THE QUANTO THEORY OF EXCHANGE RATES
by Lukas Kremens and Ian Martin

Discussed by Urban Jermann
Contribution

- No-arbitrage equation for currencies depending on quanto forwards prices and relative interest rates
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- For special case, log-investor in S&P500, forecasting equation has no residual
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- For special case, log-investor in S&P500, forecasting equation has no residual
- Data for 11 currencies 12/2009 – 05/2015
  - Quanto higher R2 than interest rates in sample
  - Out-of-sample KM equation beats UIP, RW and PPP
Theory

- No arbitrage

\[ 1 = E_t \left( M_{t+1} R_{f,t}^s \right) \quad \text{and} \quad 1 = E_t \left( M_{t+1} R_{f,t}^i \frac{e_{i,t+1}}{e_{i,t}} \right) \]

\[ E_t \frac{e_{i,t+1}}{e_{i,t}} = \frac{R_{f,t}^s}{R_{f,t}^i} - R_{f,t}^s \text{cov}_t \left( M_{t+1}, \frac{e_{i,t+1}}{e_{i,t}} \right) \]

- UIP fcst
- residual-R1
Consider $1 = \frac{1}{R_{f,t}} E_t^* (R_{t+1})$ and $\text{cov}(x, y) = Exy - ExEy$

$$E_t\left(\frac{e_{i,t+1}}{e_{i,t}}\right) = \frac{R_{f,t}^S}{R_{f,t}^i} + \frac{1}{R_{f,t}^S} \text{cov}_t^* (R_{t+1}, \frac{e_{i,t+1}}{e_{i,t}}) - \text{cov}_t (M_{t+1} R_{t+1}, \frac{e_{i,t+1}}{e_{i,t}})$$
KM equation

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E_t \left( \frac{e_{i,t+1}}{e_{i,t}} \right) = \frac{R^S_{f,t}}{R^i_{f,t}} + \frac{1}{R^S_{f,t}} \text{cov}^* \left( R_{t+1}, \frac{e_{i,t+1}}{e_{i,t}} \right) − \text{cov} \left( M_{t+1} R_{t+1}, \frac{e_{i,t+1}}{e_{i,t}} \right)
\]

If \( R_{t+1} \) S&P500 and log-investor \( M_{t+1} = 1/R_{t+1} \)

\[
E_t \left( \frac{e_{i,t+1}}{e_{i,t}} \right) = \frac{R^S_{f,t}}{R^i_{f,t}} + \frac{1}{R^S_{f,t}} \text{cov}^* \left( R_{t+1}, \frac{e_{i,t+1}}{e_{i,t}} \right)
\]

\text{UIP fcst} \quad \text{"quanto RP"}
S&P500 index forward pays $P_{t+1} - F_t$ and is priced as

$$F_t = E_t^* P_{t+1}$$
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$$F_t = E^*_t P_{t+1}$$

Quanto forward pays this in EUR

$$E^*_t [e_{i,t+1} (P_{t+1} - Q_{i,t})] = 0$$
Quantos

- S&P500 index forward pays $P_{t+1} - F_t$ and is priced as

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- Quanto forward pays this in EUR

$$E_t^* [e_{i,t+1} (P_{t+1} - Q_{i,t})] = 0$$

- Combined (and assuming known initial dividends)

$$\frac{Q_{i,t} - F_t}{R_{f,t}^i P_t} = \frac{1}{R_{f,t}^S} \text{cov}_t^* \left( R_{t+1}, \frac{e_{i,t+1}}{e_{i,t}} \right)$$
KM equation different versions

$E_t(\frac{e_{i,t+1}}{e_{i,t}}) =$

$\frac{R^s_{f,t}}{R^i_{f,t}} + \frac{1}{R^s_{f,t}} \text{cov}^*(R_{t+1}, \frac{e_{i,t+1}}{e_{i,t}}) - \text{cov}(M_{t+1}R_{t+1}, \frac{e_{i,t+1}}{e_{i,t}})$
KM equation different versions

- \( E_t \left( \frac{e_{i,t+1}}{e_{i,t}} \right) = \frac{R^s_{f,t}}{R^i_{f,t}} + \frac{1}{R^s_{f,t}} \text{cov}^*_t \left( R_{t+1}, \frac{e_{i,t+1}}{e_{i,t}} \right) - \text{cov}_t \left( M_{t+1} R_{t+1}, \frac{e_{i,t+1}}{e_{i,t}} \right) \)

- If \( R_{t+1} = R^i_{f,t} \cdot \frac{e_{i,t+1}}{e_{i,t}} \)
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\[ E_t \left( \frac{e_{i,t+1}}{e_{i,t}} \right) = \]
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\[ E_t\left(\frac{e_{i,t+1}}{e_{i,t}}\right) = \]
\[ \frac{R_f^s}{R_f^i} + \frac{1}{R_f^s} \text{cov}_t^*(R_{t+1}, \frac{e_{i,t+1}}{e_{i,t}}) - \text{cov}_t\left(M_{t+1}R_{t+1}, \frac{e_{i,t+1}}{e_{i,t}}\right) \]

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\[ \text{Della Corte, Ramadorai, and Sarno (2016)} \]
KM equation different versions

\( E_t \left( \frac{e_{i,t+1}}{e_{i,t}} \right) = \)
\( \frac{R^S_f}{R^i_f} + \frac{1}{R^S_f} \text{cov}^*(R_{t+1}, \frac{e_{i,t+1}}{e_{i,t}}) - \text{cov}_t(M_{t+1}R_{t+1}, \frac{e_{i,t+1}}{e_{i,t}}) \)

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\[ E_t\left(\frac{e_{i,t+1}}{e_{i,t}}\right) = \]
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\[ \text{Mueller, Stathopoulos and Vedolin (2016)} \]
Is new residual a priori smaller than initial?

\[ E_t(\frac{e_{i,t+1}}{e_{i,t}}) = \frac{R^s_{f,t}}{R^l_{f,t}} - R^s_{f,t} \text{cov}_t(M_{t+1}, \frac{e_{i,t+1}}{e_{i,t}}) \]

\[ E_t(\frac{e_{i,t+1}}{e_{i,t}}) = \frac{R^s_{f,t}}{R^l_{f,t}} + \frac{1}{R^s_{f,t}} \text{cov}^*_t(R_{t+1}, \frac{e_{i,t+1}}{e_{i,t}}) - \text{cov}_t(M_{t+1}R_{t+1}, \frac{e_{i,t+1}}{e_{i,t}}) \]
Is new residual a priori smaller than initial?

1. \[ E_t\left(\frac{e_{i,t+1}}{e_{i,t}}\right) = \frac{R_f^s}{R_f^i} - R_f^s \text{cov}_t\left(M_{t+1}, \frac{e_{i,t+1}}{e_{i,t}}\right) \]

2. \[ E_t\left(\frac{e_{i,t+1}}{e_{i,t}}\right) = \frac{R_f^s}{R_f^i} + \frac{1}{R_f^s} \text{cov}_t^*\left(R_{t+1}, \frac{e_{i,t+1}}{e_{i,t}}\right) - \text{cov}_t\left(M_{t+1} R_{t+1}, \frac{e_{i,t+1}}{e_{i,t}}\right) \]

Log-investor 100% in S&P500, "much more reasonable", \(R2 = 0\)
Is new residual a priori smaller than initial?

\[ E_t\left(\frac{e_{i,t+1}}{e_{i,t}}\right) = \frac{R^S_{f,t}}{R^I_{f,t}} - R^S_{f,t} \operatorname{cov}_t\left(M_{t+1}, \frac{e_{i,t+1}}{e_{i,t}}\right) \]

\[ E_t\left(\frac{e_{i,t+1}}{e_{i,t}}\right) = \frac{R^S_{f,t} \operatorname{cov}_t^*\left(R_{t+1}, \frac{e_{i,t+1}}{e_{i,t}}\right) - \operatorname{cov}_t\left(M_{t+1} R_{t+1}, \frac{e_{i,t+1}}{e_{i,t}}\right)}{R^I_{f,t}} \]

\[ R^2 \]

Log-investor 100% in S&P500, "much more reasonable", \( R^2 = 0 \)

CRRA-10 investor 100% in S&P500

\[ R^2 = \operatorname{cov}_t\left(R^{-9}_{t+1}, \frac{e_{i,t+1}}{e_{i,t}}\right) \]
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- Log-investor 100% in S&P500, "much more reasonable", \( R2 = 0 \)
- CRRA-10 investor 100% in S&P500

\[ R2 = \text{cov}_t\left(R^{-9}_{t+1}, \frac{e_{i,t+1}}{e_i,t}\right) \]

- \( R2 \) probably \(< R1 \)
Is the "Quanto Risk Premium" a risk premium?

- ?

Assume risk neutrality

\[ Q_i, t \]

\[ F_t P_t R_{if}, t = 1 R_f, t \]

Assume binomial S&P500 and EUR, long quanto position

\[ P_{t+1}, (P_{t+1} + Q_t) \]

Up, gain, positive corr, EUR up, gains is amplified

Down, loss, pos corr, EUR down, loss is weakened

Why get quanto forward on S&P500?

European investor hedges currency

Regular forward hedges expected value

Quanto hedges perfectly

"Quanto" is short for "quantity adjusting option"
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\[
\frac{Q_{i,t} - F_t}{P_t R_{f,t}^i} = \frac{1}{R_{f,t}^S} \text{cov}_t \left( \frac{e_{i,t+1}}{e_{i,t}}, R_{t+1} \right)
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- Assume binomial S&P500 and EUR, long quanto position: 
  
  \[e_{t+1} (P_{t+1} - Q_t)\]
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\frac{Q_{i,t} - F_t}{P_t R^i_{f,t}} = \frac{1}{R^S_{f,t}} \text{cov}_t \left( \frac{e_{i,t+1}}{e_{i,t}}, R_{t+1} \right)
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e_{t+1} (P_{t+1} - Q_t)
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Empirical analysis

- Detailed and well-executed
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- Only 5.5 years of data!
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  - quotes, traded prices?
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  - bid-ask spreads?
  - how illiquid?
Nikkei CME Futures USD Quanto - cov(NIK, JPY/$)
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Out-of-sample forecasts JPY/USD, 2004-2017

\[
\begin{align*}
KM & : \quad E^Q \left( \frac{e_{t+1}}{e_t} \right) - 1 = \frac{Q_{t,t+1} - f_{t,t+1}}{f_{t,t+1}} + \frac{F_{t,t+1}}{S_t} - 1 \\
UIP & : \quad E^U \left( \frac{e_{t+1}}{e_t} \right) - 1 = \frac{F_{t,t+1}}{S_t} - 1 \\
\text{Constant} & : \quad E^C \left( \frac{e_{t+1}}{e_t} \right) - 1 = 0
\end{align*}
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$UIP : \quad E^U \left( \frac{e_{t+1}}{e_t} \right) - 1 = \frac{F_{t,t+1}}{S_t} - 1$

Constant : \quad E^C \left( \frac{e_{t+1}}{e_t} \right) - 1 = 0

$R_{OS}^2 = 1 - \sum_t \left( \varepsilon_{t+1}^Q \right)^2 / \sum_t \left( \varepsilon_{t+1}^B \right)^2$
Out-of-sample forecasts JPY/USD, 2004-2017

\[ R_{OS}^2 = 1 - \sum_t \left( \varepsilon_{t+1}^Q \right)^2 / \sum_t \left( \varepsilon_{t+1}^B \right)^2 \]
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\[ R_{OS}^2 = 1 - \frac{\sum_t (\varepsilon_t^Q)^2}{\sum_t (\varepsilon_t^B)^2} \]

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<th>Squared err</th>
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Conclusion

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  - useful framework

To do: more data and more information about prices
Conclusion

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