Heterogeneous Information Content of Global FX Trading

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Motivation: Heterogeneous Market Participants

Why Study the OTC Market for FX Derivatives?

- Crucial role of OTC (derivative) markets in the financial crisis of 2008
- Average daily trading volume of 5.4 trillion USD (as of June 2017)
- Regulators' increasing attention to these "dark markets", see Duffie (2012)

Recent Policy Reforms:

- US equities: Dodd-Frank Act (2010)
- US bonds: Trade Reporting and Compliance Engine (2002)
- European version: EMIR (2012) and MiFID II (2014)

Key Research Questions:

1. Does order flow impact FX prices heterogeneously across market participants, time, and currency pairs?
2. Does this heterogeneity provide significant economic value to be revealed in a profitable trading strategy?

Contribution of Our Paper

Price Impact is Heterogeneous Across Market Participants:

- First paper to estimate price impact using a **bivariate VAR model** à la Hasbrouck (1991a) that dissects global FX order flow into end-user segments
- Order flow impacts FX prices heterogeneously. In particular, **corporates** have a significantly lower price impact than **funds**, and **non-bank financials**
- Both the **contemporary** and **permanent** price impact differ across agents, time, and currency pairs in the **FX spot market**

Information Asymmetries Can be Exploited by a Simple Trading Strategy:

- Long-short strategy based on *UIP* deviations generates an annualised **Sharpe ratio** of 1.22 and a **gross excess return** of 9.82% p.a.
- Intuition: Trading on the **aggregate permanent price impact** reduces the forward premium bias and accurately predicts currency values
- Trading signals are generated from a **rolling window regression**. Currency pairs are sorted into quintile portfolios based on the aggregate permanent price impact. Eventually, a standard **HML** portfolio is constructed

Review of Related Literature

Market Microstructure:

- Roll (1984), Choi et al. (1988), Stoll (1989), George et al. (1991), covariance spread models. Kyle (1985) relevance of order flow and price impact
- Hasbrouck (1988, 1991a,b) VAR to separate permanent and temporary effects
- Evans (2002), Payne (2003), Evans and Lyons (2005, 2006, 2008, 2012), Bjønnes and Rime (2005), Berger et al. (2008), Rime et al. (2010), Breedon and Ranaldo (2013), Mancini et al. (2013) order flow impacts FX rates
- Bacchetta and van Wincoop (2005), Evans and Lyons (2006) theoretical models dealing with heterogeneous information in FX rate determination

FX Asset Pricing:

- Lustig and Verdelhan (2007) first to build cross-sections of currency portfolios
- Lustig et al. (2011), Menkhoff et al. (2012, 2017), Aloosh and Bekaert (2017) currency factors and FX trading strategies based on excess returns
- Benchmark: Menkhoff et al. (2016), Gargano et al. (2018) information content of order flow and volume in FX markets
- Ding (1999), Hartmann (1999), Huang and Masulis (1999), Christiansen et al. (2011), Gilmore and Hayashi (2011) trading costs in FX spot and futures market

Outline of Talk

1. Motivation
2. Main Findings
3. Related Literature
4. Data
5. Summary Statistics
6. Methodology
7. Regression Results
8. Currency Portfolios
9. Conclusion

Dataset from Quandl.com

Continuous Linked Settlement FX Order Flow Data:

- **CLS Group** operates the world's largest multi-currency cash settlement system, handling over 50% of global **spot**, **swap**, and **forward** FX transaction volume
- Dataset contains **hourly** intra-day FX **spot order flow** by type of market participant and side of trade taken
- Participant categories include **banks (BA) acting as price takers**, **corporates (CO)**, **funds (FD)**, **non-bank financial firms (NB)**, **buy-side** (price takers) and **sell-side** (market makers), where corporate, fund, and non-bank financial are a subset of the total buy-side (aggregate order flow)
- Data includes **number of transactions** (trade count) and equivalent value in the **base currency** (trade volume)
- Unique dataset on **hiqh-frequency order flow** with **heterogeneous agents** that has *not* been used for academic purposes before

Dataset Snapshot

Data Characteristics:

- 16 major currencies and 30 currency pairs:
  AUDJPY, AUDNZD, AUDUSD, CADJPY, EURAUD, EURCAD, EURCHF, EURDKK, EURGBP, EURJPY, EURNOK, EURSEK, EURUSD, GBPAUD, GBPCAD, GBPCHF, GBPJPY, GBPUSD, NZDUSD, USDCAD, USDCHF, USDDKK, USDHKD, USDILS, USDJPY, USDMXN, USDNOK, USDSEK, USDSGD, USDZAR
- FX spot quotes (offer rates) are retrieved from Olsendata.com
- Timeperiod: 02/09/2012 to 19/11/2017

Sample Data:

Inst	GMT Date	h	Prc Taker	Mkt Maker	Buy C	Sell C	Buy Vol	Sell Vol	#Buy	#Sell
SPT	2017-10-31	15	CO	Bank	EUR	USD	50k	25k	2	3
SPT	2017-10-31	15	FD	Bank	EUR	USD	979k	108k	126	45
SPT	2017-10-31	15	NB	Bank	EUR	USD	25k	21k	33	18
SPT	2017-10-31	15	BA	Bank	EUR	USD	1,617k	2,425k	1,147	2,096
SPT	2017-10-31	15	Buy Side	Sell Side	EUR	USD	2,671k	2,579k	1,308	2,162

Example: On 31/10/2017, 3pm to 4pm, London time, "Funds" bought EUR from and sold USD to "Banks", in 126 spot transactions, totalling at 979k EUR. During the same period, "Funds" sold EUR to and bought USD from "Banks" in 45 other spot transactions, totalling at 108k EUR

Table 1: *Summary Statistics for Hourly Spot Returns*

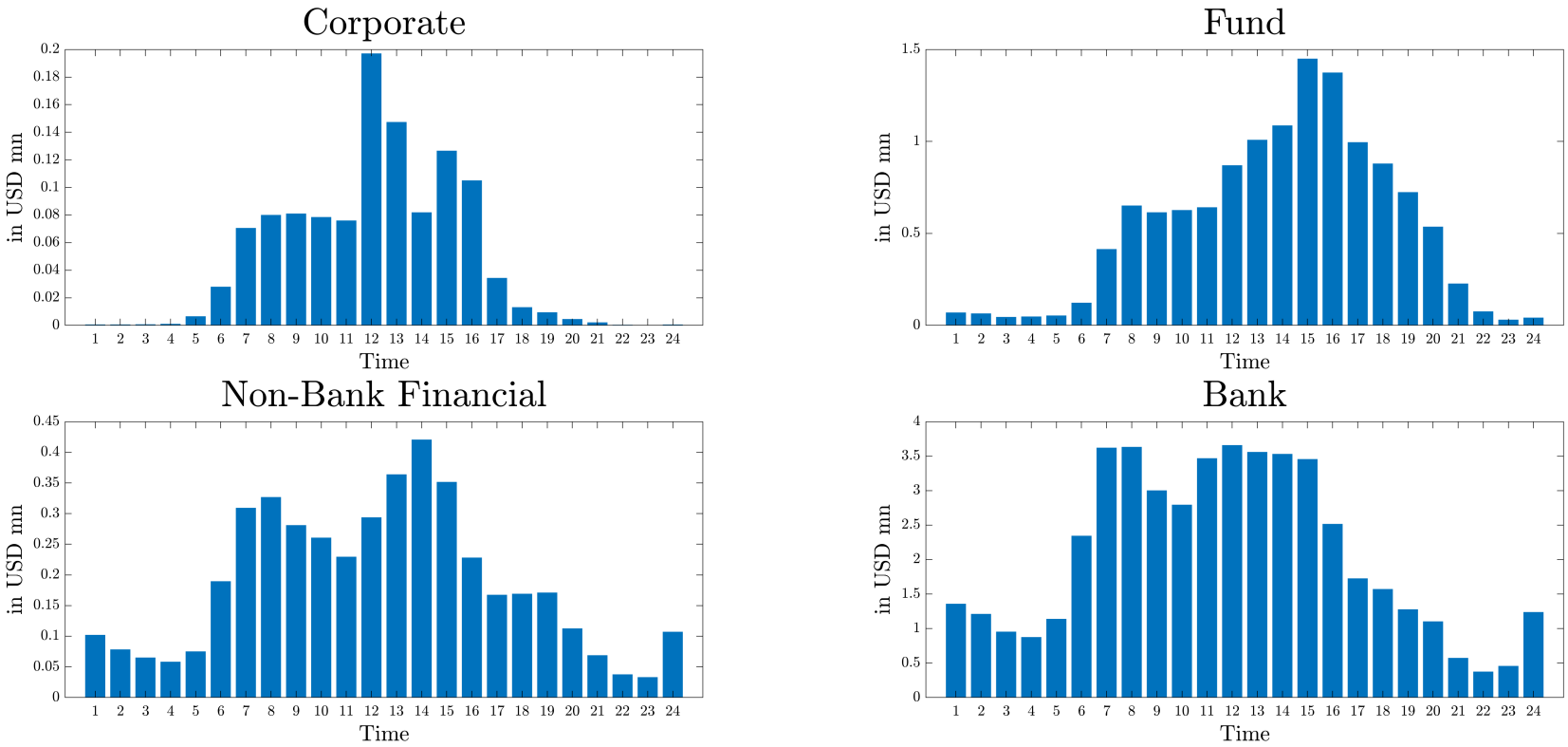
in BPS	AUDJPY	AUDNZD	AUDUSD	CADJPY	EURAUD	EURCAD
Mean(Δ_r)	0.04	−0.04	−0.08	0.05	0.08	0.06
Std(Δ_r)	16.37	10.02	13.39	15.13	13.29	12.03
Avg. Spread	4.39	4.81	3.53	4.53	3.88	3.78
in BPS	EURCHF	EURDKK	EURGBP	EURJPY	EURNOK	EURSEK
Mean(Δ_r)	0.00	0.00	0.04	0.10	0.09	0.05
Std(Δ_r)	11.10	0.54	11.15	13.77	11.23	8.77
Avg. Spread	2.87	2.73	3.36	3.39	6.53	5.67
in BPS	EURUSD	GBPAUD	GBPCAD	GBPCHF	GBPJPY	GBPUSD
Mean(Δ_r)	−0.02	0.04	0.03	−0.03	0.07	−0.05
Std(Δ_r)	11.03	13.51	12.25	14.89	15.85	11.34
Avg. Spread	2.40	4.44	4.14	4.31	4.03	2.69
in BPS	NZDUSD	USDCAD	USDCHF	USDDKK	USDHKD	USDILS
Mean(Δ_r)	−0.04	0.09	0.02	0.03	0.00	−0.04
Std(Δ_r)	14.77	10.23	14.22	11.03	0.69	10.14
Avg. Spread	4.41	2.83	3.41	2.93	1.69	23.70
in BPS	USDJPY	USDMXP	USDNOK	USDSEK	USDSGD	USDZAR
Mean(Δ_r)	0.13	0.13	0.12	0.08	0.03	0.19
Std(Δ_r)	12.54	15.77	14.72	13.19	6.79	20.35
Avg. Spread	2.75	6.11	7.50	6.44	3.91	11.32

Table 2: *Summary Statistics for Hourly Absolute (Net) Volume*

in USD mn	CO	FD	NB	BA	in USD mn	CO	FD	NB	BA
AUDJPY	0.01	0.86	1.18	14.65	GBPCHF	0.01	1.40	0.60	5.76
AUDNZD	0.00	0.72	1.41	13.35	GBPJPY	0.07	1.58	1.96	16.45
AUDUSD	0.71	24.31	9.95	98.50	GBPUSD	3.14	41.88	13.51	143.16
CADJPY	0.00	0.28	0.54	4.65	NZDUSD	0.03	6.99	3.74	38.23
EURAUD	0.06	2.31	1.82	16.96	USDCAD	1.14	23.35	11.88	190.62
EURCAD	0.91	1.78	1.53	12.22	USDCHF	0.79	9.67	11.14	71.00
EURCHF	0.45	7.74	4.53	35.95	USDDKK	0.90	3.01	0.12	7.76
EURDKK	0.13	4.44	0.66	18.99	USDHKD	0.03	10.11	1.38	41.09
EURGBP	2.32	17.26	4.44	48.21	USDILS	0.02	0.96	0.21	10.88
EURJPY	0.20	6.19	6.70	37.60	USDJPY	2.32	47.05	17.56	179.90
EURNOK	1.02	4.67	2.23	18.68	USDMXP	0.26	9.13	2.07	31.90
EURSEK	1.81	7.81	2.36	23.61	USDNOK	0.17	4.20	1.42	19.66
EURUSD	17.30	123.73	26.28	286.30	USDSEK	0.30	6.63	1.62	23.77
GBPAUD	0.02	1.20	0.90	8.01	USDSGD	0.15	5.64	1.27	37.30
GBPCAD	0.07	0.84	0.73	6.40	USDZAR	0.06	4.01	1.41	22.50

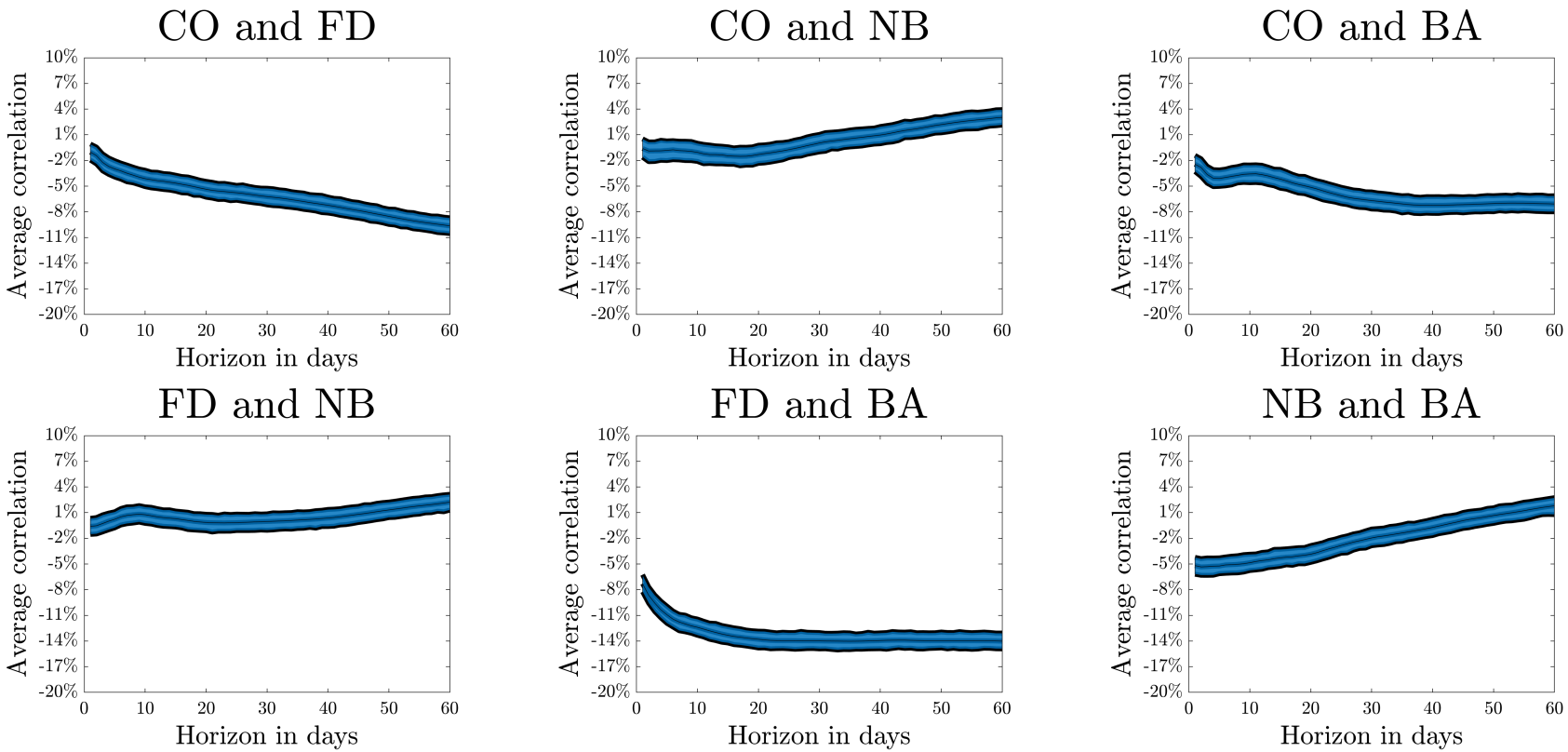
in USD mn	CO	FD	NB	BA	in USD mn	CO	FD	NB	BA
Mean	1.15	12.66	4.50	49.47	90^{th}	1.19	27.68	9.63	122.11
Std(Mean Vol)	0.05	0.27	0.09	0.50	75^{th}	0.02	7.95	3.51	56.16
Median	0.00	1.45	0.99	20.81	25^{th}	0.00	0.02	0.24	7.03
AC(1) in %	8.21	12.82	15.77	17.26	10^{th}	0.00	0.00	0.04	2.31

Figure 1: *Distribution of Trading Volume Over a Day*



Note: The average is computed across all trading days and currency pairs using the entire sample period. The numbers on the horizontal axis denote the closing time, e.g. the bar denoted 17 refers to volume between *4pm* and *5pm* (London time, no BST adjustment).

Figure 2: *Correlation of Customer Order Flows Over Longer Horizons*



Note: Correlations are based on the average correlation across all currency pairs. A one day horizon corresponds to non-overlapping hourly observations. For longer horizons we sum over daily (overlapping) observations. Shaded areas correspond to bootstrapped 95% confidence bands.

Bivariate VAR Model

The VAR picks up order flow dependence of up to 5 lags:

$$r_t = \zeta_{1,I} D_{I,t} + \sum_{i=1}^{5} \alpha_i r_{t-i} + \sum_{j \in C} \left(\sum_{i=0}^{5} \beta_i^j T_{t-i}^j + \sum_{i=0}^{5} \phi_i^j \tilde{S}_{t-1}^j \right) + \tag{1}$$
$$+ \upsilon_1 \Delta s_{k,t;t-\tau} + \upsilon_2 \Delta s_{k,t-\tau;t-5\tau} + \epsilon_{r,t},$$

$$T_t = \zeta_{2,I} D_{I,t} + \sum_{i=1}^{5} \gamma_i r_{t-i} + \sum_{j \in C} \left(\sum_{i=1}^{5} \delta_i^j T_{t-i}^j + \sum_{i=1}^{5} \omega_i^j \tilde{S}_{t-1}^j \right) + \tag{2}$$
$$+ \epsilon_{T,t},$$

where $C = \{CO, FD, NB, BA\}$. Eqs. (1) and (2) are based on Hasbrouck (1988, 1991a) and decompose the price moves into trade-related and trade-unrelated components.

Notation and Assumptions

Notation:

- $D_{l,t}$: dummy variable matrix with $l = 24$ columns and $t = n$ rows to control for time of the day fixed effects
- $T_{k,t}$: buy-sell indicator for trade t in currency k ($+1$, buys; -1, sells)
- $r_{k,t}$: log-return in the mid-quote
- $\tilde{S}_t$: order-size variable to account for the positive relation between order-size and price impact (see Appendix 1)
- $\Delta s_{k,t;t-\tau}$, $\Delta s_{k,t-\tau;t-5\tau}$: return over previous day/ week where $\tau = 24$ and t is measured at hourly frequency

Assumptions:

- Since we include contemporaneous T_t in Eq. 1, the VAR is exactly identified and hence the error terms shall have zero mean and be jointly and serially uncorrelated:

$$\begin{aligned} &E(\epsilon_{T,t}) = E(\epsilon_{r,t}) = 0 \\ &E(\epsilon_{T,t}\epsilon_{T,s}) = E(\epsilon_{r,t}\epsilon_{r,s}) = E(\epsilon_{T,t}\epsilon_{r,s}) = 0, \text{ for } s \neq t \end{aligned} \tag{3}$$

Inverting the VAR to a VMA

Following Hasbrouck (1991b) and Hendershott et al. (2011), the VAR can be inverted to its VMA representation:

$$y_t = \begin{bmatrix} r_t \\ T_t \end{bmatrix} = \Theta(L)\epsilon_t = \begin{bmatrix} a_r D_t & b_r(L) & \vec{c_r}(L) & \vec{d_r}(L) & \vec{s_r} \\ a_T D_t & b_T(L) & \vec{c_T}(L) & \vec{d_T}(L) & 0 \end{bmatrix} \begin{bmatrix} \epsilon_{D,t} \\ \epsilon_{r,t} \\ \vec{\epsilon_{T,t}} \\ \vec{\epsilon_{S,t}} \\ \vec{\epsilon_{\upsilon,t}} \end{bmatrix} \tag{4}$$

- $b_r(L), \vec{c_r}(L), \vec{d_r}(L), b_T(L), \vec{c_T}(L)$ and $\vec{d_T}(L)$ are lag-polynomial operators
- $\vec{c_r}$, $\vec{c_T}$, $\vec{d_r}$, $\vec{d_T}$ are row vectors of the form: $[\beta_i^{CO}\ \beta_i^{FD}\ \beta_i^{NB}\ \beta_i^{BA}]$, $[\delta_i^{CO}\ \delta_i^{FD}\ \delta_i^{NB}\ \delta_i^{BA}]$, $[\phi_i^{CO}\ \phi_i^{FD}\ \phi_i^{NB}\ \phi_i^{BA}]$, $[\omega_i^{CO}\ \omega_i^{FD}\ \omega_i^{NB}\ \omega_i^{BA}]$
- $\vec{s_r}$ is a row vector consisting of $[\upsilon_1\ \upsilon_2]$ from Eq. (1)

Table 3: *Return Equation Coefficients*

Eq. (1)	b_1^r	$c_0^{CO,r}$	$c_0^{FD,r}$	$c_0^{NB,r}$	$c_0^{BA,r}$	$\bar{R}^2$ in %	Eq. (1)	b_1^r	$c_0^{CO,r}$	$c_0^{FD,r}$	$c_0^{NB,r}$	$c_0^{BA,r}$	$\bar{R}^2$ in %
AUDJPY	***−5.430	0.019	*0.008	***0.010	***0.012	6.97	GBPCHF	***−9.060	*−0.065	−0.002	***0.015	***−0.005	6.79
	[3.800]	[0.280]	[1.781]	[4.986]	[12.513]			[3.032]	[1.876]	[0.927]	[3.291]	[5.341]	
AUDNZD	***−9.212	−0.016	−0.003	***−0.005	**−0.001	6.33	GBPJPY	−3.932	−0.014	0.000	**0.004	***0.008	7.16
	[12.982]	[0.538]	[1.048]	[4.999]	[2.235]			[1.506]	[0.910]	[0.043]	[2.257]	[6.806]	
AUDUSD	***−5.551	−0.012	***0.004	***0.012	0.001	7.02	GBPUSD	*−3.559	***−0.016	***0.003	***0.008	***0.004	7.31
	[7.147]	[1.640]	[4.320]	[15.489]	[1.148]			[1.817]	[4.243]	[3.856]	[11.042]	[6.309]	
CADJPY	***−4.577	0.075	−0.001	***0.009	***0.004	6.14	NZDUSD	***−7.462	*−0.044	***0.010	***0.007	***0.007	6.36
	[3.020]	[1.275]	[0.138]	[2.884]	[4.730]			[9.855]	[1.949]	[6.845]	[6.973]	[8.180]	
EURAUD	***−3.694	−0.013	0.002	0.001	***0.005	6.10	USDCAD	***−6.330	***−0.030	***0.004	***0.005	***0.003	6.88
	[3.109]	[0.775]	[1.599]	[0.878]	[6.807]			[6.820]	[5.332]	[4.284]	[7.526]	[4.976]	
EURCAD	***−5.093	***−0.036	0.002	***0.007	***−0.002	6.55	USDCHF	***−10.349	**−0.014	0.002	***0.013	0.001	7.30
	[3.911]	[5.944]	[0.955]	[4.691]	[2.784]			[3.043]	[2.546]	[1.470]	[13.146]	[1.599]	
EURCHF	**−8.790	−0.002	0.001	−0.002	***−0.006	6.64	USDDKK	***−4.316	***−0.045	−0.002	***0.017	***−0.003	6.26
	[2.365]	[0.498]	[0.920]	[1.122]	[7.575]			[4.064]	[5.375]	[1.325]	[3.423]	[3.784]	
EURDKK	***−24.854	0.000	***0.000	0.000	***0.000	11.25	USDHKD	***−17.325	0.001	***0.000	0.000	0.000	9.46
	[14.082]	[0.072]	[3.109]	[0.167]	[3.533]			[8.876]	[1.120]	[5.002]	[0.245]	[1.557]	
EURGBP	***−6.652	***−0.017	***0.003	0.001	***−0.004	6.24	USDILS	***−20.330	0.017	***0.004	***−0.011	***0.003	10.18
	[6.718]	[4.819]	[2.758]	[1.132]	[6.135]			[21.091]	[1.308]	[2.609]	[5.556]	[3.256]	
EURJPY	***−4.781	***−0.029	−0.002	***0.003	***−0.004	6.62	USDJPY	***−4.864	**−0.009	***0.006	***0.010	***0.003	7.39
	[2.906]	[2.780]	[1.401]	[3.160]	[4.482]			[3.920]	[2.379]	[6.434]	[13.681]	[3.966]	
EURNOK	***−5.893	***−0.019	***0.007	0.002	***0.002	6.54	USDMXP	−2.583	*−0.021	0.001	***−0.016	0.001	6.40
	[5.519]	[3.963]	[4.140]	[1.063]	[3.288]			[0.639]	[1.753]	[0.790]	[9.558]	[0.672]	
EURSEK	***−7.194	***−0.012	***0.005	***0.003	***0.002	6.49	USDNOK	***−5.992	***−0.039	***0.004	***0.007	***0.004	6.66
	[7.685]	[4.317]	[4.810]	[2.621]	[3.949]			[5.641]	[2.618]	[2.784]	[4.017]	[4.277]	
EURUSD	***−4.381	***−0.018	0.000	***0.007	**−0.001	7.24	USDSEK	***−5.702	−0.017	***0.005	***0.006	***0.004	6.25
	[3.989]	[9.794]	[0.364]	[10.237]	[2.041]			[5.776]	[1.500]	[3.701]	[3.997]	[4.365]	
GBPAUD	***−4.919	**0.040	***0.005	0.001	***0.003	6.25	USDSGD	***−8.103	***−0.013	***0.002	***0.003	***−0.001	6.90
	[4.545]	[2.398]	[2.728]	[0.708]	[3.541]			[10.225]	[3.080]	[4.078]	[3.628]	[2.705]	
GBPCAD	***−6.550	−0.036	−0.001	0.003	0.001	6.19	USDZAR	***−5.993	−0.025	**0.006	0.003	***0.004	6.82
	[5.409]	[0.910]	[0.504]	[1.351]	[1.086]			[5.310]	[1.128]	[2.538]	[1.226]	[2.984]	
Expected sign	-	+	+	+	+		Expected sign	-	+	+	+	+	
$D_{l,t}$						Yes	$D_{l,t}$						Yes
Lagged Ret.						Yes	Lagged Ret.						Yes
$\tilde{S}_t^j$						Yes	$\tilde{S}_t^j$						Yes

Note: All coefficients are in %. Regression coefficients are estimated by OLS on the full sample. T-stats are based on HAC errors and stars (*/ **/ ***) denote significance at the 90%/ 95%/ 99% level, respectively.

Table 4: *Order Flow Equation Coefficients*

Eq. (2)	b_1^T	$c_1^{CO,T}$	$c_1^{FD,T}$	$c_1^{NB,T}$	$c_1^{BA,T}$	$\bar{R}^2$ in %	Eq. (2)	b_1^T	$c_1^{CO,T}$	$c_1^{FD,T}$	$c_1^{NB,T}$	$c_1^{BA,T}$	$\bar{R}^2$ in %
AUDJPY	***32.245	−0.083	*0.034	0.007	***0.065	1.59	GBPCHF	***−24.533	***0.526	0.003	0.009	***0.020	0.31
	[7.708]	[0.344]	[1.657]	[0.699]	[11.206]			[3.734]	[3.835]	[0.212]	[0.604]	[3.413]	
AUDNZD	***−15.812	0.325	0.017	0.001	***0.051	0.50	GBPJPY	***29.055	0.011	**0.033	0.013	***0.045	0.82
	[2.756]	[1.542]	[0.743]	[0.070]	[8.975]			[4.648]	[0.117]	[2.358]	[1.548]	[7.794]	
AUDUSD	**−8.621	−0.005	0.010	***0.021	***0.034	0.40	GBPUSD	**−10.553	0.000	0.000	0.006	***0.043	0.57
	[2.017]	[0.132]	[1.449]	[3.621]	[5.912]			[2.210]	[0.018]	[0.016]	[0.978]	[7.556]	
CADJPY	0.926	0.395	0.032	*0.025	***0.026	0.17	NZDUSD	***−17.782	−0.006	0.011	0.005	***0.054	0.73
	[0.246]	[1.015]	[1.064]	[1.675]	[4.508]			[4.613]	[0.077]	[1.184]	[0.721]	[9.532]	
EURAUD	***−11.429	0.099	−0.001	0.003	***0.017	0.13	USDCAD	7.992	0.018	**0.016	0.006	***0.062	1.57
	[2.650]	[1.106]	[0.139]	[0.345]	[3.028]			[1.462]	[0.569]	[2.047]	[0.967]	[10.904]	
EURCAD	***−22.430	***0.122	−0.009	**0.021	***0.037	0.50	USDCHF	***−11.005	***0.135	***0.028	0.005	***0.034	0.41
	[4.777]	[3.353]	[0.806]	[2.163]	[6.383]			[3.159]	[3.623]	[3.424]	[0.786]	[5.848]	
EURCHF	−29.460	*0.063	***0.032	0.008	***0.066	1.65	USDDKK	−6.685	0.028	**0.020	0.018	***0.023	0.73
	[1.471]	[1.707]	[3.499]	[0.970]	[11.120]			[1.421]	[0.650]	[1.998]	[0.521]	[3.382]	
EURDKK	***374.927	*−0.138	**0.026	**0.087	***0.062	1.09	USDHKD	***−343.281	**0.284	0.011	0.024	***0.049	0.53
	[3.785]	[1.828]	[2.237]	[2.548]	[9.462]			[4.089]	[1.964]	[1.534]	[1.266]	[8.335]	
EURGBP	***−33.082	0.030	*0.015	−0.007	***0.041	0.88	USDILS	−3.552	0.185	0.016	−0.003	***0.076	1.34
	[6.397]	[1.377]	[1.862]	[0.973]	[7.114]			[0.715]	[1.150]	[1.211]	[0.140]	[11.322]	
EURJPY	−1.382	−0.031	**0.021	***0.017	***0.038	0.94	USDJPY	−6.166	0.017	***0.030	**0.014	***0.027	0.47
	[0.341]	[0.575]	[2.049]	[2.736]	[6.658]			[1.381]	[0.743]	[4.451]	[2.492]	[4.735]	
EURNOK	***−33.475	***0.059	***0.026	***0.042	***0.074	1.25	USDMXP	***−20.419	0.062	0.009	0.011	***0.046	0.41
	[5.964]	[2.661]	[2.579]	[4.495]	[12.543]			[4.420]	[1.375]	[1.064]	[1.304]	[7.804]	
EURSEK	***−35.644	**0.042	***0.036	***0.027	***0.073	1.10	USDNOK	*6.357	0.079	0.016	0.006	***0.061	0.76
	[5.655]	[2.328]	[3.989]	[2.868]	[12.539]			[1.705]	[1.263]	[1.645]	[0.648]	[10.207]	
EURUSD	***−21.832	**0.024	***0.028	0.000	***0.053	1.69	USDSEK	***−11.285	0.034	***0.025	0.001	***0.049	0.62
	[4.305]	[2.074]	[4.255]	[0.001]	[9.188]			[2.695]	[0.681]	[2.814]	[0.103]	[8.338]	
GBPAUD	−6.422	−0.160	0.015	**0.024	***0.020	0.12	USDSGD	***−75.327	−0.059	0.008	−0.006	***0.041	0.81
	[1.539]	[0.701]	[1.170]	[2.239]	[3.581]			[8.874]	[0.947]	[0.949]	[0.563]	[7.134]	
GBPCAD	**9.907	−0.081	0.008	***0.044	***0.026	0.23	USDZAR	***−22.957	0.013	0.007	*−0.016	***0.043	0.71
	[2.042]	[0.329]	[0.617]	[3.392]	[4.461]			[7.479]	[0.264]	[0.692]	[1.779]	[7.510]	
Expected sign	-	+	+	+	+		Expected sign	-	+	+	+	+	
$D_{l,t}$						Yes	$D_{l,t}$						Yes
Lagged Ret.						Yes	Lagged Ret.						Yes
$\tilde{S}_t^j$						Yes	$\tilde{S}_t^j$						Yes

Note: T-stats are based on HAC errors and stars (*/ **/ ***) denote significance at the 90%/ 95%/ 99% level, respectively.

Permanent Price Impact

Along Hasbrouck (1991a), the permanent price impact of a trade by market participant $j \in C$, where $C = \{CO, FD, NB, BA\}$, is:

$$\alpha_m^j(\epsilon_{T^j,t}) = \sum_{t=0}^{m} E[r_t|\epsilon_{T^j,t}] = \sum_{t=0}^{m} \beta_t^j, \tag{5}$$

where m indicates the number of lags. Using the VMA representation, the cumulative impulse response (permanent price impact) aggregated across agents is given by:

$$\alpha_m(\epsilon_{T,t}) = \sum_{j \in C} \sum_{t=0}^{m} \vec{c_{r,t}} = \sum_{j \in C} \alpha_m^j. \tag{6}$$

Interpretation of α_m according to Hasbrouck (1991a,b):

- Measure of adverse selection that accounts for the persistence in order flow, and possible positive or negative feedback trading
- Information content of the innovation net of temporary liquidity effects
- Persistent impact of a trade on the price of a security arising from asymmetric information signalled by that trade

Table 5: *Permanent Price Impact Across Agents - Joint F-test*

in BPS	α_m^{CO}	α_m^{FD}	α_m^{NB}	α_m^{BA}	in BPS	α_m^{CO}	α_m^{FD}	α_m^{NB}	α_m^{BA}
AUDJPY	2.636	−0.115	***1.073	***1.446	GBPCHF	−4.332	0.286	***1.955	***−0.107
	[0.251]	[2.174]	[7.765]	[32.220]		[1.499]	[1.202]	[8.635]	[6.218]
AUDNZD	0.952	1.049	***−0.597	*0.229	GBPJPY	−4.710	0.371	*−0.224	***1.096
	[0.460]	[2.246]	[6.285]	[2.668]		[0.482]	[0.790]	[2.753]	[13.858]
AUDUSD	0.265	***0.383	***1.036	0.405	GBPUSD	***−1.337	***0.533	***0.842	***0.909
	[1.829]	[3.949]	[43.294]	[1.480]		[8.330]	[3.944]	[24.585]	[10.873]
CADJPY	6.876	1.460	***0.593	***0.014	NZDUSD	***−5.160	***1.131	***0.915	***0.967
	[1.508]	[0.908]	[3.940]	[5.681]		[3.723]	[9.902]	[10.185]	[12.468]
EURAUD	−0.782	0.540	−0.034	***0.766	USDCAD	***−3.379	***0.560	***0.411	***0.316
	[0.289]	[1.340]	[1.093]	[8.882]		[16.296]	[7.564]	[11.882]	[4.688]
EURCAD	***−0.739	0.657	***0.398	**0.103	USDCHF	−1.353	0.541	***1.136	0.435
	[13.597]	[1.015]	[7.441]	[3.228]		[2.124]	[1.267]	[30.532]	[2.444]
EURCHF	−0.179	0.032	−0.229	***−0.245	USDDKK	***−4.548	*0.240	***1.549	***−0.186
	[0.427]	[0.486]	[0.687]	[13.336]		[14.978]	[2.742]	[3.834]	[4.544]
EURDKK	0.206	**0.046	0.032	***−0.003	USDHKD	0.153	***0.037	−0.005	0.010
	[1.106]	[2.898]	[0.960]	[4.251]		[0.343]	[5.478]	[0.350]	[2.104]
EURGBP	***−0.865	0.471	0.136	***0.221	USDILS	1.439	**1.177	***−0.869	***0.630
	[9.760]	[2.488]	[1.868]	[11.490]		[0.529]	[3.327]	[7.519]	[4.433]
EURJPY	***2.446	−1.153	**0.407	***0.227	USDJPY	**−0.896	***0.513	***0.443	***0.663
	[6.276]	[2.425]	[3.353]	[5.525]		[3.349]	[8.878]	[35.970]	[4.392]
EURNOK	***−1.993	***0.973	0.060	***0.495	USDMXP	***1.601	**−0.593	***−1.668	**0.663
	[11.413]	[7.980]	[2.098]	[3.658]		[4.798]	[3.056]	[27.065]	[3.304]
EURSEK	***−0.781	***0.875	***0.539	***0.434	USDNOK	***1.014	**0.657	***1.393	***0.068
	[11.287]	[9.837]	[4.627]	[4.168]		[4.203]	[3.354]	[7.387]	[5.625]
EURUSD	***−1.548	0.200	***0.476	***0.407	USDSEK	**−3.091	***1.608	***1.356	***0.278
	[34.875]	[1.129]	[20.045]	[4.211]		[2.986]	[7.565]	[7.253]	[4.265]
GBPAUD	10.471	0.440	0.636	***0.704	USDSGD	−0.057	***0.112	***0.605	*−0.007
	[1.619]	[1.561]	[2.386]	[3.901]		[2.117]	[3.856]	[4.714]	[2.705]
GBPCAD	−4.120	0.281	1.019	0.292	USDZAR	**−6.317	0.755	**0.502	***2.177
	[0.377]	[1.275]	[1.857]	[1.452]		[3.223]	[1.856]	[2.810]	[12.339]

Note: The numbers in brackets correspond to the test statistic for a joint F-test that the parameters in Eq. (5) are jointly different from zero. Stars (*/ **/ ***) denote significance at the global 90%/ 95%/ 99% level (α_g), respectively. For each individual test a Bonferroni correction is applied such that the local significance level is $\frac{\alpha_g}{m}$, where m is the number of multiple tests in the joint hypothesis. All regression coefficients are in BPS.

Heterogeneous Information Flows

Why Focus on the Permanent Price Impact?

1. Separate permanent (*information*) and temporary (*inventory*) effects
2. Qualitatively unchanged results for tests based on the contemporary price impact

Heterogeneous Price Impact Across Agents

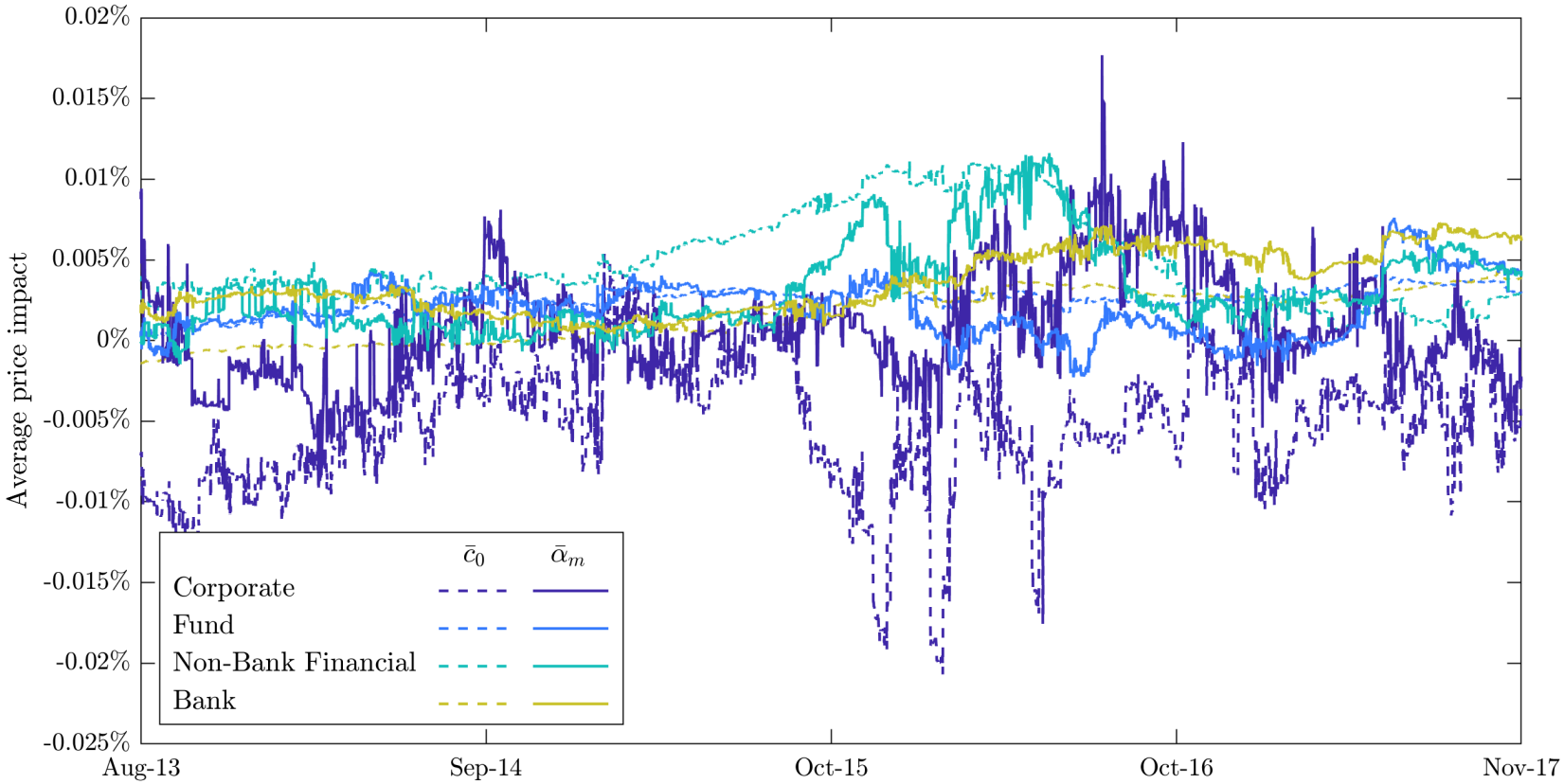
- Q: Does the contemporary/ permanent price impact vary across agents?
- Joint F-test: $F = (R\hat{\theta}_n^{i,k} - \hat{\theta}_n^{j,k})'[R(\hat{V}_n/n)R']^{-1}(R\hat{\theta}_n^{i,k} - \hat{\theta}_n^{j,k})$
- A: Yes, raising evidence of asymmetric information

Fragmentation in the FX Spot Market Across Currencies

- Q: Do agents have different price impact parameters across currency pairs?
- Joint F-test: $F = (R\hat{\theta}_n^{i,k} - \hat{\theta}_n^{i,q})'[R(\hat{V}_n/n)R']^{-1}(R\hat{\theta}_n^{i,k} - \hat{\theta}_n^{i,q})$
- A: Yes, raising evidence of local, currency specific information

Note: In both specifications $\hat{\theta}^{i,k} = \sum_{l=0}^{5} \hat{\beta}_l^{i,k}$, $F \xrightarrow{D} \chi_Q^2$ and R is a $Q \times L$ matrix, where Q is the number of hypothesis tested and L the number of estimated coefficients. $\hat{V}_n$ is an estimator of the covariance matrix with sample size n. For each test, $i \neq j/\ k \neq q$ and $k \in$ [currency pairs] must hold. Individual test levels are Bonferroni corrected

Figure 3: *Twelve Months Rolling Window Regression for* $c_0^{r,k}$ / α_m^k



Note: The cross-sectional average contemporary ($\bar{c}_0^r$) and permanent ($\bar{\alpha}_m$) price impact are calculated after removing any coefficients that are either heavy outliers with respect to the median or not significant at a 95% confidence level applying a simple two-sided t-test and joint F-test, respectively.

Currency Portfolios I

Intuition:

- High (*low*) aggregate permanent price impact (α_m^k) currencies systematically deviate from *UIP* i.e. $f_{t,t+1} \geq s_{t+1}$ $(f_{t,t+1} \leq s_{t+1})$
- ALP_{HML} exploits information asymmetries across market participants

Assumptions:

- US-American (USD) or European (EUR) investor perspective
- Forward rates satisfy the *CIP* condition
- Transaction costs are implemented using accurate quoted bid and ask rates

Five Ingredients:

1. *Timing*: **no lag**, immediate investment upon signal extraction
2. *Weighting*: **zero net exposure**, equally weighted long-short portfolio
3. *Rebalancing*: daily, weekly, and **monthly**

Currency Portfolios II

4. *Signal Generation*:
   - Estimate Eq. (1) in a **twelve months** rolling window fashion at daily frequency based on **order flow** and **mid-quote**
   - Extract the permanent price impact $\alpha_m^{j,k}$
   - Sort the aggregate price impact $(\sum_{j \in C} \alpha_m^{j,k})$ across currency pairs
   - Form quintile portfolios and derive ALP_{HML} as $Q_5 - Q_1$
5. *Excess Returns*: **net** log excess return for going **long** in foreign currency x:

$$rx_{t+1} = f^b_{t,t+1} - s^a_{t+1} - \mathbb{1}_{x \notin USD} \Delta s^{*,b,a}_{t,t+1}, \tag{7}$$

where *USD* is the basket of all USD (base) currency pairs and $\Delta s^{*,b,a}_{t,t+1}$ is the change in the *USDXXX* spot rate, *XXX* being the base currency of a non-US currency pair. f_t and s_t are both in units of the foreign currency per USD. Analogously, the **net** log excess return for going **short** the foreign currency x:

$$rx_{t+1} = -f^a_{t,t+1} + s^b_{t+1} + \mathbb{1}_{x \notin USD} \Delta s^{*,a,b}_{t,t+1} \tag{8}$$

Trading Performance Prior Transaction Costs

Table 6: *Performance Benchmarking* - ***Gross*** *Returns*

Panel a)	Q_1		Q_2		Q_3		Q_4		Q_5		ALP_{HML}	
	USD	EUR	USD	EUR	USD	EUR	USD	EUR	USD	EUR	USD	EUR
SR	−1.06	−0.82	−0.62	−0.34	−0.24	−0.17	0.66	0.29	0.29	0.64	1.22	1.22
Mean in %	**−7.51	−4.22	−4.94	−1.73	−2.19	−0.90	5.24	2.24	2.13	5.38	***9.80	***9.82
	[2.11]	[1.40]	[1.28]	[0.73]	[0.60]	[0.28]	[1.29]	[0.80]	[0.61]	[1.51]	[2.81]	[2.81]
MDD in %	5.48	12.02	10.20	9.52	22.07	18.38	33.71	14.65	12.79	5.06	3.50	3.50
Θ in %	5.43	2.59	3.33	0.72	−3.37	0.06	−7.01	−3.53	0.40	3.63	8.95	8.96

Panel b)	*DOL*		*RER*		MOM_{HML}		CAR_{HML}		*BMS*		ALP_{HML}	
	USD	EUR	USD	EUR	USD	EUR	USD	EUR	USD	EUR	USD	EUR
SR	−0.43	−0.05	0.73	0.68	−0.10	−0.14	0.48	0.43	0.33	0.25	1.22	1.22
Mean in %	−2.79	−0.23	*1.69	*1.60	−0.77	−1.00	3.12	2.82	1.08	0.82	***9.80	***9.82
	[0.84]	[0.11]	[1.76]	[1.69]	[0.24]	[0.33]	[1.21]	[1.11]	[0.70]	[0.55]	[2.81]	[2.81]
MDD in %	23.49	5.79	1.81	1.79	11.24	11.83	10.47	10.61	4.05	4.11	3.50	3.50
Θ in %	−4.06	−1.03	0.31	0.50	−3.53	−3.38	0.32	0.57	−1.33	−1.07	8.95	8.96

Note: Panel a) reports the annualised Sharpe ratio (SR), the annualised average (simple) *gross* excess return (*Mean*), the maximum drawdown (MDD) and the Θ performance measure of Goetzmann et al. (2007) for the quintile portfolios (Q_1, Q_2, …, Q_5). Panel b) lists the same measures as Panel a) but for common FX trading strategies based on monthly rebalancing. In particular, *DOL* is based on USD (or EUR) currency pairs, *RER* on the real exchange rate (cf. Menkhoff et al. (2017)), MOM_{HML} on $f^m_{t-1,t} - s^m_t$ (cf. Asness et al. (2013)), CAR_{HML} on the forward discount/ premium ($f^m_{t,t+1} - s^m_t$, cf. Lustig et al. (2011)), and *BMS* is based on lagged standardised order flow (cf. Menkhoff et al. (2016)). Significance at the 90%/ 95%/ 99% level are represented by stars (*/ **/ ***), respectively.

Figure 4: *Equity and Drawdown Curves **Prior** Transaction Costs (US Investor)*

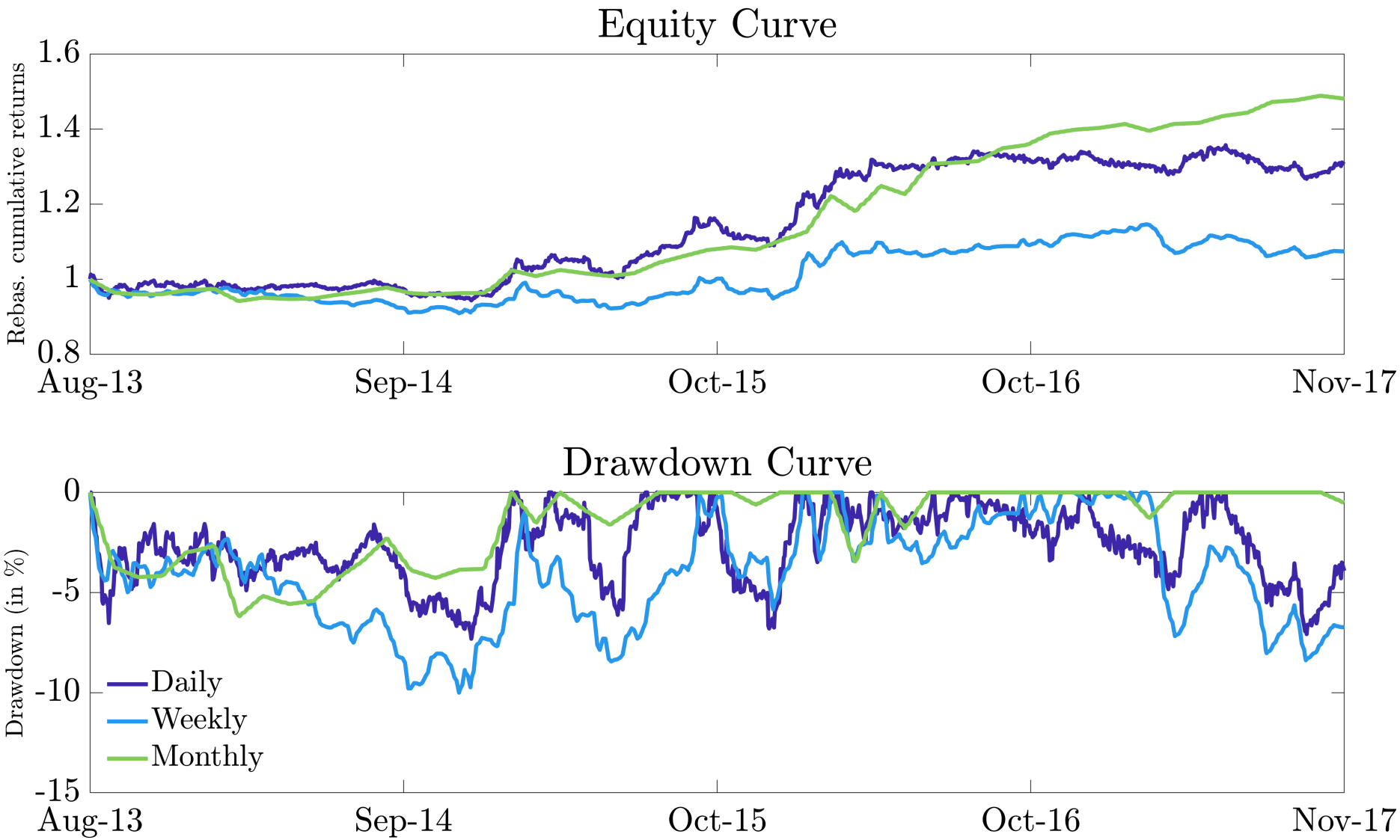
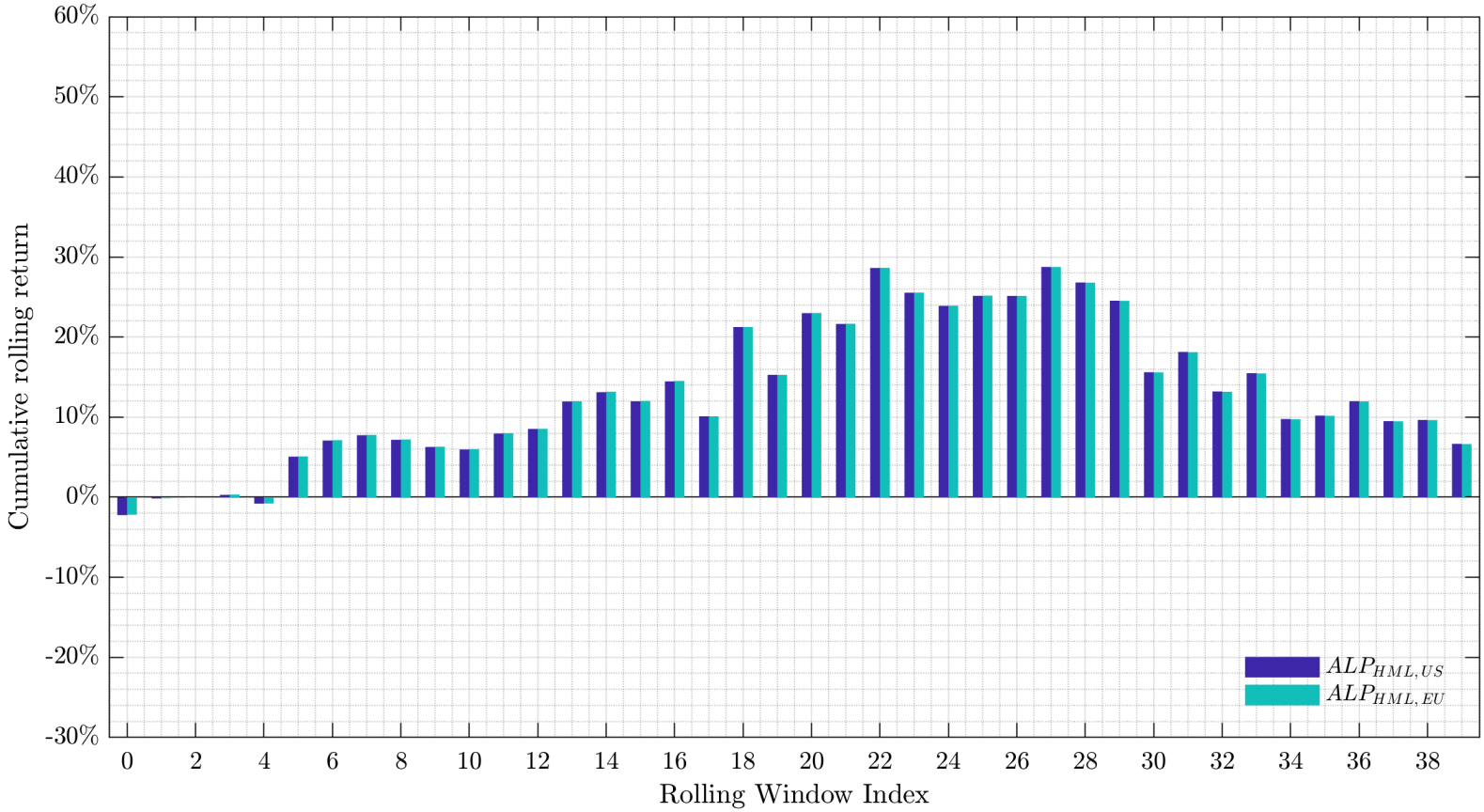


Figure 5: *Cumulative Rolling **Gross** Returns*



Note: Rolling window *gross* return for monthly rebalancing and one year investment horizon.

Exposure Regression

Table 7: *Exposure Regression Based on Monthly* ***Gross*** *USD-Excess Returns*

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
α	***0.008	***0.008	**0.007	**0.006	**0.008	***0.008	***0.008	**0.008	**0.008	**0.007
	[2.832]	[2.718]	[2.574]	[2.265]	[2.419]	[2.637]	[2.717]	[2.571]	[2.513]	[2.465]
DOL		−0.138	−0.009	−0.050	−0.100	−0.070	−0.153	−0.124	−0.136	0.240
		[0.644]	[0.033]	[0.257]	[0.464]	[0.368]	[0.644]	[0.572]	[0.609]	[1.137]
RER_{HML}			0.459							
			[1.134]							
RER				0.983						**1.835
				[1.543]						[2.189]
MOM_{HML}					0.308					
					[1.296]					
CAR_{HML}						−0.167				**−0.527
						[0.978]				[2.201]
BMS							−0.120			
							[0.350]			
ΔVIX								0.000		
								[0.976]		
ΔCDS									0.000	0.000
									[0.436]	[0.516]
R^2 in %	N/A	1.12	5.92	9.02	6.47	2.99	1.38	2.03	1.35	22.01
IR	0.35	0.34	0.30	0.30	0.36	0.37	0.34	0.33	0.34	0.37
#Obs	51	51	51	51	51	51	51	51	51	51

Note: In this table, we regress monthly *gross* excess returns by ALP_{HML} on monthly excess returns associated with common risk factors, where *DOL* is based on USD (or EUR) currency pairs; *RER*/ RER_{HML} are based on the real exchange rate (cf. Menkhoff et al. (2017)); MOM_{HML} is based on $f^m_{t-1,t} - s^m_t$ (cf. Asness et al. (2013)), CAR_{HML} is based on the forward discount/ premium ($f^m_{t,t+1} - s^m_t$, cf. Lustig et al. (2011)), and *BMS* is based on lagged standardised order flow (cf. Menkhoff et al. (2016)). ΔVIX is the return on the VIX index and ΔCDS the change in the iTraxx Europe CDS index. The information ratio (IR) is defined as α divided by residual standard deviation. Significance at the 90%/ 95%/ 99% level are represented by stars (*/ **/ ***), respectively. The numbers inside the brackets are the corresponding test statistics based on HAC errors correcting for serial correlation and small sample size (using the plug-in procedure for automatic lag selection by Newey and West (1994)).

Summary

Contribution:

- Order flow impacts FX prices **heterogeneously**. In particular, **corporates** have a significantly lower price impact than **funds**, and **non-bank financials**
- Both the **contemporary** and **permanent** price impact differ across agents, time, and currency pairs in the **FX spot market**
- Long-short strategy based on *UIP* deviations generates an annualised **Sharpe ratio** of 1.22 and a net **excess return** of 9.82% p.a.

Social and Regulatory Relevance:

- *Global Investors*: grasp and minimise the **price impact** of **global FX trading**
- *Academics*: seek novel insight in the **determination** of **FX rates** and the economics of order flow
- *Policy Makers*: understand **FX drivers** and improve **OTC market design**

Appendix I: Controlling for Order Size

$\tilde{S}_t$: order-size variable to account for the positive relation between order-size and price impact:

- Logarithms control for presumed non-linearities between order size and quote revisions:

$$v_t = \begin{cases} +log(z_t) & \text{if } z_t > 0 \\ 0 & \text{if } z_t = 0 \\ -log(-z_t) & \text{if } z_t < 0 \end{cases}$$

- v_t is regressed against current and lagged values of T_t
- $\tilde{S}_t$ denotes the residuals of this regression (uncorrelated with T_t)

Table 8: *Heterogeneous Contemporary Price Impact Across Agents*

	CO	FD	NB	CO	FD	NB	CO	FD	NB	CO	FD	NB	CO	FD	NB
FD	1.32	-	**AUDJPY**	**2.68	-	**AUDNZD**	***9.89	-	**AUDUSD**	***8.56	-	**CADJPY**	***5.54	-	**EURAUD**
NB	*2.33	0.73	-	***6.05	1.40	-	***16.94	***9.96	-	***11.71	**2.52	-	***5.60	0.85	-
BA	***3.41	**2.73	1.82	***13.49	1.70	***5.02	***9.39	***3.69	***14.78	***40.94	***3.25	***3.27	***12.59	**2.67	***4.03
FD	***14.89	-	**EURCAD**	1.67	-	**EURCHF**	2.08	-	**EURDKK**	***12.95	-	**EURGBP**	***9.05	-	**EURJPY**
NB	***17.86	***3.58	-	0.34	2.04	-	0.00	*2.37	-	***12.13	1.67	-	***17.53	***4.40	-
BA	***27.14	***3.57	***9.43	**2.41	***7.03	***3.92	**2.43	1.19	**2.65	***11.83	***8.56	***6.57	***17.55	1.03	***7.60
FD	***10.83	-	**EURNOK**	***11.30	-	**EURSEK**	***15.65	-	**EURUSD**	***10.49	-	**GBPAUD**	***9.45	-	**GBPCAD**
NB	***9.40	***3.34	-	***9.17	1.73	-	***25.50	***9.66	-	***12.66	*2.18	-	***9.59	1.90	-
BA	***17.38	***4.27	0.86	***14.95	***3.60	1.01	***17.83	1.39	***12.47	***25.32	*2.14	1.45	***26.76	1.69	2.02
FD	***14.49	-	**GBPCHF**	***3.56	-	**GBPJPY**	***14.11	-	**GBPUSD**	***19.86	-	**NZDUSD**	***19.48	-	**USDCAD**
NB	***9.89	***5.60	-	***5.82	1.92	-	***19.94	***6.07	-	***26.71	**2.49	-	***29.56	0.58	-
BA	***36.68	1.91	***13.74	***10.34	***5.02	**2.80	***17.59	1.46	***5.11	***31.80	***2.96	0.19	***31.14	*2.14	***3.35
FD	***7.27	-	**USDCHF**	***19.66	-	**USDDKK**	***5.50	-	**USDHKD**	***5.27	-	**USDILS**	***10.44	-	**USDJPY**
NB	***16.35	***9.30	-	***10.06	***9.04	-	***3.24	***3.82	-	***8.03	***9.03	-	***15.79	***5.28	-
BA	***11.84	0.91	***13.79	***25.64	1.63	***13.13	***11.03	***7.06	0.39	***9.64	1.06	***12.20	***10.19	***3.69	***9.93
FD	***7.81	-	**USDMXP**	***15.00	-	**USDNOK**	***9.54	-	**USDSEK**	***14.81	-	**USDSGD**	***7.31	-	**USDZAR**
NB	1.81	***10.43	-	***14.52	1.59	-	***9.19	0.61	-	***11.44	0.91	-	***6.64	1.33	-
BA	***10.70	0.41	***12.44	***23.99	0.32	**2.46	***13.70	1.20	1.96	***17.13	***7.44	***7.79	***12.34	1.42	0.51

Note: The numbers correspond to two-sided tests for equal price impact: T-Stat $= \frac{|c_0^{i,k} - c_0^{j,k}|}{se_0^{i,k}}$, where $i \neq j$, $k \in$ [currency pairs] and $se_0^{i,k}$ refers to HAC errors and stars (*/ **/ ***) denote significance at the global 90%/ 95%/ 99% level (α_g), respectively. For each individual test a Bonferroni correction is applied such that the local significance level is $\frac{\alpha_g}{m}$, where m is the number of multiple tests. Averages are calculated to account for both directions, i.e. CO $\rightarrow$ FD/ FD $\rightarrow$ CO.

Table 9: *Heterogeneous Contemporary Price Impact Across Currency Pairs - CO & FD*

CO	AUDJPY	AUDNZD	EURCHF	EURGBP	EURNOK	EURUSD	GBPCHF	GBPUSD	USDCHF
AUDNZD	0.84								
EURCHF	2.32	1.66							
EURGBP	***5.29	0.13	**3.58						
EURNOK	***4.20	0.32	**3.43	0.45					
EURUSD	***10.34	0.38	***5.78	0.19	0.53				
GBPCHF	1.83	1.50	***7.30	***7.38	***5.44	***13.78			
GBPUSD	***4.80	0.00	*3.23	0.23	0.63	0.54	***7.01		
USDCHF	*3.20	0.24	2.25	0.71	0.96	1.31	***5.32	0.49	
USDSEK	1.83	0.06	2.17	0.03	0.25	0.10	2.74	0.18	0.43
FD	AUDJPY	AUDNZD	EURCHF	EURGBP	EURNOK	EURUSD	GBPCHF	GBPUSD	USDCHF
AUDNZD	*3.16								
EURCHF	2.89	2.20							
EURGBP	*3.18	***3.86	1.12						
EURNOK	0.58	***4.69	**3.33	*3.12					
EURUSD	***5.97	2.08	1.60	**3.39	***6.37				
GBPCHF	**3.28	0.29	1.94	**3.52	***4.62	1.55			
GBPUSD	*3.18	***4.74	1.76	0.63	2.90	***4.32	***4.36		
USDCHF	2.73	2.67	0.47	0.57	3.01	2.30	2.41	1.17	
USDSEK	1.52	***4.36	2.46	1.86	1.19	***5.12	***4.18	1.47	2.04

Note: The numbers correspond to two-sided tests for equal price impact: T-Stat $= \frac{|c_0^{i,k} - c_0^{i,q}|}{se_0^{i,k}}$, where $k \neq q$, $k \in$ [currency pairs] and $se_0^{i,k}$ refers to HAC errors. Stars (*/ **/ ***) denote significance at the global 90%/ 95%/ 99% level (α_g), respectively. For each individual test a Bonferroni correction is applied such that the local significance level is $\frac{\alpha_g}{m}$, where m is the number of multiple tests. Averages are calculated to account for both directions, i.e. EURUSD $\rightarrow$ GBPUSD/ GBPUSD $\rightarrow$ EURUSD.

Table 10: *Heterogeneous Contemporary Price Impact Across Currency Pairs - FD & BA*

NB	AUDJPY	AUDNZD	EURCHF	EURGBP	EURNOK	EURUSD	GBPCHF	GBPUSD	USDCHF
AUDNZD	***11.23								
EURCHF	***6.78	2.74							
EURGBP	***6.77	***6.18	2.36						
EURNOK	***5.03	***5.53	2.19	0.37					
EURUSD	*3.24	***14.78	***9.20	***7.18	***5.76				
GBPCHF	1.93	***12.38	***7.47	***8.85	***6.27	***7.45			
GBPUSD	1.65	***15.49	***9.93	***8.41	***6.79	2.04	***5.62		
USDCHF	2.19	***18.06	***12.25	***12.03	***9.70	***7.72	1.56	***5.53	
USDSEK	2.56	***9.10	***5.04	***3.97	2.91	1.16	***4.42	2.54	***6.15

BA	AUDJPY	AUDNZD	EURCHF	EURGBP	EURNOK	EURUSD	GBPCHF	GBPUSD	USDCHF
AUDNZD	***18.67								
EURCHF	***21.26	***6.59							
EURGBP	***20.61	***4.53	2.08						
EURNOK	***12.03	***5.70	***10.92	***9.34					
EURUSD	***17.74	0.02	***6.32	***4.36	***5.43				
GBPCHF	***18.44	***4.75	1.24	0.63	***8.88	***4.55			
GBPUSD	***9.55	***9.04	***13.91	***12.46	2.96	***8.63	***11.66		
USDCHF	***13.17	***3.81	***9.14	***7.52	1.60	**3.63	***7.25	***4.52	
USDSEK	***9.65	***7.21	***11.79	***10.43	1.66	***6.86	***9.72	1.09	*3.12

Note: The numbers correspond to two-sided tests for equal price impact: T-Stat $= \frac{|c_0^{i,k} - c_0^{i,q}|}{se_0^{i,k}}$, where $k \neq q$, $k \in$ [currency pairs] and $se_0^{i,k}$ refers to HAC errors. Stars (*/ **/ ***) denote significance at the global 90%/ 95%/ 99% level (α_g), respectively. For each individual test a Bonferroni correction is applied such that the local significance level is $\frac{\alpha_g}{m}$, where m is the number of multiple tests. Averages are calculated to account for both directions, i.e. EURUSD $\rightarrow$ GBPUSD/ GBPUSD $\rightarrow$ EURUSD.

Table 11: *Heterogeneous Permanent Price Impact Across Agents*

	CO	FD	NB	CO	FD	NB	CO	FD	NB	CO	FD	NB	CO	FD	NB
FD	***31.67	-	**AUDJPY**	***16.71	-	**AUDNZD**	***48.38	-	**AUDUSD**	***282.67	-	**CADJPY**	***12.58	-	**EURAUD**
NB	***124.42	***4.90	-	***108.96	***9.51	-	***109.27	***19.14	-	***1,063.09	***4.04	-	***21.29	**3.28	-
BA	***366.24	***12.01	1.32	***301.95	***12.41	***8.44	***47.61	**3.88	***40.80	***7,321.86	***15.96	***7.28	***59.01	2.17	***7.52
FD	***91.58	-	**EURCAD**	***4.49	-	**EURCHF**	***20.40	-	**EURDKK**	***53.57	-	**EURGBP**	***93.15	-	**EURJPY**
NB	***152.81	***6.18	-	***4.28	2.04	-	**3.31	***5.79	-	***54.44	2.31	-	***240.75	***9.60	-
BA	***284.07	**3.33	***24.30	***13.29	***14.84	***5.42	***89.03	***4.44	***16.79	***42.89	***18.49	***15.47	***235.62	***9.76	***13.21
FD	***57.78	-	**EURNOK**	***55.30	-	**EURSEK**	***67.52	-	**EURUSD**	***262.23	-	**GBPAUD**	***64.29	-	**GBPCAD**
NB	***44.71	***9.36	-	***36.21	***4.54	-	***164.69	***20.94	-	***360.71	*3.02	-	***74.49	2.81	-
BA	***98.21	***8.16	***4.28	***76.00	***4.66	**3.77	***78.21	**3.74	***33.02	***1,293.79	2.01	*3.20	***347.50	*3.23	*3.07
FD	***89.94	-	**GBPCHF**	***14.15	-	**GBPJPY**	***64.27	-	**GBPUSD**	***210.93	-	**NZDUSD**	***180.55	-	**USDCAD**
NB	***136.99	***10.70	-	***35.75	**3.31	-	***125.49	***8.14	-	***382.93	1.63	-	***302.83	***5.21	-
BA	***590.49	2.74	***50.78	***112.22	***9.86	***5.99	***105.17	1.50	***7.35	***490.32	1.91	0.21	***314.46	***4.83	2.56
FD	***34.34	-	**USDCHF**	***137.98	-	**USDDKK**	***61.13	-	**USDHKD**	***32.23	-	**USDILS**	***42.68	-	**USDJPY**
NB	***93.18	***18.81	-	***37.14	***27.05	-	***9.16	***4.88	-	***35.58	***16.59	-	***82.75	***6.93	-
BA	***68.47	2.54	***33.82	***237.50	***4.04	***57.52	***119.19	***10.21	2.94	***129.32	***4.90	***42.39	***42.64	***4.08	***24.15
FD	***85.53	-	**USDMXP**	***113.45	-	**USDNOK**	***69.88	-	**USDSEK**	***81.77	-	**USDSGD**	***61.96	-	**USDZAR**
NB	***56.20	***30.15	-	***118.71	1.57	-	***77.27	2.27	-	***56.33	**3.51	-	***65.77	2.92	-
BA	***130.53	***9.20	***47.14	***293.15	1.88	***7.34	***120.06	***8.99	***6.27	***122.85	***13.22	***14.47	***162.93	***6.26	***8.23

Note: The numbers correspond to the test statistic of a joint F-test: $F = (R\hat{\theta}_n^{i,k} - \hat{\theta}_n^{j,k})'[R(\hat{V}_n/n)R']^{-1}(R\hat{\theta}_n^{i,k} - \hat{\theta}_n^{j,k})$, where $\hat{\theta}^{i,k} = \sum_{l=0}^{5} \hat{\beta}_l^{i,k}$ are parameter estimates and F converges to a χ_Q^2 distribution. R is a $Q \times L$ matrix, where Q is the number of hypothesis and L the number of coefficients. $\hat{V}_n$ is an estimator of the covariance matrix with sample size n. For each pairwise test, $i \neq j$ and $k \in$ [currency pairs] must hold. Stars (*/ **/ ***) denote significance at the global 90%/ 95%/ 99% level (α_g), respectively. For each individual test a Bonferroni correction is applied such that the local significance level is $\frac{\alpha_g}{m}$, where m is the number of multiple tests. Averages are calculated to account for both directions, i.e. CO vs. FD/ FD vs. CO.

Table 12: *Heterogeneous Permanent Price Impact Across Currency Pairs - CO & FD*

CO	AUDJPY	AUDNZD	EURCHF	EURGBP	EURNOK	EURUSD	GBPCHF	GBPUSD	USDCHF
AUDNZD	0.69								
EURCHF	***17.70	**4.49							
EURGBP	***75.68	***11.40	***5.31						
EURNOK	***72.99	***11.16	***5.92	1.24					
EURUSD	***284.66	***48.74	***16.63	1.16	2.40				
GBPCHF	1.86	1.38	***26.23	***59.57	***56.14	***207.76			
GBPUSD	***81.74	***16.72	***5.92	1.50	3.02	1.69	***53.26		
USDCHF	***19.65	**4.77	3.15	***6.46	***5.96	***15.41	***13.23	**4.53	
USDSEK	***11.23	3.79	**4.71	***8.15	***6.67	***26.38	***10.98	***7.57	***5.70

FD	AUDJPY	AUDNZD	EURCHF	EURGBP	EURNOK	EURUSD	GBPCHF	GBPUSD	USDCHF
AUDNZD	***8.01								
EURCHF	***9.24	***8.16							
EURGBP	***15.70	***10.62	1.18						
EURNOK	***6.94	***11.90	***7.62	***6.67					
EURUSD	***27.02	***10.54	1.69	2.82	***15.83				
GBPCHF	***6.93	2.37	**4.40	***5.74	***9.59	**4.90			
GBPUSD	***16.53	***13.40	2.45	1.68	3.48	***5.82	***9.20		
USDCHF	***11.02	**4.79	1.23	0.43	***5.58	1.81	3.17	1.59	
USDSEK	***10.37	***6.98	***9.30	***5.99	3.15	***13.91	***8.08	***5.52	**4.39

Note: The numbers correspond to the test statistic of a joint pairwise F-test: $F = (R\hat{\theta}_n^{i,k} - \hat{\theta}_n^{i,q})'[R(\hat{V}_n/n)R']^{-1}(R\hat{\theta}_n^{i,k} - \hat{\theta}_n^{i,q})$, where $\hat{\theta}^{i,k} = \sum_{l=0}^{5} \hat{\beta}_l^{i,k}$, and $F \xrightarrow{D} \chi_Q^2$. R is $Q \times L$, where Q is the number of hypothesis tested and L the number of estimated coefficients. $\hat{V}_n$ is an estimator of the covariance matrix with sample size n. For each test, $k \neq q$ and $k \in$ [currency pairs] must hold. Stars (*/ **/ ***) denote significance at the global 90%/ 95%/ 99% level (α_g), respectively. For each individual test a Bonferroni correction is applied such that the local significance level is $\frac{\alpha_g}{m}$, where m is the number of multiple tests. Averages are calculated to account for both directions, i.e. $\hat{\theta}_n^{i,k}$ vs. $\hat{\theta}_n^{i,q}$/ $\hat{\theta}_n^{i,q}$ vs. $\hat{\theta}_n^{i,k}$.

Table 13: *Heterogeneous Permanent Price Impact Across Currency Pairs - FD & BA*

NB	AUDJPY	AUDNZD	EURCHF	EURGBP	EURNOK	EURUSD	GBPCHF	GBPUSD	USDCHF
AUDNZD	***33.72								
EURCHF	***18.22	2.99							
EURGBP	***15.29	***10.60	3.52						
EURNOK	***9.17	***9.51	3.86	0.88					
EURUSD	***5.99	***45.59	***22.39	***13.33	***11.15				
GBPCHF	2.80	***58.10	***32.81	***36.19	***22.27	***26.00			
GBPUSD	2.93	***52.09	***26.49	***17.61	***13.81	2.01	***15.21		
USDCHF	2.24	***65.22	***38.20	***32.70	***22.33	***13.56	*4.23	***6.91	
USDSEK	3.60	***25.52	***12.26	***7.97	***6.16	***8.19	***9.42	***5.17	***10.99

BA	AUDJPY	AUDNZD	EURCHF	EURGBP	EURNOK	EURUSD	GBPCHF	GBPUSD	USDCHF
AUDNZD	***70.71								
EURCHF	***98.35	***8.81							
EURGBP	***89.15	***5.67	2.91						
EURNOK	***28.88	***8.07	***26.42	***19.79					
EURUSD	***62.53	1.65	***10.24	**4.67	***8.29				
GBPCHF	***61.14	***6.40	2.64	2.69	***14.74	***7.39			
GBPUSD	***20.96	***16.71	***42.71	***32.38	3.35	***14.57	***28.55		
USDCHF	***29.31	***5.23	***18.77	***14.24	2.48	*4.15	***10.93	***5.32	
USDSEK	***21.57	***11.82	***29.46	***25.15	3.40	***12.64	***18.57	*4.26	**4.51

Note: The numbers correspond to the test statistic of a joint pairwise F-test: $F = (R\hat{\theta}_n^{i,k} - \hat{\theta}_n^{i,q})'[R(\hat{V}_n/n)R']^{-1}(R\hat{\theta}_n^{i,k} - \hat{\theta}_n^{i,q})$, where $\hat{\theta}^{i,k} = \sum_{l=0}^{5} \hat{\beta}_l^{i,k}$, and $F \xrightarrow{D} \chi_Q^2$. R is $Q \times L$, where Q is the number of hypothesis tested and L the number of estimated coefficients. $\hat{V}_n$ is an estimator of the covariance matrix with sample size n. For each test, $k \neq q$ and $k \in$ [currency pairs] must hold. Stars (*/ **/ ***) denote significance at the global 90%/ 95%/ 99% level (α_g), respectively. For each individual test a Bonferroni correction is applied such that the local significance level is $\frac{\alpha_g}{m}$, where m is the number of multiple tests. Averages are calculated to account for both directions, i.e. $\hat{\theta}_n^{i,k}$ vs. $\hat{\theta}_n^{i,q}$/ $\hat{\theta}_n^{i,q}$ vs. $\hat{\theta}_n^{i,k}$.

Appendix II: Diagnostic Tests

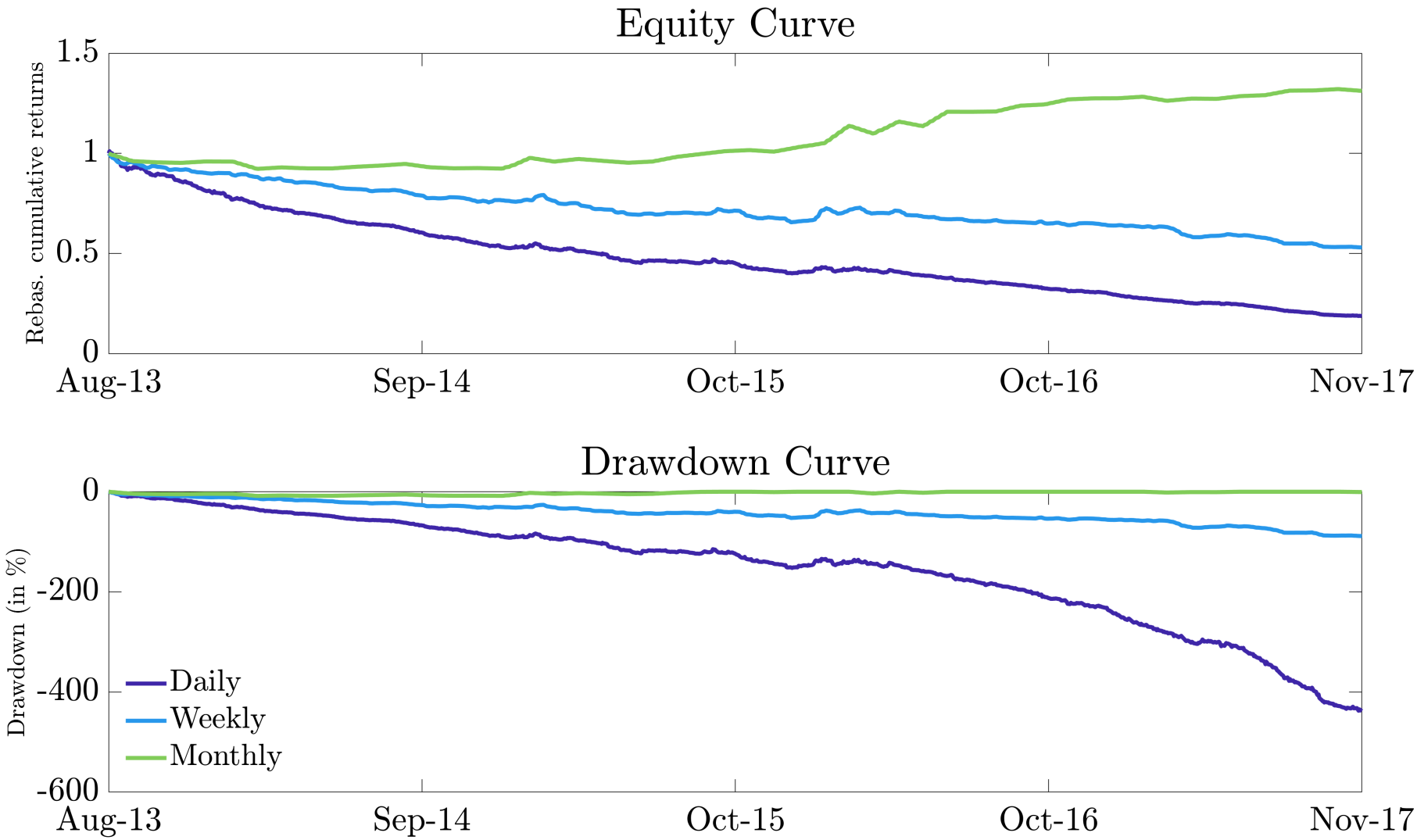
Table 14: *Diagnostic Tests*

Test	H_0	**Return Equation**	**Order Flow Equation**
Ljung-Box	Independent distribution	✓	✗
Durbin-Watson	No First Order Autocorrelation	✗	✗
White	Homoscedasticity	✓	✗
Kwiatkowski-Phillips-Schmidt-Shin	(Covariance) Stationarity	✗	✗
Dickey-Fuller	Unit root	✓	✓

Note: For all tests we apply a significance level of 5%, except for the Durbin-Watson (DW) test, where the difference between the DW test statistic and its critical value 2 is ≤ 0.001 for the entire cross-section. Check/ Cross-marks are based on applicability to at least 85% of all currency pairs. A check-mark indicates that the H_0 is rejected.

Appendix III: Trading Performance After Transaction Costs

Figure 6: *Equity and Drawdown Curves **After** Transaction Costs (US Investor)*



Appendix IV: After Transaction Costs Performance

Table 15: *Performance Benchmarking* - ***Net*** *Returns*

Panel a)	Q_1		Q_2		Q_3		Q_4		Q_5		ALP_{HML}	
	USD	EUR	USD	EUR	USD	EUR	USD	EUR	USD	EUR	USD	EUR
SR	−0.84	−0.55	−0.49	−0.19	−0.35	−0.07	0.84	0.44	0.13	0.50	0.86	0.89
Mean in %	*−5.91	−2.79	−3.76	−0.87	−3.06	−0.25	6.58	3.28	0.74	4.10	*6.69	**7.00
	[1.68]	[0.93]	[1.00]	[0.40]	[0.89]	[0.11]	[1.63]	[1.25]	[0.27]	[1.18]	[1.91]	[2.00]
MDD in %	6.42	14.58	11.01	10.88	24.77	20.12	40.35	17.34	14.53	6.36	4.22	4.12
Θ in %	5.43	2.59	3.33	0.72	−3.37	0.06	−7.01	−3.53	0.40	3.63	6.10	6.39

Panel b)	*DOL*		RER_{HML}		*RER*		MOM_{HML}		CAR_{HML}		ALP_{HML}	
	USD	EUR	USD	EUR	USD	EUR	USD	EUR	USD	EUR	USD	EUR
SR	−0.61	−0.27	0.21	0.31	0.16	0.24	−0.54	−0.51	0.11	0.15	0.86	0.89
Mean in %	−3.85	−0.98	0.80	1.21	0.34	0.53	−3.35	−3.20	0.56	0.82	*6.69	**7.00
	[1.19]	[0.60]	[0.56]	[0.80]	[0.39]	[0.59]	[1.29]	[1.21]	[0.29]	[0.38]	[1.91]	[2.00]
MDD in %	26.54	7.78	3.48	3.37	2.77	2.58	17.03	16.74	12.87	12.41	4.22	4.12
Θ in %	−4.06	−1.03	0.70	1.10	0.31	0.50	−3.53	−3.38	0.32	0.57	6.10	6.39

Note: Panel a) reports the annualised Sharpe ratio (SR), the annualised average (simple) *net* excess return (*Mean*), the maximum drawdown (MDD) and the Θ performance measure of Goetzmann et al. (2007) for the quintile portfolios (Q_1, Q_2, ..., Q_5). Panel b) lists the same measures as Panel a) but for common FX trading strategies based on monthly rebalancing. In particular, *DOL* is based on USD (or EUR) currency pairs, *RER*/ RER_{HML} on the real exchange rate (cf. Menkhoff et al. (2017)), MOM_{HML} on $f^m_{t-1,t} - s^m_t$ (cf. Asness et al. (2013)), CAR_{HML} on the forward discount/ premium ($f^m_{t,t+1} - s^m_t$, cf. Lustig et al. (2011)). Significance at the 90%/ 95%/ 99% level are represented by stars (*/ **/ ***), respectively.

Appendix V: After Transaction Costs Exposure Regression

Table 16: *Exposure Regression Based on Monthly* ***Net*** *USD-Excess Returns*

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
α	*0.006 [1.944]	*0.005 [1.750]	*0.005 [1.753]	*0.005 [1.699]	*0.006 [1.830]	*0.005 [1.653]	0.005 [1.601]	*0.005 [1.648]	*0.005 [1.669]	*0.006 [1.895]
DOL		−0.133 [0.622]	−0.001 [0.004]	−0.044 [0.226]	−0.097 [0.463]	−0.070 [0.367]	−0.143 [0.607]	−0.119 [0.553]	−0.131 [0.597]	0.245 [1.145]
RER_{HML}			0.469 [1.134]							
RER				0.988 [1.552]						**1.840 [2.183]
MOM_{HML}					0.301 [1.273]					
CAR_{HML}						−0.156 [0.895]				**−0.517 [2.120]
BMS							−0.086 [0.247]			
ΔVIX								0.000 [0.977]		
ΔCDS									0.000 [0.467]	0.000 [0.548]
R^2 in % IR #Obs	N/A 0.25 51	1.05 0.23 51	6.01 0.24 51	8.97 0.24 51	6.15 0.28 51	2.69 0.25 51	1.18 0.22 51	1.93 0.22 51	1.30 0.23 51	21.56 0.30 51

Note: In this table, we regress monthly *net* excess returns by ALP_{HML} on monthly excess returns associated with common risk factors, where *DOL* is based on USD (or EUR) currency pairs; *RER*/ RER_{HML} are based on the real exchange rate (cf. Menkhoff et al. (2017)); MOM_{HML} is based on $f^m_{t-1,t} - s^m_t$ (cf. Asness et al. (2013)), CAR_{HML} is based on the forward discount/ premium ($f^m_{t,t+1} - s^m_t$, cf. Lustig et al. (2011)), and *BMS* is based on lagged standardised order flow (cf. Menkhoff et al. (2016)). ΔVIX is the return on the VIX index and ΔCDS the change in the iTraxx Europe CDS index. The information ratio (IR) is defined as α divided by residual standard deviation. Significance at the 90%/ 95%/ 99% level are represented by stars (*/ **/ ***), respectively. The numbers inside the brackets are the corresponding test statistics based on HAC errors correcting for serial correlation and small sample size (using the plug-in procedure for automatic lag selection by Newey and West (1994)).

Appendix VI: Correlation with Common FX Risk Factors

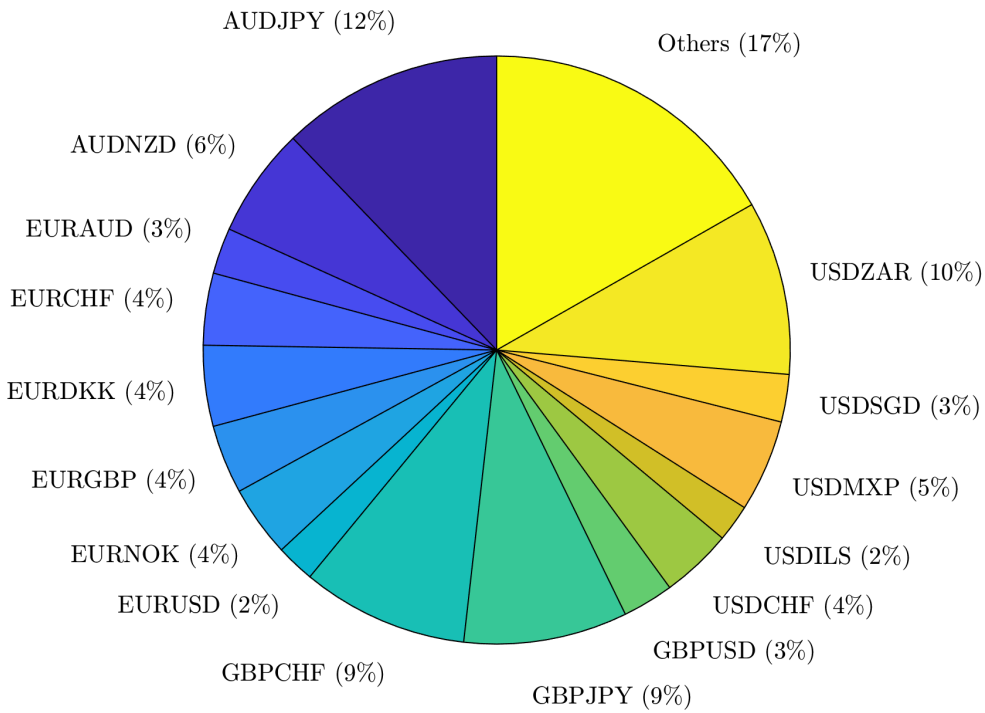
Table 17: *Correlation with Common FX Risk Factors in %*

	ΔVIX	ΔCDS	DOL	RER_{HML}	RER	MOM_{HML}	CAR_{HML}	BMS
ΔCDS	25.41							
DOL	7.58	14.11						
RER_{HML}	4.03	−3.88	−41.43					
RER	1.23	1.61	−23.57	88.02				
MOM_{HML}	17.18	14.68	−12.05	2.60	3.46			
CAR_{HML}	21.89	13.94	35.48	31.13	43.28	−15.79		
BMS	−4.21	−14.62	−21.57	−8.70	−2.21	−4.46	−4.39	
ALP_{HML}	1.87	−10.12	−10.22	24.51	29.77	23.66	−15.62	−1.40

Note: This table shows the time series cross-correlation at lag 0 between the *gross* excess return of HML_α (US perspective) and those associated with different FX risk factors, where DOL is based on USD (or EUR) currency pairs; RER/ RER_{HML} are based on the real exchange rate (cf. Menkhoff et al. (2017)); MOM_{HML} is based on $f^m_{t-1,t} - s^m_t$ (cf. Asness et al. (2013)), CAR_{HML} is based on the forward discount/ premium ($f^m_{t,t+1} - s^m_t$, cf. Lustig et al. (2011)), and BMS is based on lagged standardised order flow (cf. Menkhoff et al. (2016)). ΔVIX is the return on the VIX index and ΔCDS the change in the iTraxx Europe CDS index.

Appendix VII: Currency Exposure

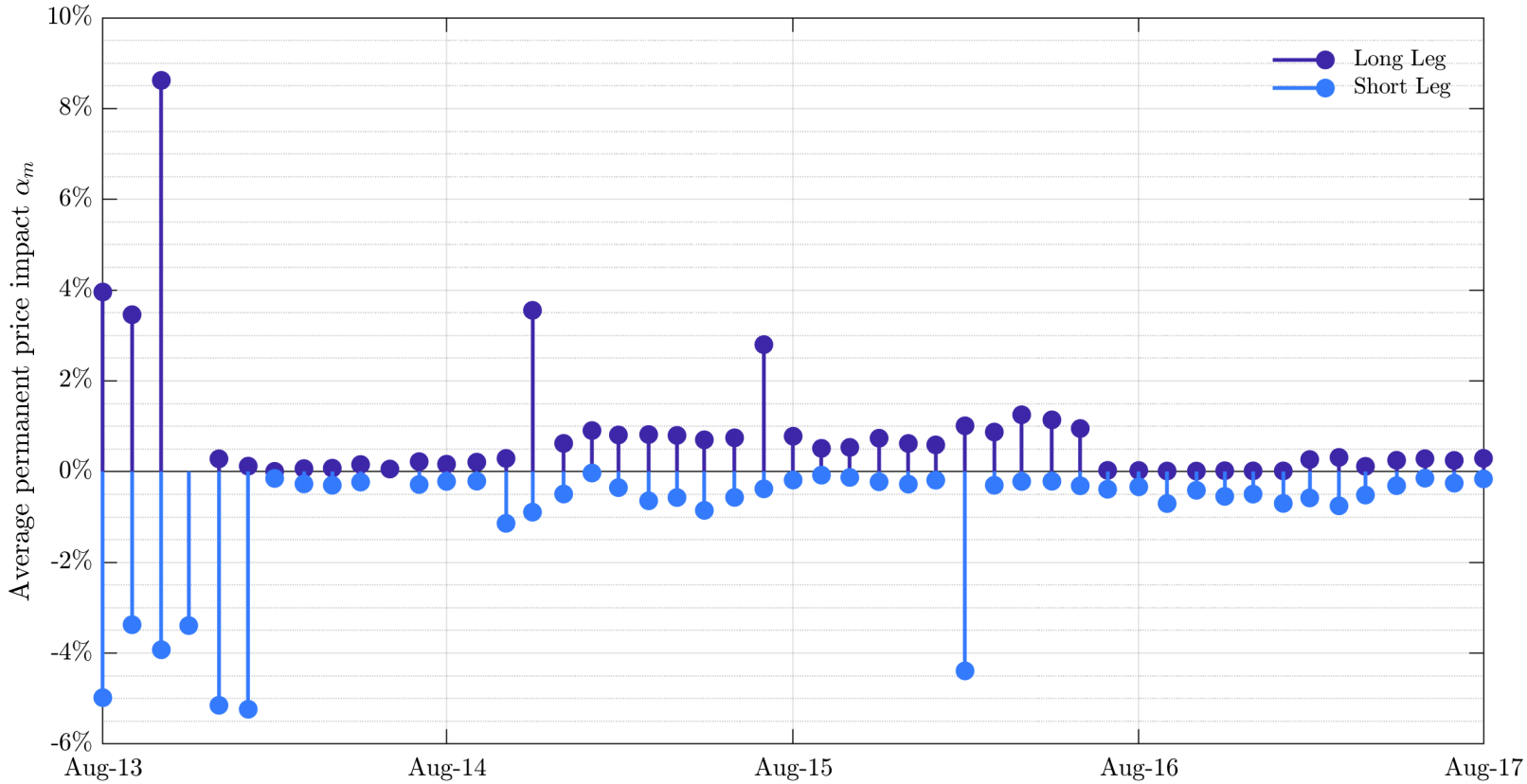
Figure 7: *Distribution of Absolute Currency Exposure (US Investor)*



Note: Sum up absolute exposure to each currency pair over time and then normalise to one. 'Others' comprise currency pairs with a relative share $\leq$ 2%: AUDUSD, CADJPY, EURCAD, EURJPY, EURSEK, GBPAUD, GBPCAD, NZDUSD, USDCAD, USDDKK, USDHKD, USDJPY, USDNOK, and USDSEK.

Appendix VIII: Permanent Price Impact in the Legs

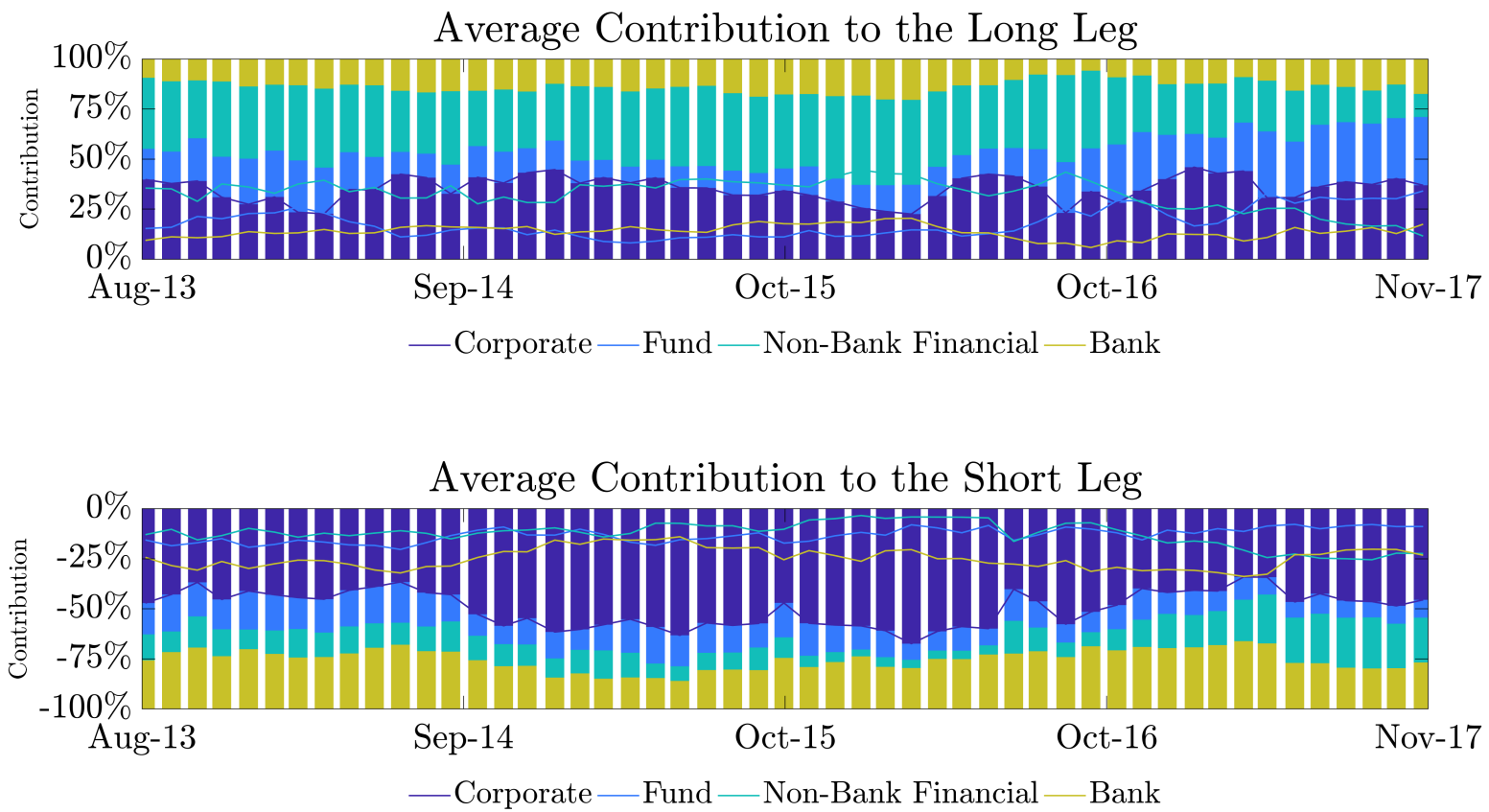
Figure 8: *Average Permanent Price Impact in the Long and Short Leg*



Note: We remove heavy outliers with respect to the median.

Appendix IX: Agents' Contribution to Long/ Short Leg

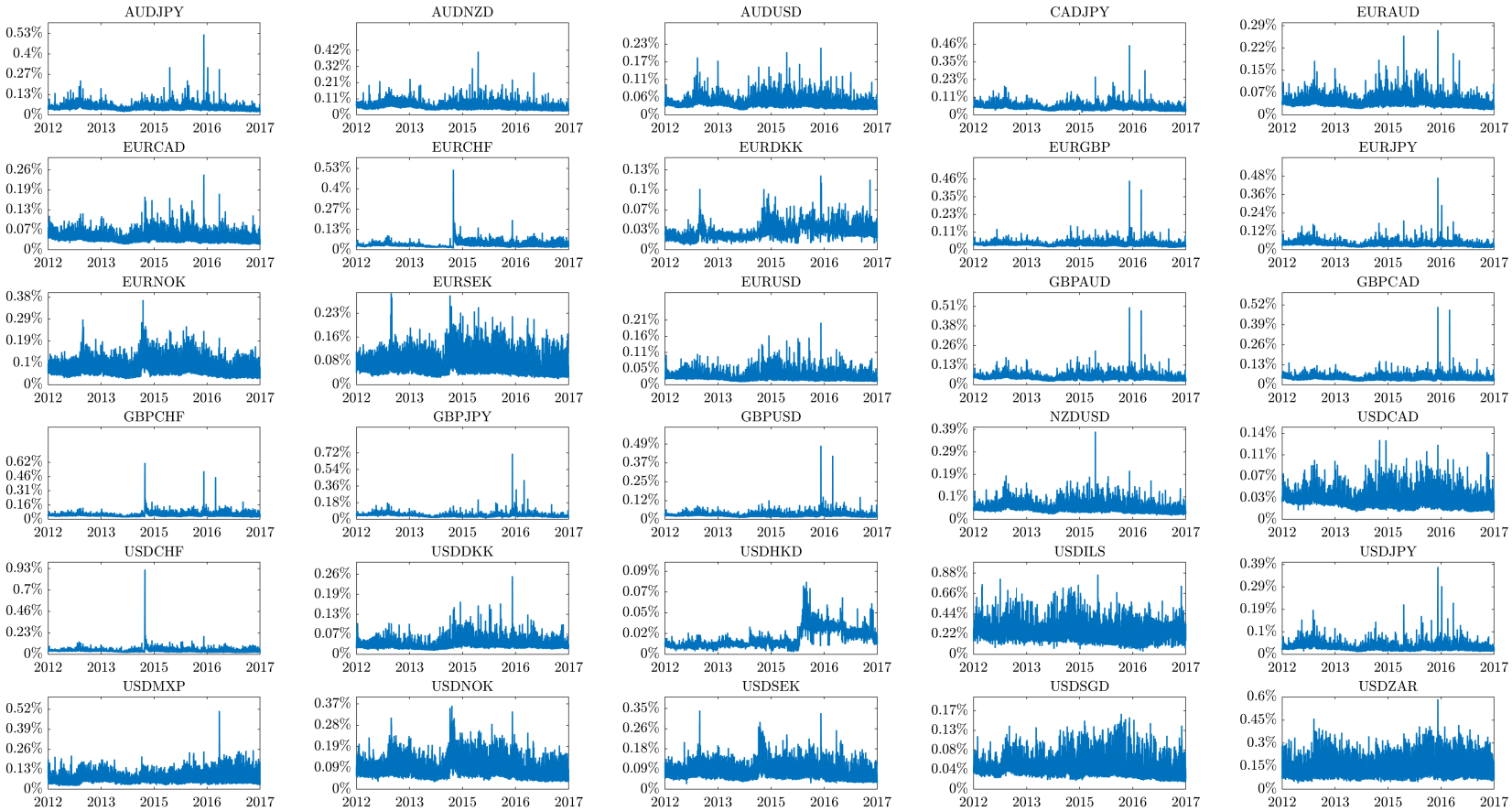
Figure 9: *Average Contribution to the Long and Short Leg*



Note: Compute the relative share of each agent's $\alpha_m^{j,k}$ to the aggregate α_m^k and calculate the mean across all currency pairs.

Appendix X: Cross-Sectional Bid-Ask Spreads

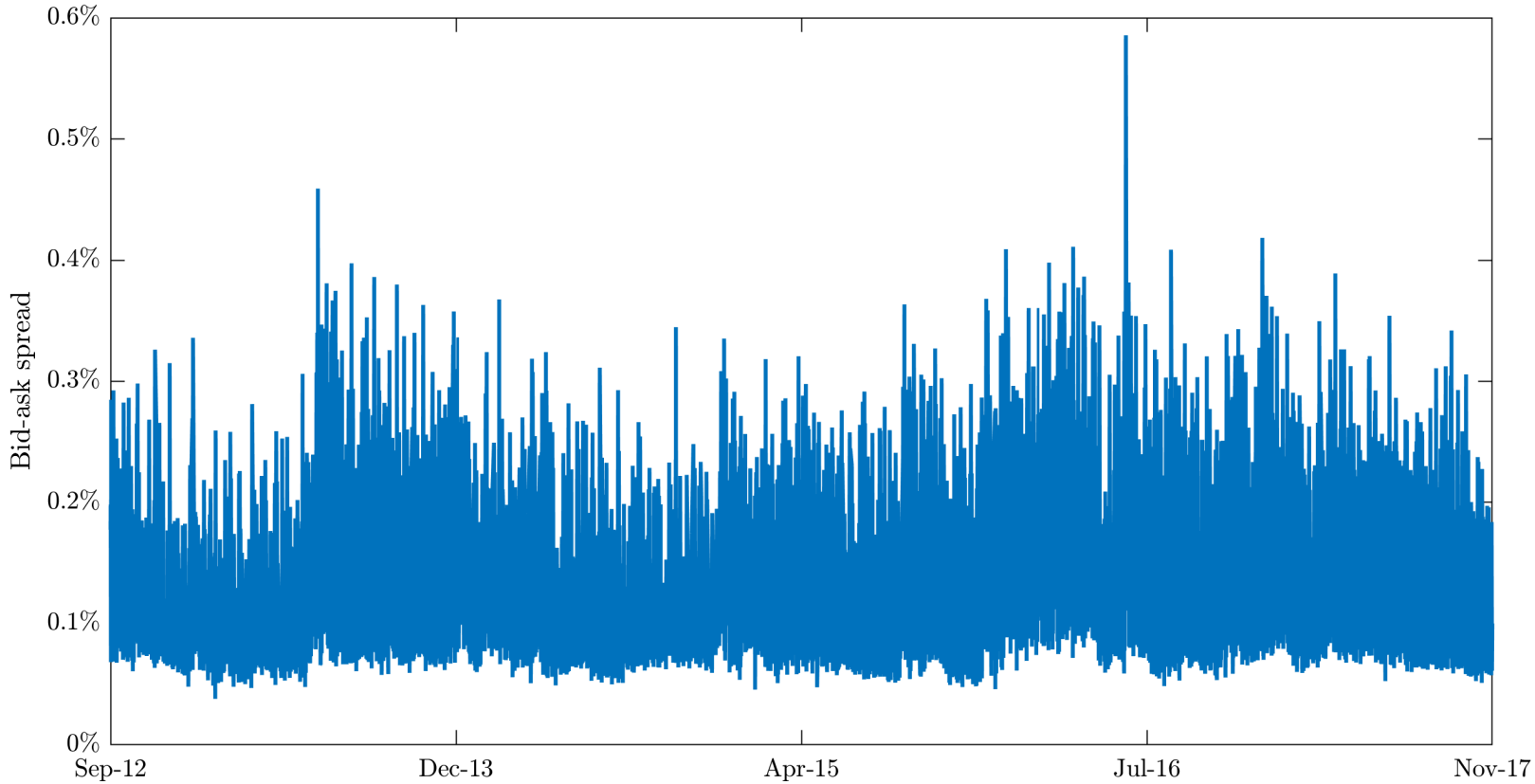
Figure 10: *Bid-Ask Spreads in the Cross-Section*



Note: Relative bid-ask spread as a fraction of the daily mid-quote for the entire cross-section of currency pairs.

Appendix XI: Average Bid-Ask Spread

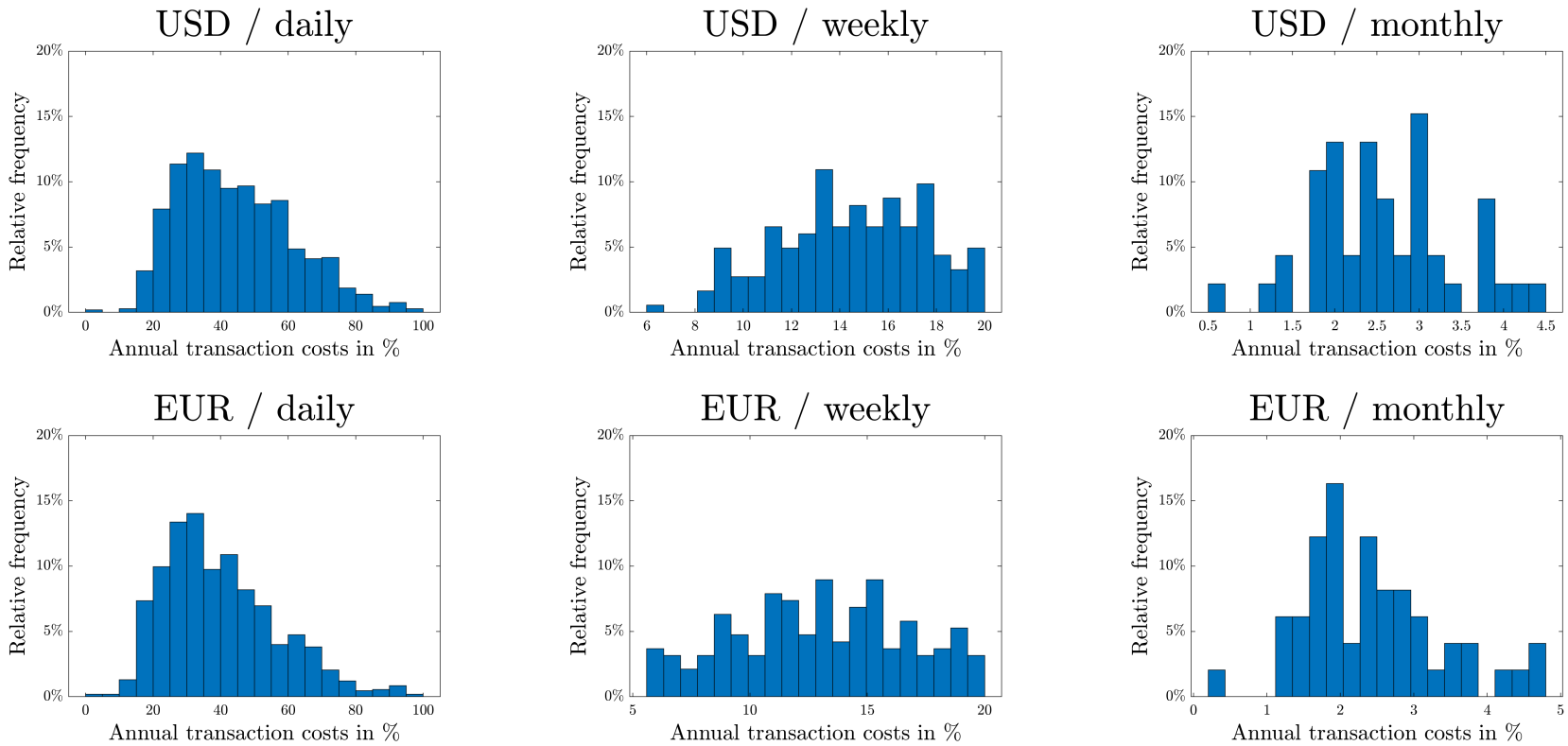
Figure 11: *Cross-Sectional Average Bid-Ask Spread*



Note: Cross-sectional average relative bid-ask spread as a fraction of the daily mid-quote.

Appendix XII: Transaction Costs

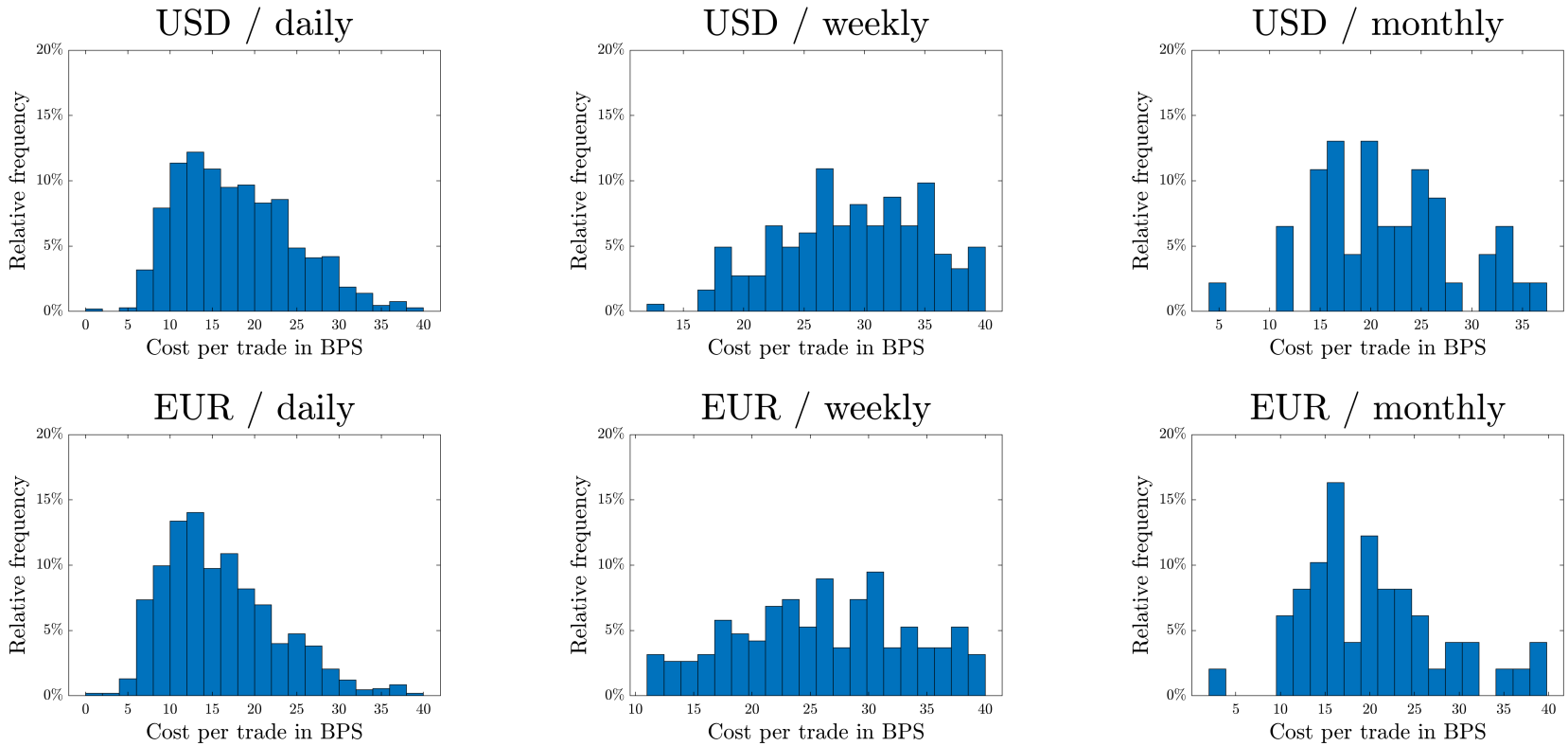
Figure 12: *Distribution of Annual Trading Costs*



Note: This figure shows the empirical distribution of annual transaction costs for different rebalancing frequencies: daily, weekly, and monthly. Annualised transaction costs are approximated by the cost per trade times number of trading days, weeks, and months per year.

Appendix XIII: Transaction Costs Per Trade

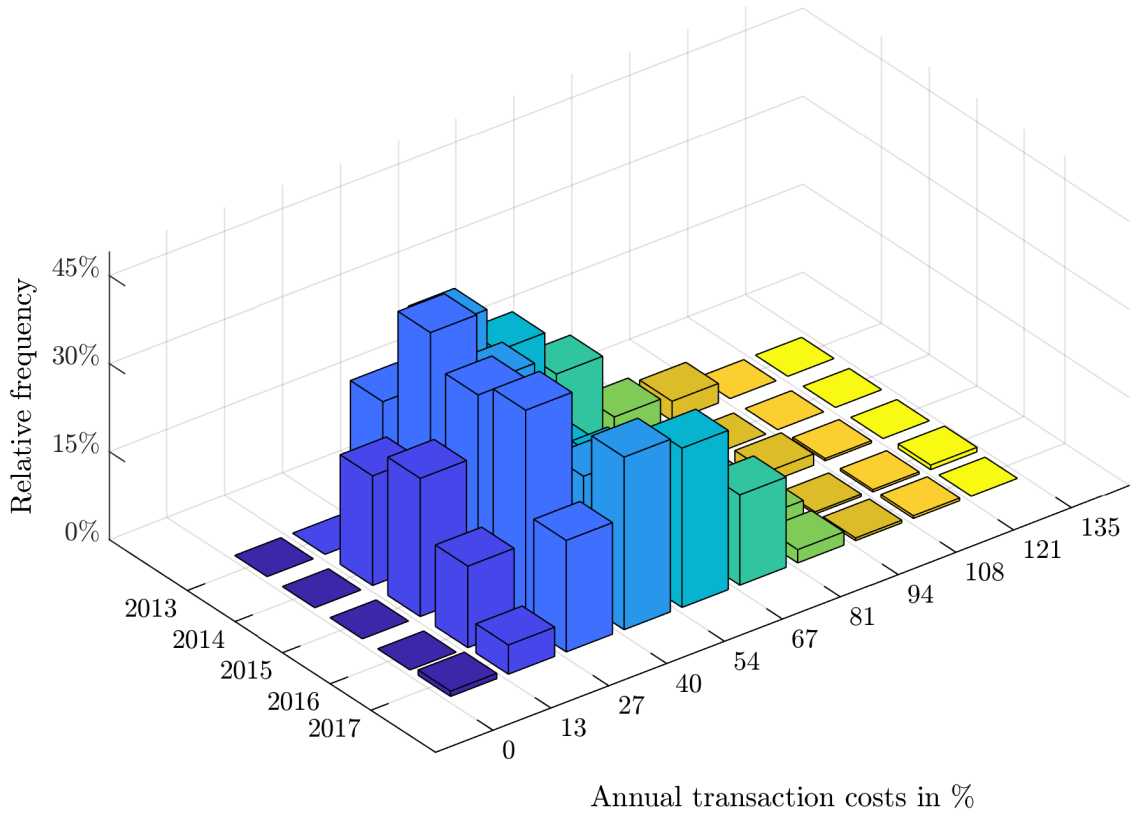
Figure 13: *Distribution of Cost Per Trade*



Note: This figure shows the empirical distribution of cost per trade for different rebalancing frequencies: daily, weekly, and monthly.

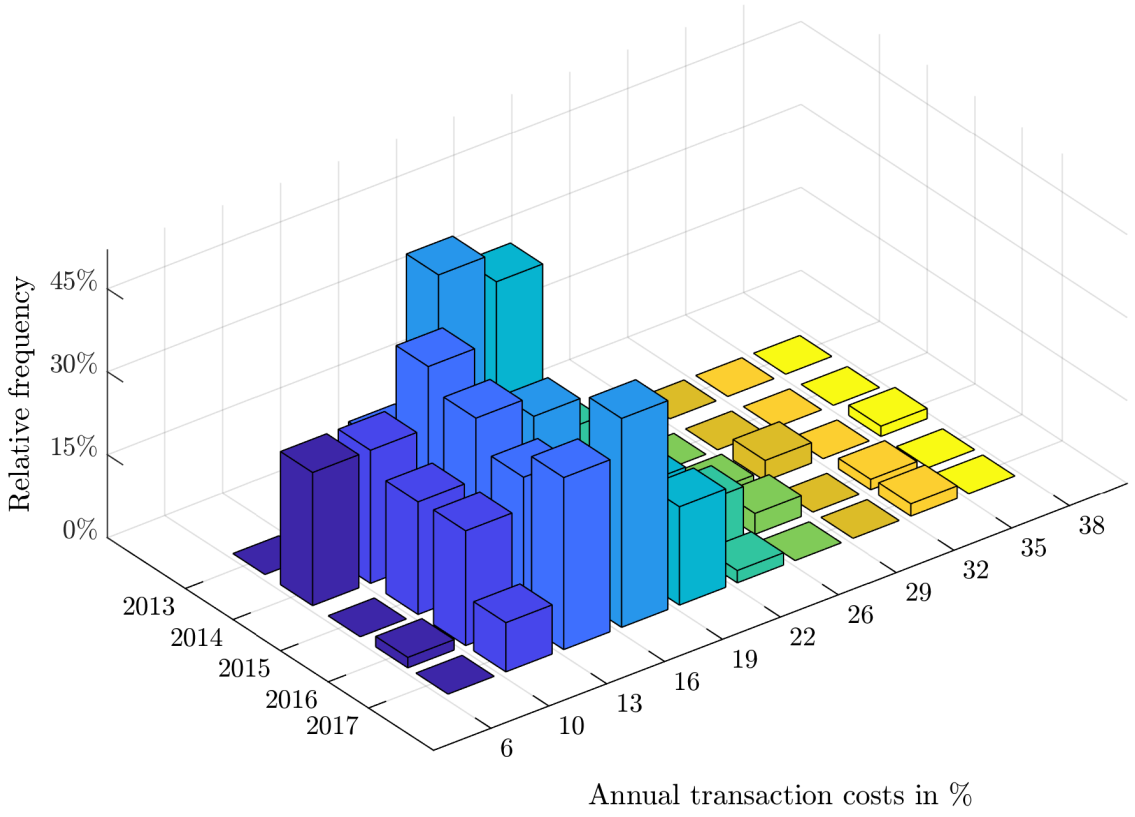
Appendix XIV: Transaction Costs Distribution - Daily

Figure 14: *Distribution of Transaction Costs - Daily Rebalancing - US Perspective*



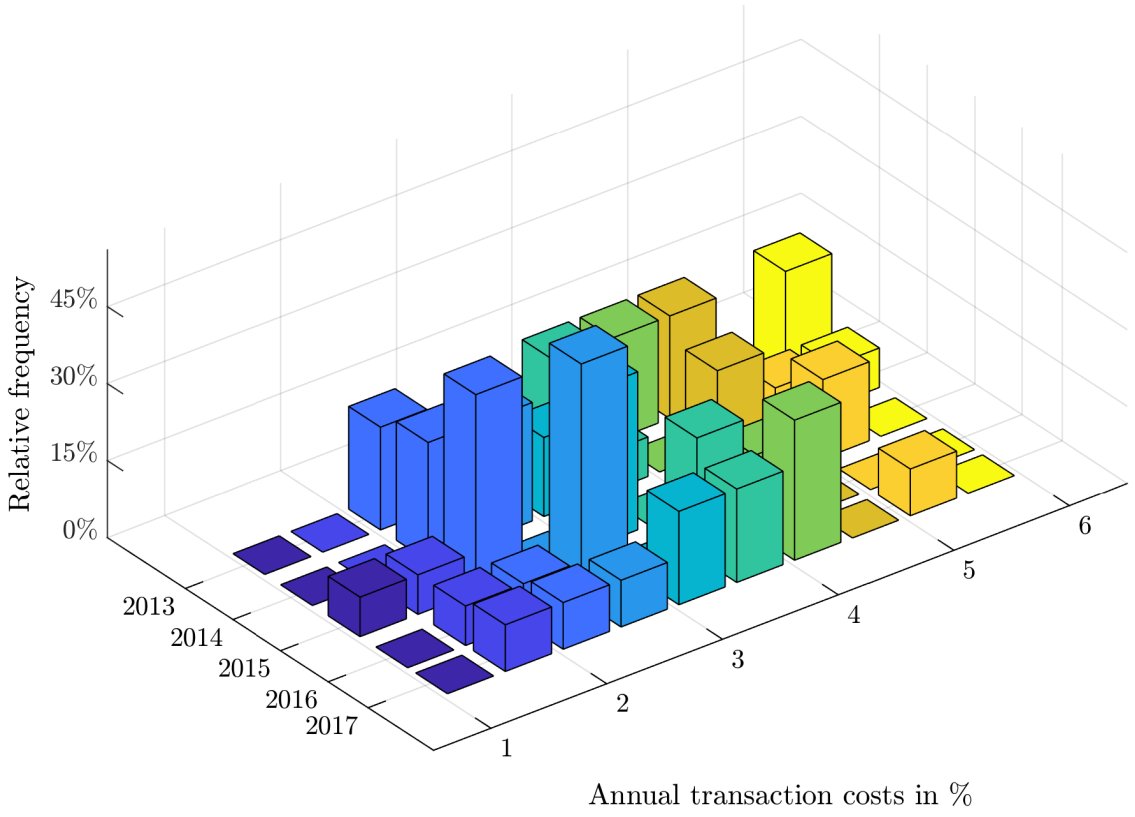
Appendix XV: Transaction Costs Distribution - Weekly

Figure 15: *Distribution of Transaction Costs - Weekly Rebalancing - US Perspective*



Appendix XVI: Transaction Costs Distribution - Monthly

Figure 16: *Distribution of Transaction Costs - Monthly Rebalancing - US Perspective*



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