de Haan et al. (1994) semi-parametric EVT estimator:

$$\widehat{P} = \frac{m}{n} \left(X_{n-m,n}\right)^{\alpha} s^{-\alpha}$$

- Hill estimator for α

- Alternative for denominator: copula-based estimator that assumes tail dependence

Technical note on the De Haan estimator

$$
\begin{aligned}
X_{1,n} &\leq \cdots \leq X_{n-m,n} = t \leq \cdots \leq X_{n,n} < s \\
p_t &= P\left\{X > X_{n-m,n}\right\} \approx a \left(X_{n-m,n}\right)^{-\alpha} \\
&= m/n \Longrightarrow a = \frac{m}{n} \left(X_{n-m,n}\right)^{\alpha} \\
&= \text{[in-sample]} \\
p_s &= P\left\{X > s\right\} \approx a s^{-\alpha} \\
&= \text{[out-of-sample]} \\
p_s &= \frac{m}{n} \left(X_{n-m,n}\right)^{\alpha} s^{-\alpha}
\end{aligned}
$$

Data

- Daily nominal USD bilateral exchange rates taken from Datastream

- Developed, Asia, Latin America block of equal size (5 currencies)

- Sample length: January 3, 1994 until September 13, 2006 (T=3,313)

Extreme bilateral currency linkages (1)

	Developed currency pairs (/US$)				
	DEM	CHF	JPY	GBP	AUD
DEM	-				
CHF	1.590	-			
JPY	1.105	1.120	-		
GBP	1.120	1.080	1.03	-	
AUD	1.115	1.120	1.09	1.132	-

- Non-US fundamentals more volatile than US base currency fundamental $((a_0 < a_1 \approx a_2) \Rightarrow E < 4/3)$

Extreme bilateral currency linkages (2)

	Asian currency pairs (/US$)				
	THB	IDR	PHP	HKD	MYR
THB	-				
IDR	1.060	-			
PHP	1.190	1.090	-		
HKD	1.002	1.002	1.002	-	
MYR	1.170	1.160	1.185	1.005	-

- Asian fundamentals more volatile than US base currency fundamental $((a_0 < a_1 \approx a_2) \Rightarrow E < 4/3)$

Extreme bilateral currency linkages (3)

	Latin American currency pairs (/US$)				
	MXN	CLP	BOB	COP	VEB
MXN	-				
CLP	1.060	-			
BOB	1.005	1.000	-		
COP	1.060	1.035	1.010	-	
VEB	1.000	1.010	1.002	1.010	-

- Latin American fundamentals more volatile than US base currency fundamental (E $<$4/3)

Extreme multilateral currency linkages (3)

	E-estimates
DEV	1.280
AS	1.240
LA	1.005
	equality tests
DEV=LA	9.76
DEV=AS	0.447
AS=LA	3.31

- $1 \leq E\{\kappa \,|\, \kappa \geq 1\} \leq 5$

- Joint currency crash potential highest in industrial world, lowest Latin America

- Systemic risk significantly differs across blocks

Cross currency linkages (1)

	Asian cross rate pairs			
	numeraire=Thai baht (THB)			
	IDR	PHP	HKD	MYR
IDR	-			
PHP	1.11	-		
HKD	1.095	1.320	-	
MYR	1.170	1.225	1.510	-
	numeraire=Indonesian rupiah (IDR)			
	THB	PHP	HKD	MYR
THB	-			
PHP	1.595	-		
HKD	1.660	1.710	-	
MYR	1.655	1.695	1.835	-

Cross currency linkages (2)

	Latin American cross rate pairs			
	numeraire=Mex.peso (MXN)			
	CLP	BOB	COP	VEB
CLP	-			
BOB	1.342	-		
COP	1.252	1.347	-	
VEB	1.140	1.165	1.135	-
	numeraire=Venezolan bolivar (VEB)			
	MXN	CLP	BOB	COP
MXN	-			
CLP	1.580	-		
BOB	1.615	1.740	-	
COP	1.585	1.680	1.780	-

Concluding remarks

- Financial/FX returns + fundamentals nonnormally distributed

- Joint likelihood as extreme comovement (systemic risk) measure

- Heavy tailed common factors induce systemic risk

  - it increases with common factor volatility (measured by their scales)

  - it is underestimated when fundamental heavy tail feature is neglected

  - integrated risk management: use copula that feature tail dependence