Collateral-adjusted CIP Arbitrages

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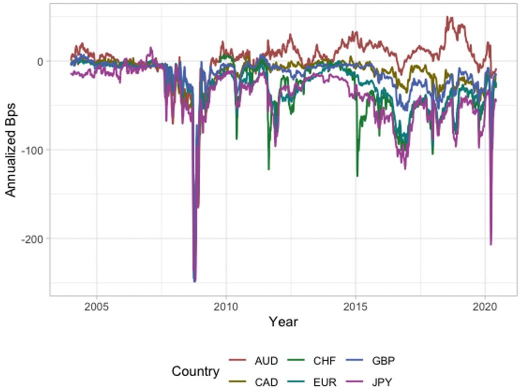
Motivation

- Since the GFC → persistent violation of the CIP measured by xccy basis



- Apart from AUD, for most G7 currencies, the 3-month OIS based xccy basis is negative → borrowing US dollars via the xccy swap market is more expensive vs. the cash market

5-year xccy

What is this paper about?

- Research Question: Do CIP violations really reflect arbitrage opportunities?
- Answer: Not necessarily
  - Costly collateral rental yield explains up to about two-thirds of the “apparent” CIP violations
- So xccy bases are not arbitrarily determined, as may be the case given all plausible constraints

What is the CIP?

Textbook formula - in continuous time:

$$F_{t+1} = S_t \times exp\left(r^{\$}_{t+1} - (r^{i}_{t+1} + \underbrace{x^{i}_{T}}_{=0})\right)$$

Where the spot S_t and the forward F_{t+1} exchange rates are expressed as the price in domestic currency \$ (e.g. USD) for one unit of foreign currency i (e.g. 1 EUR)

1. If $x^{i}_{t+1} \neq 0$ → Violation of CIP
2. Explicit knowledge of unique $r^{\$}_{t+1}$ and r^{i}_{t+1} **risk-free rates** in each currency required → **no counterparty credit risk**
3. The lending and borrowing risk-free rates should be accessible to any counterparty in the market

Classic CIP arbitrage diagram | Pricing FX forward

Related literature

1. CIP Violations
   - Attribute violations to various types of **frictions**, ranging from the dominant explanation of balance sheet constraints, costs of regulation, to costs of borrowing and counterparty risk, as well as FX hedging demand and market segmentation

   Baba et al. (2008), Baba at al. (2009), Geffey et al. (2009), Mancini-Griffoli et al. (2012), Hui et al. (2011), McCauley et al. (2014) and Ivashina et al. (2015), Du et al., (2016), Lida et al., (2016), Borio et al., (2016), Sishko et al., (2016), Shin (2016), Avdjiev et al., (2016), Rime et al., (2017), Wong et al., (2018), Kohler et al., (2019), Cenedese et. al., (2020), Augustin et al., (2020)

2. Funding Value Adjustments (FVA)
   Fleckenstein and Longstaff (2020) and Anderson, Duffie, and Song (2020)

3. Dealer Capital Structure and Limits to Arbitrage
   Adrian, Etula, and Muir (2014), Garleanu and Pedersen (2009), Brunnermeir and Pederson (2009), and Shleifer and Vishny (1997)

This paper adds to and reconciles with existing literature by pointing to an important collateral channel that contributes to explaining standard CIP violations.

This paper narrative

- The hypothesis is that the "apparent" violation of the standard CIP is predominantly a reflection of collateralization as documented in the ISDA CSA of the derivatives contracts and due to:

  1. Mark-to-Market (MtM) of collateral
  2. Choice of collateral currency (USD for transactions involving USD leg)
  3. Contactual collateral remuneration rate which is different than a risk-free rate

- I quantify and summarize these collateralization features in a no-arbitrage consistent single metric called collateral rental yield

CIP measurement details

Introducing the collateral rental yield

$$y_t = r_t - o_t$$

where r_t and o_t are the *risk-free rate* and the *collateral-rate*. A common market practice, under a standard CSA, is to set the $o(t)$ equal to the overnight (OIS) rate

- Economically y_t can be interpreted as *dividend yield* for collateral receiver and *collateral funding cost* for the collateral payer
- Since we have a derivative where the collateral is a different currency (e.g., USD), we have:

$$\boxed{y_t^{i/\$} = y_t^i - y_t^\$}$$

Representing the difference in collateral rental yields between currency (i) and $(\$)$

However, for a stochastic setting, the above collateral rental yield needs to be adjusted for a change in measure between the currencies Stochastic case

Collateralized FX forward

- Single period price of FX forward, in terms of domestic currency (e.g. USD) per 1 unit of foreign currency (e.g. EUR), where domestic currency is used as the collateral for the contract is:

$$F_{t+1} = S_t \times e^{o^{\$}_{t+1} - (o^{i}_{t+1} + y^{i/\$}_{t+1})}$$

  where o_{t+1} are OIS collateral remuneration rates in each currency (ISDA CSA standard)

  Why? Mapping to Funding Rates CIP Formula

- Comparing the no-arbitrage FX forward pricing formula with the CIP textbook formula, if one is to measure the CIP violation (basis) using the contractual collateral OIS rates in each currency, then the xccy basis x_{t+1} is allowed to deviate from 0 and is simply equal to the added collateral rental yield adjustment $y^{i/\$}_{t+1}$ to the discounting rates

Empirical Strategy

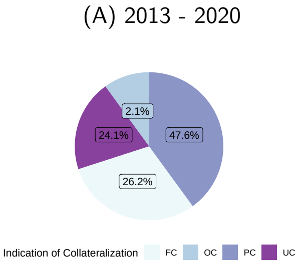
- Data: FX Forwards and xccy swaps for G7 currencies from Bloomberg (1 January 2009 to 31 May 2020). US dollars BOX rates are from van Binsbergen, Diamond, and Grotteria (2019). Data on leverage of security broker dealers from Adrian, Etula, and Muir (2014) and on leverage and capital factors of bank holding companies from He, Kelly, and Manela (2017)

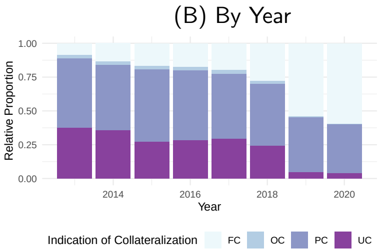
- Consistently calculate CIP Violations using OIS rates:
  - Short-term CIP violations: $x^{i}_{t+1} = r^{\$,OIS}_{t+1} - \left(r^{i,OIS}_{t+1} - (f_{t+1} - s_t)\right)$
  - Long-term CIP violations: $x^{i,OIS}_{t+1} = (IRS^{\$,OIS}_{t+1} - \left(IRS^{i,OIS}_{t+1} - (f_{t+1} - s_t)\right)$ Graph

- Construct 3 observable proxies for the collateral rental yield:
  1. proxy using GC repo rates rates: $y^{i/\$}_{n,gc} = (r^{i}_{n,gc} - o^{i}_{n}) - (r^{\$}_{n,gc} - o^{\$}_{n})$
  2. proxy using T-bill rates rates: $y^{i/\$}_{tbill} = (r^{i}_{tbill} - o^{i}_{3m}) - (r^{\$}_{tbill} - o^{\$}_{3m})$
  3. proxy using BOX rates rates: $y^{i/\$}_{BOX} = (r^{i}_{tbill} - o^{i}_{3m}) - (r^{\$}_{BOX} - o^{\$}_{3m})$

Empirical Findings

- How prevalent is collateralization in the xccy market?





Note: This figure reports the level of collateralization in the reported executed xccy basis trades between January 1, 2013 and March 31, 2020, which are publicly distributed by the Depository Trust & Clearing Corporation (DTCC) Data Repository (U.S.) LLC (DDR)

Empirical Findings

- Collateral-adjusted xccy basis across currency pairs:

Short-Term Mean CIP deviations

		1W		1M		3M			
		x_{1w}^{OIS}	$x_{1w,gc}^{adj}$	x_{1m}^{OIS}	$x_{1m,gc}^{adj}$	x_{3m}^{OIS}	$x_{3m,gc}^{adj}$	$x_{3m,tbill}^{adj}$	$x_{3m,BOX}^{adj}$
Post-Crisis	Mean	-27.05	-14.58	-41.3	-24.87	-33.67	-19.07	-23.53	6.51
		(82)	(81.08)	(33.84)	(29)	(24.81)	(21.52)	(23.45)	(22.78)
Crisis	Mean	-47.66	-55.16	-65.92	-53.74	-52.11	-47.13	-57.27	10.11
		(84.47)	(88.42)	(86.73)	(74.12)	(64.35)	(59.94)	(73.06)	(41.38)

  - Tranquil period: about 2/3 reduction in the mean the OIS-based CIP deviation
  - Crisis period: No reduction

Empirical Findings

- Short-Term CIP Violations and Collateral:

Table 1: Panel Regression Results for the Short-Term OIS-based Xccy Basis on the Observable Proxies for the Collateral Rental Yield

PANEL A: *In Levels*

	Dependent variable: x_n^{OIS}									
	$n = 1w$		$n = 1m$		$n = 3m$					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
$y_{n,GC}^{i/\$}$	1.10^{***}	0.91^{**}	1.42^{***}	1.23^{***}	0.51^{***}	0.18^{***}				
	(0.38)	(0.36)	(0.32)	(0.22)	(0.11)	(0.07)				
$y_{3m,Tbill}^{i/\$}$							0.56^{***}	0.50^{***}		
							(0.06)	(0.05)		
$y_{3m,BOX}^{i/\$}$									0.60^{***}	0.43^{***}
									(0.04)	(0.05)
Qend		-25.78^{***}		-8.24^{**}		1.90		0.61		0.58
		(7.19)		(3.74)		(1.41)		(1.21)		(0.97)
Yend		-36.11^{**}		-43.07^{***}		-2.62^{**}		-3.25^{**}		-3.80^{**}
		(14.73)		(9.66)		(1.07)		(1.37)		(1.59)
LiborOISs		0.33^{*}		0.68^{***}		0.63^{***}		0.22^{***}		0.25^{***}
		(0.18)		(0.14)		(0.07)		(0.02)		(0.03)
FXbidask		-43.99^{*}		16.68		-11.90^{**}		-18.80^{***}		-22.06^{***}
		(22.85)		(10.60)		(5.89)		(4.54)		(6.49)
US factor		0.10		0.32		-1.04^{***}		-1.30^{***}		-0.82^{***}
		(0.79)		(0.60)		(0.25)		(0.28)		(0.24)
$\Delta lnFX$		150.13		30.05		57.80^{*}		41.54		26.03
		(124.38)		(56.69)		(31.46)		(25.67)		(24.60)
lnVol		23.02^{**}		8.11		−0.92		−2.79		−0.90
		(9.51)		(8.96)		(2.42)		(2.58)		(3.35)
lnVix		−5.40		2.22		-6.42^{*}		-8.80^{**}		−3.39
		(8.64)		(7.02)		(3.70)		(4.14)		(4.04)
Currency pairs	4	4	3	3	4	4	5	5	5	5
Within Adj-R^2	0.02	0.08	0.37	0.46	0.09	0.33	0.15	0.38	0.39	0.51
Observations	8,440	7,576	5,458	4,854	10,491	9,520	14,604	13,355	11,234	11,127

- If the proxy collateral rental yield measures collateral costs effectively and the FX forward market in aggregate is fully collateralized, the model suggests a slope coefficient of 1 and an R^2 of 1
- Almost one-for-one economically meaningful relationship and large R^2

Empirical Findings

- Long-Term CIP Violations and Collateral:

Table 2: Panel Regression Results for the Long-Term Synthetic OIS-Based Xccy Basis on the Various Collateral Rental Yield Measures

PANEL A: *For GC-based collateral rental yield proxy (in levels)*

	Dependent variable: x_n^{OIS}					
	1-year xccy basis		5-year xccy basis		10-year xccy basis	
	(1)	(2)	(3)	(4)	(5)	(6)
$y_{3m,GC}^{i/\$}$	0.41***	0.19***	0.44***	0.21***	0.34***	0.25***
	(0.07)	(0.06)	(0.09)	(0.08)	(0.05)	(0.10)
Yend		−6.28***		−3.12		−1.61
		(2.18)		(2.20)		(2.31)
HKM leverage		−0.02**		−0.05***		−0.04***
		(0.01)		(0.01)		(0.01)
HKM capital		−19.27**		−41.65***		−35.35***
		(9.65)		(11.97)		(12.72)
LiborOISs		−0.05		−0.16**		−0.14*
		(0.06)		(0.07)		(0.07)
US factor		−0.26***		−0.65***		−0.72***
		(0.11)		(0.23)		(0.29)
$\Delta lnFX$		−16.69		−17.57		−15.50
		(19.52)		(19.60)		(21.09)
lnVol		−10.23***		−8.30**		−5.33
		(3.89)		(3.83)		(4.06)
FXbidask		23.14*		19.87*		26.43**
		(12.00)		(10.78)		(12.39)
lnVix		−8.58**		−3.38		−1.05
		(3.84)		(3.82)		(4.03)
Currency pairs	4	4	4	4	4	4
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Within Adj-R^2	0.01	0.11	0.01	0.22	0.01	0.13
Observations	344	264	335	257	331	253

- In this case, too, collateral rental yield has an economically and statistically significant relationship
- But there are also regulatory frictions such as leverage and capital, as well as the strength of the US dollar

Empirical Findings

- Do crises affect the collateral? Diff-in-Diff

Table 3: Difference-in-Difference of the Collateral Rental Yield Pre and Post-Crisis

	Dependent variable: x_n^{OIS}				
	$n = 1w$	$n = 1m$	$n = 3m$		
	(1)	(2)	(3)	(4)	(5)
$y_{n,gc}^{i/\$}$	0.12	0.53	0.39		
	(0.25)	(0.48)	(0.30)		
$y_{n,gc}^{i/\$} \times PostCrisis$	0.93**	1.14**	0.49**		
	(0.38)	(0.45)	(0.20)		
$y_{tbill}^{i/\$}$				−0.23	
				(0.21)	
$y_{tbill}^{i/\$} \times PostCrisis$				0.91***	
				(0.20)	
$y_{BOX}^{i/\$}$					0.86***
					(0.07)
$y_{BOX}^{i/\$} \times PostCrisis$					0.16**
					(0.08)
PostCrisis	28.08*	21.06*	28.75***	22.50**	−3.82
	(15.12)	(11.39)	(4.52)	(11.21)	(3.04)
Currency pairs	4	3	4	5	5
Within Adj-R^2	0.03	0.30	0.21	0.16	0.52
Observations	8616	5546	10667	14954	11565

- All proxies are significant and important in magnitude only during the tranquil post-crisis times
- Collateral is not very relevant in crisis times

Empirical Findings

- Do global risks and intermediaries' frictions affect the collateral channel?

Table 4: Panel Regression Results for the Various Collateral Rental Yield Measures on Several Factors

PANEL A: *In Levels*

	$y^{i/\$}_{3m,GC}$	$y^{i/\$}_{Tbill}$	$y^{i/\$}_{BOX}$
	(1)	(2)	(3)
Yend	-6.44^{***}	-1.87	-3.08
	(1.96)	(2.01)	(2.37)
HKM leverage	-0.01	0.01	-0.04^{***}
	(0.01)	(0.01)	(0.01))
HKM capital	1.23	3.15	-31.96^{**}
	(10.78)	(10.78)	(12.62)
LiborOISs	0.11	0.13^{***}	0.28^{***}
	(0.23)	(0.04)	(0.04)
US factor	-0.22	-0.30	-0.39^{**}
	(0.25)	(0.26)	(0.16)
$\Delta lnFX$	-7.55	-15.11^{**}	-12.92^{*}
	(5.96)	(5.99)	(6.95)
lnVol	11.58^{***}	-4.41	-14.40^{***}
	(3.53)	(3.82)	(4.55)
FXbidask	-22.97^{**}	-28.76^{**}	-30.40^{*}
	(10.98)	(12.73)	(16.77)
lnVix	-8.91^{**}	0.65	-0.93
	(3.51)	(3.72)	(4.97)
Currency pairs:	4	5	5
Within Adj-R^2	0.16	0.02	0.26
Observations	264	369	344

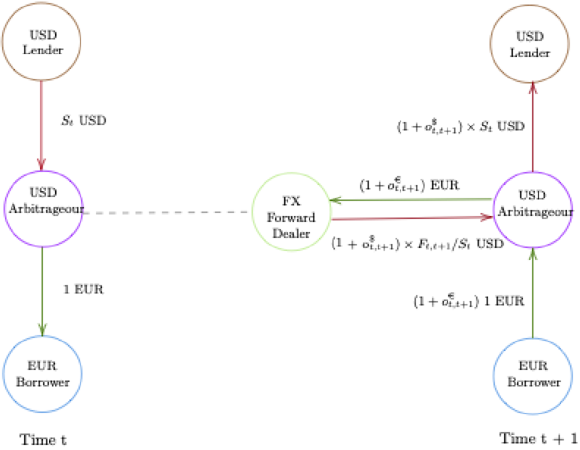
- GC-based collateral rental yield is statistically significant and systematically larger for contracts that cross year-end reporting dates but still GC rates appear to be superior proxies for the risk-free rate (as no Libor-OIS counterparty covariation in them)
- No persistent relation to proxies for intermediaries' frictions imposed by counterparty and funding constraints, leverage, or capital regulation

Conclusion

- Taken together, the empirical results suggest that collateralization details in derivative contracts are an important and persistent factor contributing (about two-thirds on average) to the violations of the standard CIP conditions.
- Results point to an important collateral channel that operates independently of some of the previously documented global risks and intermediary frictions and contributes to explaining standard CIP violations.
- The findings help to reconcile existing explanations in the CIP literature and clarify CIP trade pricing and risk management for market participants.

THANK YOU

A1: Cash Flow Diagram for Standard CIP Arbitrage in USD



Arbitrageour's Net Cash Flow: 0 USD $-(1+o^{\$}_{t,t+1}) \times S_t/F_{t,t+1} + (1+o^{€}_{t,t+1}) \approx -x_{t,t+1} \geq 0$ USD

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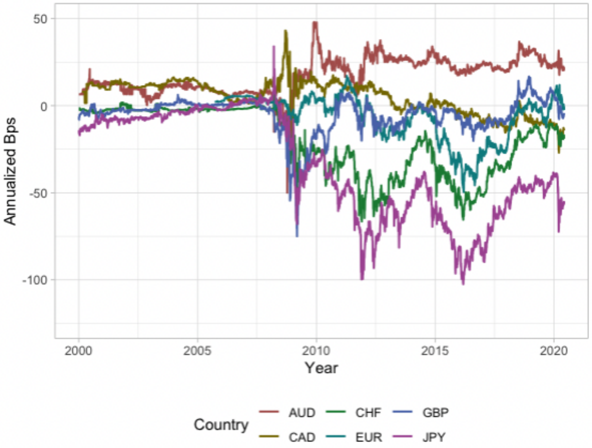
A2: 5-year xccy basis



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A3: Detour - But how do we measure CIP deviation?

- The textbook formula specifies that $r_t^{(i)}$ and $r_t^{(\$)}$ should be risk-free rates in each currency $\longrightarrow$ no counterparty credit risk

- But what risk-free rates should we use?
  1. Empirical literature uses Libors as proxies, but Libors $\neq$ risk-free after GFC because they:
     - ★ Misrepresent actual trading rates - no transaction costs
     - ★ Prone to distortions (i.e. Libor rigging cases)
     - ★ Reflect credit risk of banks in the panel setting Libor rates
  2. Next obvious candidate are the Overnight Rates (FedFunds, Sonia, Eonia etc.), but they are:
     - ★ Un-collateralized money market rates $\rightarrow$ not risk-free
  3. Government bonds? But they are:
     - ★ Governed by regulation on risk management and taxation
     - ★ Receive different liquidity premiums for each maturity
  4. GC repo rates? Could work, but:
     - ★ Lack of ample term repo liquidity and data to extrapolate a complete term structure

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A4: Pricing - Stochastic Collateral Rental Yield

$$y^{i/\$}(s) = E_t^{Q^i}[(y^i(s)ds] - E_t^{Q^\$}[y^\$(s)ds] = E_t^{Q^i}[(y^i(s) - y^\$(s))ds]$$

where $E_t^{Q^i}[\cdot]$ and $E_t^{Q^\$}[\cdot]$ are the time t conditional expectation under the risk-neutral measure of currency (i) and (\$) respectivelly, where the money market account of each currency respectivelly is used as a numeraire ($\beta^i_\cdot = exp(\int_0^i r^i(s)ds)$).

Notice that I am changing the measure using the Radon-Nikodym density:

$$\frac{dQ^\$}{dQ^i}|_t = \frac{\beta_t^\$ S^{(i/\$)}(0)}{\beta_t^i S^{(i/\$)}(t)}$$

where $S^{i/\$}$ is the spot FX rate in terms of the domestic currency (\$) per unit of foreign currency (i). I will use the above measure for the collateral rental yield in analyzing the long-term CIP violations in the remainder of the paper.

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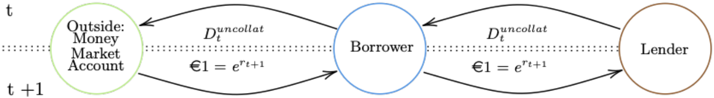
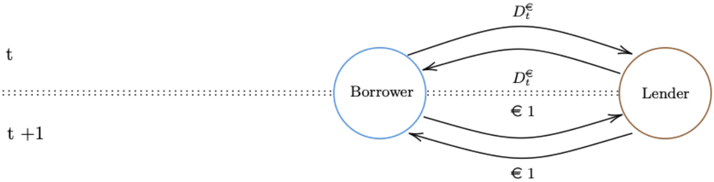
Mapping collateralization to funding/discount rates in simple terms. Why do we discount at OIS rates

Penel A: No-Arbitrage replicating strategy when borrowing by issuing a ZC bond in € that is not collateralized



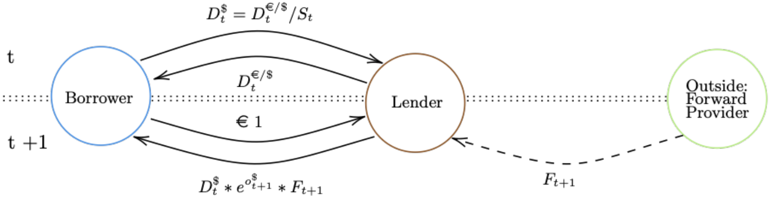
No-arbitrage brake-even present value of ZC bond: $D_t^{uncollat} = e^{-r_{t+1}}$

Penel B: No-Arbitrage replicating strategy when borrowing by issuing a ZC bond in € that is collateralized in the same currency €



No-arbitrage brake-even present value of ZC bond: $D_t^{€} = e^{-o_{t+1}}$

Penel C: No-Arbitrage replicating strategy when borrowing by issuing a ZC bond in € that is collateralized in another currency $



No-arbitrage brake-even present value of ZC bond: $D_t^{€/\$} = e^{-(o_{t+1}^{€} - y_{t+1}^{€/\$})}$

A5: Algebra deriving Panel C

Based on the diagram in Panel C, the no-arbitrage brake-even at $t+1$ is:

$$€1 = D_t^{\$} \times e^{o_{t+1}^{\$}} \times F_{t+1}$$

since $D_t^{\$} = D_t^{€/\$}/S_t$ and counterparty risk free FX forward is $F_{t+1} = S_t \times e^{r_{t+1}^{€} - r_{t+1}^{\$}}$, substituting:

$$€1 = D_t^{€/\$}/S_t \times e^{o_{t+1}^{\$}} \times S_t \times e^{r_{t+1}^{€} - r_{t+1}^{\$}}$$

since $y_{t+1} = r_{t+1} - o_{t+1}$, then $r_{t+1} = y_{t+1} + o_{t+1}$, substituting:

$$€1 = D_t^{€/\$} \times e^{o_{t+1}^{\$}} \times e^{y_{t+1}^{€} + o_{t+1}^{€} - y_{t+1}^{\$} - o_{t+1}^{\$}}$$

$$€1 = D_t^{€/\$} \times e^{y_{t+1}^{€} + o_{t+1}^{€} - y_{t+1}^{\$}}$$

$$D_t^{€/\$} = e^{-(y_{t+1}^{€} + o_{t+1}^{€} - y_{t+1}^{\$})}$$

since $y^{€/\$} = y_{t+1}^{€} - y_{t+1}^{\$}$, substituting, the price of the bond is:

$$D_t^{€/\$} = e^{-(o_{t+1}^{€} - y_{t+1}^{€/\$})}$$

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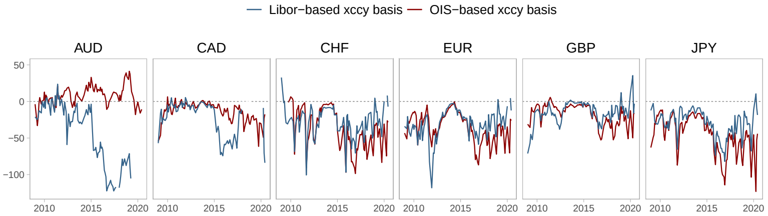
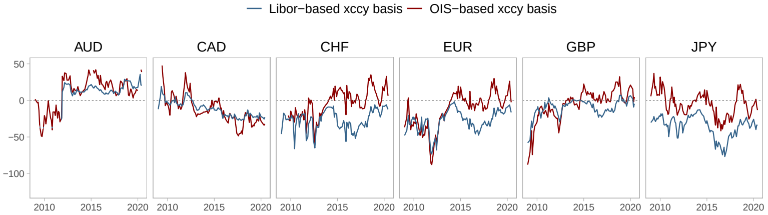
Standard Libor Versus OIS-Based CIP Violations

Panel A: 3-month Horizon

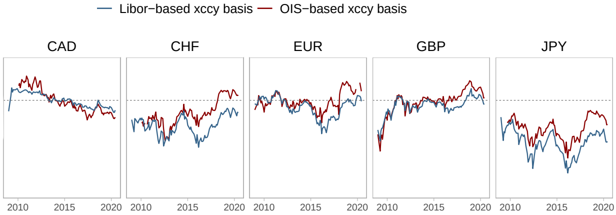


Panel B: 1-year Horizon

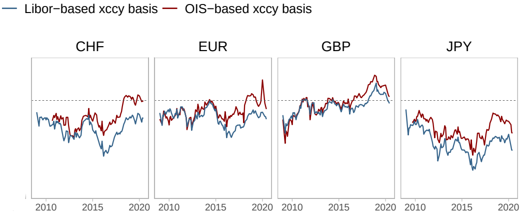


Standard Libor Versus OIS-Based CIP Violations

Panel C: 5-year Horizon



Panel D: 10-year Horizon



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Pricing a collateralized Xccy basis swap

- It is composed of a domestic currency floating rate bond, $h_0^{\$}$, and a foreign currency floating rate bond, h_0^i, put together by a market condition:

$$S_0 \times h_0^{\$} = h_0^i$$

The present value of the domestic bond at time 0 is:

$$h_0^{\$} = -1 + D^{\$}(0, T_N) \sum_{n=1}^{N} \delta_n D^{\$}(0, T_n) E^{T_n^{\$}}[L^{\$}(T_{n-1}, T_n)] \tag{1}$$

where $D^{\$}(0, \cdot) = e^{-\int_0^{\cdot} o^{\$}(s)ds}$, δ_n denotes a day-count fraction for the period $[T_{n-1}, T_n]$, $E^{T_n^{\$}}[L^{(\$)}(T_{n-1}, T_n)]$ is the set of collateralized forward 3-month Libors at each fixed T_{n-1} and maturing at T_n in currency (\$), and $o^{\$}(\cdot)$ denotes a set of contractual collateral (OIS) zero-coupon discounting rates.

The present value of the foreign currency leg at time 0 is:

$$h_0^i \approx -1 + D^{i/\$}(0, T_N) + \sum_{n=1}^{N} \delta_n D^{i/\$}(0, T_n) E^{T_n^i} \left([L^i(T_{n-1}, T_n)] + x_N \right) \qquad (2)$$

where $D^{i/\$}(0, \cdot) = e^{-\int_0^{\cdot} o^i(s) + y^{i/\$}(s) ds}$, x_N is the "xccy basis" swap price for a tenor-N xccy swap, and $D^{i/\$}(0, \cdot)$ includes the set of $y^{i/\$}(\cdot)$ collateral rental yields

What matters for the pricing of xccy basis?

1. $y^{i/\$}$ $\longrightarrow$ representing the collateral rental yield
   - Unobservable - endeavor to proxy it

2. Dynamics of FX rate S_0
   - Xccy swap MtM is most sensitive to FX fluctuations, which affect the need to post collateral

3. For long tenor xccy swaps (>3-months): Dynamics of the Libor-to-Collateral rate ($Libor - OIS$) spread
   - Xccy swaps, unlike arbitrage strategies, exchange Libors but are discounted at OIS rates (collateral rates)
   - Heuristically, this spread represents both credit counterparty risks and funding liquidity strains in the respective money-markets across the term structure