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Abstract

Following a series of manipulation scandals in the global foreign exchange and money markets, recent lawsuits, regulatory reform proposals and bank compliance changes have explicitly targeted anti-competitive behaviour. By empirically investigating the determination of bid-ask spreads in foreign exchange swap markets, this paper addresses some contradictions where reciprocality, trust and conventions remain fundamental and logical. By doing so, the paper critically reflects upon the bid-ask spread in traditional market microstructure theory, the definition of the spread as a 'component of price' in antitrust law, and the policy implications in light of the recent regulatory investigations into financial benchmarks and OTC markets.

JEL Classification Numbers: D4, F3, G1, G3, K2

Keywords: Foreign exchange; LIBOR; market microstructure theory; bid-ask spreads; collusion; OTC markets.

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1 Introduction

Up until the London Interbank Offered Rate (LIBOR)[1] scandal broke in 2012, the global foreign exchange (FX) market was widely perceived to be sufficiently large, liquid and competitive to withstand successful attempts of manipulative or collusive practices. Indeed, with a daily turnover of $5.1 trillion (BIS, 2016) and immensely tight bid-ask spreads even during times of volatility and crisis, hardly any market could be seen as more competitive. In June 2013, this assumption was radically challenged in a Bloomberg article with the headline 'Traders Said to Rig Currency Rates to Profit Off Clients' (Vaughan, Finch and Choudhury, 2013). In November 2014, six global banks were fined $4.3 billion in total for manipulative trading conduct in the FX markets (CTFC, 2014). Six months later, Bank of America, Barclays, Citigroup, JP Morgan Chase, RBS and UBS received fines of $5.6 billion in total for rigging the global FX markets. Transcripts made public by the regulators revealed that traders at large banks had been engaging in collusive practices in the global, and largely unregulated, FX spot market which, according to the FBI, involved criminality 'on a massive scale' (Chon, Binham and Noonan, 2015).

In light of these revelations, this paper investigates the determination of the bid-ask spreads in the FX swap market. Surprisingly, although the FX swap market has been subject to similar changes in regulation and compliance following the events above, it has hitherto largely escaped thorough scrutiny by regulators, lawyers, academics and the media. The lack of 'interest' in the FX swap market is surprising for three reasons. First, the market is enormous. According to the Bank for International Settlements (BIS, 2016), FX swaps and forwards counts for 47% and 14% of the global FX turnover respectively. Second, the majority of the key market participants (i.e. banks and interdealer brokers) are almost identical to those caught up in the LIBOR and FX scandals. FX swaps play an important dual role in the financial markets, by being integrated into the FX market *as well as* the interest rate market. As an FX swap involves an FX spot transaction with a simultaneous FX forward transaction in the opposite direction, an FX swap can also be seen as a loan in one currency versus a

[1] List of abbreviations: London Interbank Offered Rate (LIBOR), foreign exchange (FX), over-the-counter (OTC), Tokyo Interbank Offered Rate (TIBOR), Den Norske Bank (DNB), Skandinaviska Enskilda Banken (SEB), Danske Bank (DDB), Norwegian Interbank Offered Rate (NIBOR), fixed income, currency and commodity (FICC).

simultaneous deposit in another currency for the same maturity and with the same counterparty following the covered interest parity.[2] Given that the FX swap desks typically are located within close proximity of the FX spot and money market desks on the trading floors, they share similar conventions and 'cultures'. Third, whereas other several money markets were extremely illiquid, completely frozen or not tradable per se (e.g. LIBOR) during the financial crisis of 2007-08, the FX swap market continued to function as a *tradable* funding instrument.

However, the lack of scrutiny can also be logically explained. First, FX swaps have always received considerably less attention than other FX markets in the finance literature. Instead, FX swaps tend to be mentioned simply as components of something else (e.g. FX forwards, FX futures and currency options), or in the economics literature in relation to arbitrage (Akram, Rime and Sarno, 2008), the failure of arbitrage during times of stress (Baba and Packer, 2009; McGuire and von Peter, 2012) or interest rate parity conditions under balance sheet constraints (Ivashina, Scharfstein and Stein, 2015; Avdijev *et al*., 2016; Sushko *et al*., 2016). Second, the FX swap market has traditionally been less embracing of electronic trading platforms than the FX spot market. Consequently, given that actual transaction data is scarce, it could be argued that empirical studies using indicative (but available) quotes have few relevant insights to offer.

This paper aims to break that tradition. As the LIBOR scandal has shown, even prices and numbers that are not tradable per se can have far-reaching implications on end-users and submitters alike. For reputational, regulatory or legal reasons, no bank would like to come to realise that its screen submission process (whether involving tradable or indicative prices) had been used with the intent to manipulate or collude. Likewise, no bank would like to come to defend that its submission process (whether involving tradable or indicative prices) simply had followed a convention that was based upon 'what everyone else in the market had been doing' or that no harm was intended by doing so.

[2] This is stated formally as: $(1 + i_t^C) = \frac{F_t^{BC}}{S^{BC}}(1 + i_t^B)$, where i_t^B (i_t^C) is the base (counter) currency interest rate for maturity t. S^{BC} (F_t^{BC}) represents the FX spot (FX forward) rate between the two currencies. According to the covered interest rate parity, interest rate differentials between two currencies should be reflected in the FX swap price ($F_t^{BC} - S^{BC}$). Otherwise, arbitrage would be possible.

By empirically investigating the USD/JPY and USD/NOK FX swap markets, this paper critically reflects upon how the competition aspect of the FX swap bid-ask spread determination ought to be conceptualised. It is found that neither traditional market microstructure theory, where the bid-ask spread at the outset is assumed to be determined competitively, nor screening methodologies widely used by antitrust authorities to present evidence to the contrary (elements that could suggest anti-competitive behaviour), offers satisfactory insights into how market makers behave in practice. Instead, the findings suggest that conventions are central to the bid-ask spread determination process in the FX swap market. Thus, this paper not only strives to contribute to the already vast literature on bid-ask spreads following the pioneering work by Demsetz (1968) but also more specifically to recent work on manipulation by, and regulation of, market makers and liquidity providers in the interbank money markets (Abrantes-Metz, Judge and Villas-Boas, 2011; Abrantes-Metz *et al*., 2012; Stenfors, 2014a; Duffie and Stein, 2015), the stock markets (Cumming, Johan and Li, 2011) and the FX markets (Evans, 2014).

The structure of the paper is as follows. Section 2 provides an overview of the literature on bid-ask spread determination. Section 3 outlines the data and methodology used in the paper. Section 4 summarises the empirical results. In Section 5, the results are then analysed and discussed in terms of whether the bid-ask spread could be said to be determined competitively, anti-competitively or following a convention. Section 6 concludes and reflects upon the implications for policy makers and compliance departments in light of the recent investigations and reform proposals affecting the global FX and money markets.

2 Literature Review

In market microstructure theory, market makers are assumed to quote two-way prices (in other words determine the bid-ask spread) *competitively* following the original Bertrand analysis. This process results in some kind of equilibrium bid-ask spread, which is as tight as possible. However, because the bid-ask spread must cover three types of costs (order processing costs, asymmetric information costs and inventory

carrying costs), it is always greater than zero (Bessembinder, 1994; Stoll, 1989). The theoretical starting point is, therefore, a purely hypothetical mid-price, and the various costs can be seen as deviations from a perfect market. According to Demsetz (1968), the bid-ask spread is 'the mark-up that is paid for immediacy of exchange in organised markets'. Hence, it can be seen as compensation paid to market makers for standing ready to absorb the risk borne by others 'immediately'. Consequently, the magnitude of the bid-ask spread is closely connected to the liquidity of the market (or the perceived future liquidity of it).

Given its size, the global FX market presents itself as the ideal setting for the study of competitive processes. Indeed, previous studies on the FX spot market generally seem to confirm the logic above. The bid-ask spread has shown to be positively correlated with exchange rate volatility (Bassembinder, 1994; Bollerslev and Melvin, 1994; Glassman, 1987; Hartmann, 1998; Hua and Li, 2011). Spreads also tend to widen in thin markets, around specific events and ahead of weekends and holidays, because of higher inventory risk (Bassembinder 1994; Glassman 1987; Kaul and Sapp, 2006; Mende, 2006). However, empirical results are more mixed with regards to trading volume. On the one hand, bid-ask spreads tend to widen with trading activity, order size and quoting frequency, which are linked to greater uncertainty (Bollerslev and Domowitz, 1993; Glassman, 1987; Lyons, 1995; Melvin and Yin, 2000). On the other hand, Hartmann (1998) shows that the volume effect is negative in the long run. Naturally, transaction costs should be lower (and bid-ask spreads tighter) in large and liquid markets. In sum, the bid-ask spread can be seen as a proxy for market liquidity, an element that is ultimately determined by the trading volume, turnover and volatility in a competitive market.

However, when studies have involved a more detailed investigation into individually quoted prices, other patterns have often emerged. For instance, prices (and consequently also bid-ask spreads) have sometimes been shown to be coarsely "granulated" and "sticky". The phenomenon that prices often tend to cluster around some numbers (such as 0 or 5) more frequently than others (such as 7 or 8) has also been shown to be prevalent in financial markets, such as FX spot (Goodhart and Curcio, 1991), bond futures (Gwilym, Clare and Thomas, 1998) and bank deposits (Kahn, Pannachi and Sopranzetti, 1999). A plausible psychological explanation for

this behaviour, referred to as the 'attraction hypothesis' or the 'round number effect', might lie in the desire to look for approximate 'anchors' when exact precision might be difficult (Yule, 1927; Tversky and Kahneman, 1974). Another theory explaining such behaviour is the 'price resolution hypothesis'. It has been shown that price clustering tends to vary inversely with the knowledge of the fundamental value of an asset (Ball *et al*., 1985). Consequently, thin, volatile and uncertain markets can force market participants to form some kind of grid, or price/spread matrix, in order to transact fast enough and to minimise negotiating costs. Although from different perspectives, these two theories imply that price clustering is natural, and sometimes a rational phenomenon arising from how individuals face decisions under uncertainty.

Post-Keynesian economists (see, for instance, Harvey, 2009) go even further and tend to reject the idea of 'fundamental drivers' in the FX market. Instead, given a prevailing uncertainty about the future direction of the market prices are seen to be determined by whatever market participants expect the future drivers to be. As Keynes (1936, pp. 162-163) wrote: 'human decisions affecting the future […] cannot depend on strict mathematical expectations since the basis for making such calculations does not exist'. However, uncertainty about the future does not need to result in chaos - because of the central role of *conventions*, or 'that the existing state of affairs will continue indefinitely, except in so far as we have specific reasons to expect a change' (ibid, p. 152). Conventions allow expectations about the future, at least to a degree, to become harmonised and receive an orderly status. Conventions might, of course, change at any time. However, if they become attached to the daily trading routine or part of the institutional structure, the confidence in their relevance and validity increases (Carvalho, 1983-1984; Lawson, 1985). Indeed, according to Cheung and Wong (2000), having conducted a survey among 392 FX spot dealers in Hong Kong, Singapore and Tokyo, 77,4%, 69.9% and 71.3% respectively cited the 'market convention' as the main driver for choosing the interbank bid-ask spread. A similar study by Cheung and Chinn (2001) on 142 banks operating in the FX market in New York found that 69% argued in favour of the market convention, rather than potential costs, being the key determinant of the bid-ask spread.

Indeed, there is a fundamental difference between auction markets (the starting point of the original bid-ask spread literature) and over-the-counter (OTC) markets to which

the FX market belongs. The FX market relies on market-making banks quoting prices to end-users on demand, and to each other to maintain liquidity. Further, given that the FX swap market involves element of credit and funding liquidity risk, individually submitted bid-ask spreads might also depend on search mechanisms typical of OTC markets (Lamoureux and Schnitzlein, 1997) or the bargaining power of different market participants (Duffie, Gârleanu and Pedersen, 2005). For instance, studies by Schultz (2001), Harris and Piwowar (2006) and Green, Hollifield and Schürhoff (2007) show that smaller investors face wider bid-ask spreads in some bond markets. Such two-tier markets have also been found to exist in the highly liquid EUR/USD FX spot market (Osler, Mende and Menkhoff, 2011). The observation that market makers might quote more competitive bid-ask spreads in larger amounts to informed traders (thus also competing market makers) contradicts the traditional market microstructure approach, where adverse selection would result in the exact opposite outcome. However, the existence of various degrees of market power could, of course, also be linked to issues related to abuse of such power. An explanation for anomalous price patterns could, therefore, be that of collusion: that market makers agree upon certain pre-determined bid-ask spreads. Potential collusion with regards to bid-ask spreads in financial markets was brought to light already two decades ago in two empirical studies by Christie and Schultz (1994ab) on NASDAQ stocks.

Although the academic literature provides little direct insight into potential collusive behaviour in the FX market (let alone bid-ask spreads in the FX swap markets), Abrantes-Metz, Judge and Villas-Boas (2011) show that an empirical screening methodology could have been applied to individual LIBOR submissions by banks – ultimately suggesting that collusive practices potentially could have been detected prior to the LIBOR scandal erupted in 2012. As the purpose of this paper is to seek to detect, and then to analyse and discuss, potentially anti-competitive practices, the lens applied is based upon their methodology.

3 Data and Methodology

The FX market is a decentralised quote-driven market. Market making banks quote prices to end-users upon request and to be able to do also quote prices to each other.

The number of market makers generally differs (from a handful to several dozens) differs depending on the size of the market and generally includes a selection of the large universal banks as well as the major domestic banks in the respective currency pair.

Given that the FX market is largely unregulated, informal market conventions play an important role. These range from agreed-upon opening hours of the interbank market to standardised amounts and the number of seconds a firm price would be considered to be tradable. Although the FX swap market shares many of the characteristics of the FX spot market (which is of similar size), it also has some unique aspects. For instance, whereas end-users may request FX swap and FX forward prices for 'broken dates' in a range of possible currency pairs, market makers only tend to provide liquidity to each other in FX swaps only, for standardised maturities (1-month, 3months, 6-months etc.) and in currencies against US dollars. Moreover, given the interest rate risk involved in the transactions, FX swaps are frequently hedged with or traded alongside OTC derivatives such as interest rate swaps, forward rate agreements and overnight index swaps.

The average daily turnover in the FX swap market is $2.4 trillion, of which 74% is interbank. Other financial institutions (institutional investors, hedge funds etc.) make up another 19%. Although electronic trading gradually has become more common among all FX instruments, 45% of FX swaps are still voice-executed. Approximately 20% of the volume is executed through voice brokers (BIS, 2016). Consequently, as they typically intermediate between banks only, brokers play a very important role in the price discovery process and the facilitation of liquidity for market marking banks. Being independent financial institutions and, in contrast to the market making banks, not holding any inventories, interdealer brokers compete in the FX swap market for commissions from banks.

Two different markets have been chosen in order to capture different aspects of the FX swap bid-ask spread determination process: US dollars against Japanese yen (USD/JPY) and US dollars against Norwegian krone (USD/NOK). Given their status as G10 currencies, they share important features in terms of the broader market microstructure (such as standard market conventions and the physical location of the

trading desks within the dealing rooms of the banks and interdealer brokers). In terms of market size and turnover, however, there are notable differences. USD/JPY is the second most traded currency pair globally (with a share of 17.8%), and the daily turnover in the USD/JPY FX swap market was $396 billion in April 2016. USD/NOK, on the other hand, is ranked 19th (0.9%) with a daily turnover of $32 billion in the USD/NOK FX swap market (BIS, 2016). Thus, as FX swaps conventionally are quoted against US dollars in the interbank market, the Japanese yen represents the largest currency after the euro, whereas the Norwegian krone is the smallest G10 currency subject to a floating exchange rate regime. Moreover, the vast majority of the trading in USD/NOK takes place in the European time zone, whereas the activity in USD/JPY is larger when the Asian markets are open. With regard to recent regulatory sanctions and scrutiny in similar financial markets and/or benchmarks, there are also notable differences. Several market-making banks have been found to have been involved in manipulative and/or collusive practises in relation to the Japanese yen LIBOR and TIBOR (Tokyo Interbank Offered Rate), as well as the USD/JPY FX spot market (see, for instance, CFTC, 2014; Financial Services Agency, 2011; Financial Services Authority, 2012). This, however, has not been the case in the Norwegian krone market.

Indicative price quotes by three interdealer broker and banks respectively are studied in order to capture the behaviour of brokers towards each other and their customers (banks), as well as the behaviour of banks towards each other and their customers (end-users). Three data sets are used for this purpose. As data is scarce and given that it is not a cross-country study per se, the longest possible samples are used.

The USD/JPY data set from 28 May 2009 to 9 June 2016 is from Bloomberg and consists of 1-month, 3-month and 6-month USD/JPY FX swap bid and ask quotes (end-of-day) from the three leading interdealer brokers in the USD/JPY FX swap market: Tullett [Prebon], ICAP and Meitan [Tradition] (Risk, 2015). Given that the FX interdealer broker market is highly concentrated, the selection ought to be representative. A larger data set has been obtained for USD/NOK and runs from 20 January 2005 to 9 June 2016. It consists of 1-month, 3-month and 6-month USD/NOK FX swap bid and ask quotes (end-of-day) from three Nordic banks: Den Norske Bank (DNB), Skandinaviska Enskilda Banken (SEB) and Danske Bank

(DDB). A number of banks could, of course, claim to be prepared to quote two-way prices to end-users in a range of currency pairs, including the smaller ones. Interbank trading, however, tends to be concentrated among relatively few banks and the Norwegian market is no exception - having between six and ten active market makers at any point in time. Unfortunately, extensive historical data is difficult to obtain. However, three major market-making banks have posted indicative prices at least since 2005: DNB, DDB and SEB. Conveniently in terms of representativeness, these not only happen to be dominant players in the USD/NOK FX swap market but are also considered the largest FX dealers in Norway, Denmark and Sweden respectively (Euromoney, 2015). For the discussion in Section 5.1, a long-term data set is also used. It is from Bloomberg and consists of USD/JPY and USD/NOK FX spot (composite), 3-month USD/JPY and USD/NOK FX swap (Tullett and DNB respectively) bid and ask quotes (end-of-day), as well as daily 3-month USD LIBOR from 12 August 1997 to 9 June 2016. FX turnover data is collected from the BIS triennial central bank surveys. Indications of market shares for banks and interdealer brokers are from Euromoney and Risk respectively.

It is impossible to obtain precise information on which methodology each bank or interdealer broker adopts to determine a price or a bid-ask spread at each moment in time. Therefore, competition authorities often apply different kinds of screening methodologies in order to detect suspicious patterns in data that might suggest the existence of manipulation or price-fixing conspiracies. One such mathematical screen is drawn from Benford (1938). According to Benford's First Significant Digit Law, first digits (d=1,2,…9) are not randomly distributed, and therefore occurring 11.11% of the time. Instead, the digit 1 occurs most frequently, followed by 2, 3, 4 and so on. Consider, for instance, the shirt numbers of soccer players. Teams have at least 11 players, but often around double that to account for rest, tactics, injuries etc. If the shirts are numbered from 1 to 11, the first digit 1 occurs 27.27% of the time (1, 10 and 11). If the shirts are numbered from 1 to 23, the lower first digits 1 and 2 are again overrepresented. It has been shown that for large data sets, the probability that a number starts with a specific digit tends to be same (e.g. population of cities, electricity usage, stock prices, eBay auction prices) (see, for instance, Brähler *et al*., 2011; Varian, 1972; Giles, 2007). Importantly, a seminal paper by Abrantes-Metz, Judge and Villas-Boas (2011) showed that Benford's Law also could be applied

individual LIBOR submissions by banks, suggesting that collusive practices among banks potentially could have been detected earlier.

Formally, the distribution of the 1st digit can be written as:

$$Prob(1^{st} = d) = log_{10}(1 + d^{-1}), \qquad (1)$$

where $d = 1,2, \dots ,9$.

However, given that the 1st (and sometimes even the 2nd or 3rd) digit often tends to be 'sticky' in financial markets, it might be more useful to look for patterns of the 2nd digit (or 3rd or 4th…), which includes the digit 0:

$$Prob(2^{nd} = d) = \sum_{k=1}^{9} log_{10}\left(1 + (10k + d^{-1})\right), \qquad (2)$$

where $d = 0,1, \dots ,9$.

Methodologically, the analysis in this paper is conducted in four steps. First, Benford's Law is applied as a screening methodology on the 3-month FX forwards market. In the FX markets, non-bank participants often hedge risk via FX forwards. By adding the two components (end-of-day FX spot prices and FX swap prices from the three interdealer brokers and banks respectively), we can run 2nd, 3rd, 4th and 5th digit tests on the 3-month USD/JPY and USD/NOK FX forward market to investigate potentially suspicious patterns. Second, since banks conventionally quote FX spot and FX swaps as *separate* components to each other, the same methodology is then applied to the FX swap bid-ask spreads. Third, to detect whether any form of communication (or even collusion) between the interdealer brokers (for USD/JPY) or the banks (for USD/NOK) could have taken place ahead of determining the bid-ask spreads, a comparative analysis of each individually submitted 1-month, 3-month and 6-month bid-ask spread over time is then conducted. The empirical results are finally interpreted and discussed in relation to the literature to shed light on whether the bid-ask spreads are determined competitively, anti-competitively or following some kind of convention.

4 Empirical Results

Table 1 shows the results from having run 2nd, 3rd, 4th and 5th digit tests on the 3-month USD/JPY FX forward market from 28 May 2009 to 9 June 2016.

Table 1: Benford's Law 2nd, 3rd, 4th and 5th digit tests 28.05.2009 – 09.06.2016 on 3-month USD/JPY FX forward bid prices.

Digit	Benford's Law	Broker (2nd)	Broker (3rd)	Broker (4th)	Broker (5th)
0	11.97%	24.62%	9.29%	11.59%	10.42%
1	11.39%	17.97%	12.91%	10.73%	11.21%
2	10.88%	15.11%	13.61%	9.85%	9.19%
3	10.43%	5.82%	11.04%	10.16%	9.58%
4	10.03%	3.63%	9.29%	10.15%	9.30%
5	9.67%	2.91%	6.48%	8.81%	10.48%
6	9.34%	6.48%	7.89%	8.17%	11.14%
7	9.04%	6.32%	8.94%	9.98%	10.49%
8	8.76%	8.42%	10.09%	11.61%	8.83%
9	8.50%	8.72%	10.46%	8.94%	9.36%
χ^2		1,712.12	191.61	77.93	72.09

Sources: Bloomberg and author's calculations. Notes: The table shows the expected observed frequency following Benford's Second Significant Digit Law (see Equation 2) and the actual observed frequency of the 2nd, 3rd, 4th and 5th digits as percentages. The 3-month USD/JPY FX forward bid prices are calculated using end-of-day USD/JPY FX spot (composite) bid prices and 3-month USD/JPY FX swap bid quotes from Tullett, ICAP and Meitan. The number of observations is 5,460.

Given the large sample size (5,460 observations), it is not surprising that we get inflated χ^2 test values. However, from Table 1 we can see how the 'big figure' matters. Even by removing the 1st digit, the Benford's Law test indicates some degree of price clustering around the numbers 0,1 and 2. When applying the methodology to the 3rd, 4th and 5th digits, however, the pattern appears to be receding – suggesting that the data set is of little interest for competition authorities at least.

Table 2 shows the results for the 3-month USD/NOK FX forward market using bank rather than interdealer broker data and a larger data set (8,823 observations from 20 January 2005 to 9 June 2016).

Table 2: Benford's Law 2nd, 3rd, 4th and 5th digit tests 20.01.2005 – 09.06.2016 on 3-month USD/NOK FX forward bid prices.

Digit	Benford's Law	Bank (2nd)	Bank (3rd)	Bank (4th)	Bank (5th)
0	11.97%	10.31%	9.00%	10.10%	10.25%
1	11.39%	10.78%	9.74%	11.74%	9.00%
2	10.88%	7.46%	9.93%	10.27%	10.22%
3	10.43%	6.06%	9.27%	9.66%	9.76%
4	10.03%	10.16%	8.51%	10.67%	10.04%
5	9.67%	9.29%	9.54%	9.60%	10.28%
6	9.34%	8.09%	8.12%	10.27%	10.47%
7	9.04%	18.30%	9.54%	8.94%	10.50%
8	8.76%	9.12%	14.54%	8.87%	9.75%
9	8.50%	10.42%	11.81%	9.88%	9.74%
χ^2		1,172.62	592.40	66.69	135.35

Sources: Bloomberg and author's calculations. Notes: The table shows the expected observed frequency following Benford's Second Significant Digit Law (see Equation 2) and the actual observed frequency of the 2nd, 3rd, 4th and 5th digits as percentages. The 3-month USD/NOK FX forward bid prices are calculated using end-of-day USD/NOK FX spot (composite) bid prices and 3-month USD/NOK FX swap bid quotes from DNB, SEB and DDB. The number of observations is 8,823.

Again, some price clustering is prevalent when running the 2nd and 3rd digit tests (numbers 7 and 8 respectively). However, anything that potentially could be regarded as a suspicious pattern disappears when the test is applied to the 4th and 5th digits.

When running a test on the 3-month USD/JPY FX *swap bid-ask spread* for the same period, however, we get remarkably different results. From Table 3 we can immediately see that Benford's Law is violated when disregarding the FX spot rates and applying it directly to the swap spreads submitted by the three interdealer brokers. Having removed the 1st digit from the dataset, we get an extremely high χ^2 test values when comparing the frequency of each 2nd digit with the expected frequency expected according to Benford's Law. The digit 1 appears more than 37% of the time, whereas digits 7, 8 and 9 hardly appear at all. We can also conduct a similar test on the 3rd digit of the bid-ask spread.[3] As the Table 3 shows, three digits are prevalent: 0, 1 and 5.

[3] A fourth digit does not exist for the 3-month USD/JPY and USD/NOK FX swap bid-ask spreads.

Table 3: Benford's Law 2nd and 3rd digit tests 28.05.2009 – 09.06.2015 on 3-month USD/JPY FX swap bid-ask spreads.

Digit	Benford's Law	Broker (2nd)	Broker (3rd)
0	11.97%	10.97%	64.65%
1	11.39%	37.73%	7.69%
2	10.88%	15.40%	1.28%
3	10.43%	17.71%	0.05%
4	10.03%	4.67%	0.71%
5	9.67%	9.05%	15.15%
6	9.34%	3.39%	1.87%
7	9.04%	0.24%	0.92%
8	8.76%	0.73%	2.69%
9	8.50%	0.11%	4.98%
χ^2		5,397.65	15,426.79

Sources: Bloomberg and author's calculations. Notes: The table shows the expected observed frequency following Benford's Second Significant Digit Law (see Equation 2) and the actual observed frequency of the 2nd and 3rd digits as percentages. The 3-month USD/JPY FX swap bid-ask spreads are calculated using end-of-day bid and ask quotes from Tullett, ICAP and Meitan. The number of observations is 5,460.

Table 4 shows the corresponding results for the USD/NOK dataset. Digits 0 and 5 are totally dominant when running the 2nd digit test and 0 the only one appearing in the 3rd digit test.

Table 4: Benford's Law 2nd and 3rd digit tests 20.01.2005 – 09.06.2015 on 3-month USD/NOK FX swap bid-ask spreads.

Digit	Benford's Law	Bank (2nd)	Bank (3rd)
0	11.97%	42.28%	100.00%
1	11.39%	0.05%	0.00%
2	10.88%	0.14%	0.00%
3	10.43%	0.02%	0.00%
4	10.03%	0.06%	0.00%
5	9.67%	57.16%	0.00%
6	9.34%	0.00%	0.00%
7	9.04%	0.28%	0.00%
8	8.76%	0.02%	0.00%
9	8.50%	0.00%	0.00%
χ^2		34,160.71	64,887.16

Sources: Bloomberg and author's calculations. Notes: The table shows the expected observed frequency following Benford's Second Significant Digit Law (see Equation 2) and the actual observed frequency of the 2nd and 3rd digits as percentages. The 3-month USD/NOK FX swap bid-ask spreads are calculated using end-of-day bid and ask quotes from DNB, SEB and DDB. The number of observations is 8,823.

Next, Table 5 shows the frequency of occasions when the three competing interdealer brokers have posted *precisely* the same bid-ask spreads for 1-month, 3-month and 6-month USD/JPY FX swaps on their respective screens.

Table 5: Harmonised USD/JPY FX swap bid-ask spreads 28.05.2009 – 09.06.2015

Interdealer broker combination	Tullett / Meitan	Tullett / ICAP	Meitan / ICAP	Tullett / Meitan / ICAP
Total days	1820	1820	1820	1820
Same 1M USD/JPY FX swap bid-ask spread	15 (0.8%)	887 (48.7%)	22 (1.2%)	1 (0.1%)
Repetition of the same bid-ask spread	1 (6.7%)	634 (71.5%)	5 (22.7%)	0 (0.0%)
Same 3M USD/JPY FX swap bid-ask spread	28 (1.5%)	803 (44.1%)	5 (0.3%)	3 (0.2%)
Repetition of the same bid-ask spread	11 (39.3%)	577 (71.9%)	0 (0.0%)	0 (0.0%)
Same 6M USD/JPY FX swap bid-ask spread	28 (1.5%)	597 (32.8%)	4 (0.2%)	2 (0.1%)
Repetition of the same bid-ask spread	14 (50.0%)	516 (86.4%)	1 (25.0%)	0 (0.0%)

Sources: Bloomberg and author's calculations. Notes: The table first shows the number (and percentage) of trading days when two or all three interdealer brokers have submitted exactly the same bid-ask spread, and then the number (and percentage) of trading days such behaviour has been repeated the following day.

As can be seen, during the period from 28 May 2009 to 9 June 2016, Tullett and ICAP posted *exactly* the same bid-ask spreads on 803 occasions out of 1,820 (44.1% of the time). Moreover, the period consisted of 577 trading days when the two competitors replicated their harmonised behaviour from the previous day. Seen from this perspective, the quotes by Meitan have clearly been outliers. The pattern is similar when applying it to other maturities. As Table 5 demonstrates, Tullett and ICAP not only seem to have coordinated their bid-ask spread behaviour in the 3-month USD/JPY FX swap market. The results indicate that an identical bid-ask spread matrix (akin to a 'price list') often has been applied to 1-month and 6-month maturities as well. This matrix has then, despite movements in the prices themselves, remained 'sticky' until a recalibration has taken place.

Given the large dataset for USD/NOK, the observations have been split into three periods. Table 6 (the period before the financial crisis of 2007-8) depicts a consistent pattern. Between 20 January 2005 and 8 August 2007 (the day before the outbreak of the crisis), the three competing banks submitted *identical* bid-ask spreads for 1-month, 3month and 6-month USD/NOK FX swaps on more than 99% of the occasions.

Table 6: Harmonised USD/NOK FX swap bid-ask spreads 20.01.2005 – 08.08.2007

Bank combination	SEB+DNB	SEB+DDB	DNB+DDB	SEB+DNB+DDB
Total days	661	661	661	661
Same 1M USD/NOK FX swap bid-ask spread	656 (99.2%)	657 (99.4%)	654 (98.9%)	653 (98.8%)
Repetition of the same bid-ask spread	653 (98.8%)	653 (98.8%)	649 (98.2%)	647 (97.9%)
Same 3M USD/NOK FX swap bid-ask spread	657 (99.4%)	660 (99.8%)	658 (99.5%)	657 (99.4%)
Repetition of the same bid-ask spread	653 (98.8%)	659 (99.7%)	655 (99.1%)	653 (98.8%)
Same 6M USD/NOK FX swap bid-ask spread	655 (99.1%)	660 (99.8%)	656 (99.2%)	655 (99.1%)
Repetition of the same bid-ask spread	649 (98.2%)	659 (99.7%)	651 (98.5%)	649 (98.2%)

Sources: Bloomberg and author's calculations. Notes: The table first shows the number (and percentage) of trading days when two or all three banks have submitted exactly the same bid-ask spread, and then the number (and percentage) of trading days such behaviour has been repeated the following day.

As is well documented, the financial crisis caused substantial volatility, uncertainty and illiquidity in the FX swap markets. It would, therefore, be plausible to assume that pre-agreed spread matrices might become increasingly difficult to adhere to by market makers. However, as Table 7 demonstrates, SEB, DNB and DDB still managed to 'successfully' harmonise their bid-ask spread quotations in on 388, 389 and 465 out of 522 trading days in the 1-month, 3-month and 6-month markets respectively during the 2-year period starting 9 August 2007.

Table 7: Harmonised USD/NOK FX swap bid-ask spreads 09.08.2007 – 07.08.2009

Bank combination	SEB+DNB	SEB+DDB	DNB+DDB	SEB+DNB+DDB
Total days	522	522	522	522
Same 1M USD/NOK FX swap bid-ask spread	465 (89.1%)	389 (74.5%)	422 (80.8%)	388 (74.3%)
Repetition of the same bid-ask spread	457 (85.7%)	372 (71.3%)	402 (77.0%)	370 (70.9%)
Same 3M USD/NOK FX swap bid-ask spread	469 (89.8%)	390 (74.7%)	412 (78.9%)	389 (74.5%)
Repetition of the same bid-ask spread	465 (89.1%)	373 (71.5%)	390 (74.7%)	371 (71.1%)
Same 6M USD/NOK FX swap bid-ask spread	467 (89.5%)	469 (89.8%)	492 (94.3%)	465 (89.1%)
Repetition of the same bid-ask spread	461 (88.3%)	462 (88.5%)	483 (92.5%)	457 (87.5%)

Sources: Bloomberg and author's calculations. Notes: The table first shows the number (and percentage) of trading days when two or all three banks have submitted exactly the same bid-ask spread, and then the number (and percentage) of trading days such behaviour has been repeated the following day.

Since the aftermath of the financial crisis (from 10 August 2009 to 9 June 2016), however, the pattern has almost returned to pre-crisis levels (see Table 8).

Table 8: Harmonised USD/NOK FX swap bid-ask spreads 10.08.2009 – 09.06.2016

Bank combination	SEB+DNB	SEB+DDB	DNB+DDB	SEB+DNB+DDB
Total days	1,758	1,758	1,758	1,758
Same 1M USD/NOK FX swap bid-ask spread	1,753 (99.7%)	1,609 (91.5%)	1,614 (91.8%)	1,609 (91.5%)
Repetition of the same bid-ask spread	1,749 (99.5%)	1,600 (91.0%)	1,609 (91.5%)	1,600 (91.0%)
Same 3M USD/NOK FX swap bid-ask spread	1,754 (99.8%)	1,593 (90.6%)	1,596 (90.8%)	1,593 (90.6%)
Repetition of the same bid-ask spread	1,750 (99.5%)	1,585 (90.2%)	1,591 (90.5%)	1,585 (90.2%)
Same 6M USD/NOK FX swap bid-ask spread	1,745 (99.3%)	1,604 (91.2%)	1,616 (91.9%)	1,604 (91.2%)
Repetition of the same bid-ask spread	1,738 (98.9%)	1,595 (90.7%)	1,613 (91.8%)	1,595 (90.7%)

Sources: Bloomberg and author's calculations. Notes: The table first shows the number (and percentage) of trading days when two or all three banks have submitted exactly the same bid-ask spread, and then the number (and percentage) of trading days such behaviour has been repeated the following day.

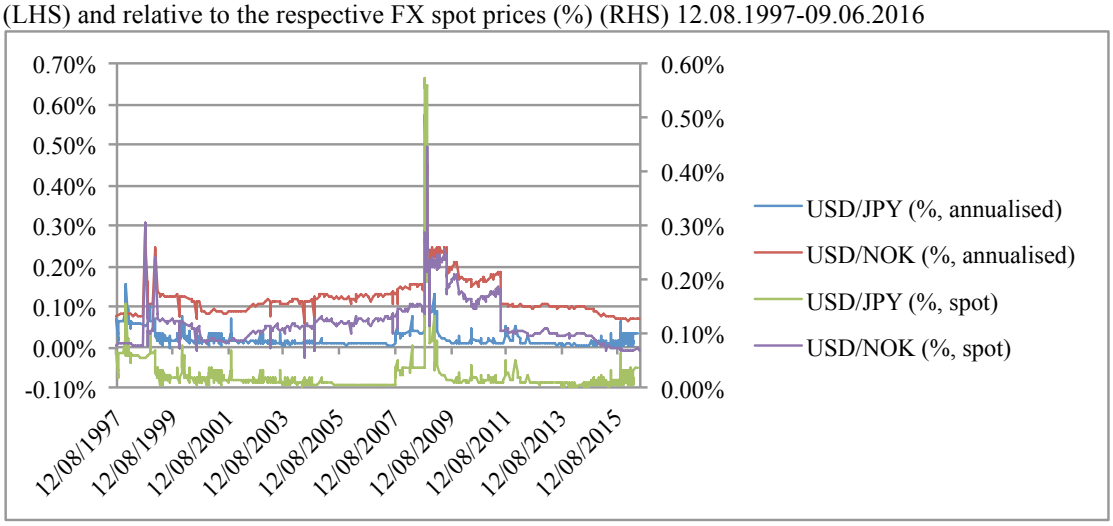
5 Discussion

5.1 A Competitive Market?

Before the manipulative and collusive practices in relation to LIBOR and FX were revealed, the FX spot market was widely perceived to be too competitive to be subject to market abusive behaviour. In fact, few markets (if any) were perceived as more competitive than the global FX markets – lending support to the logic that the bid-ask spread determination is a function of three types of costs (Bessembinder, 1994; Stoll, 1989). Following traditional market microstructure theory, large and competitive markets ought to drive bid-ask spreads towards zero when market liquidity is good and volatility low. The logic also works the other way round. Large, liquid and fairly stable markets could give indications of a competitive price determination process. Although it is beyond the scope (and purpose) of this paper to deconstruct the FX swap bid-ask spread in a similar fashion as has been conducted in the FX spot market, it is useful to highlight some long-term differences and similarities between the markets before analysing the empirical results presented in Section 4.

At the outset, the USD/JPY and USD/NOK FX swap markets present themselves as highly liquid markets. Figure 1, depicting the daily bid-ask spreads in the 3-month USD/JPY and USD/NOK FX swap markets, illustrates this.

Figure 1: 3-month USD/JPY and USD/NOK FX swap bid-ask spreads, annualised in terms of yield (%) (LHS) and relative to the respective FX spot prices (%) (RHS) 12.08.1997-09.06.2016



Sources: Bloomberg and author's calculations. Notes: The bid-ask spreads are calculated using end-of-day bid and ask quotes for USD/JPY and USD/NOK FX spot (composite) as well as 3-month USD/JPY and USD/NOK FX swap quotes (Tullett and DNB respectively). The FX swap bid-ask spreads are annualised in terms of yield following the covered interest rate parity (see Footnote 1).

Historically, the bid-ask spread in the 3-month USD/JPY FX swap market has been remarkably tight. Prior to August 2007, only extreme events such as the Japanese banking crisis, Y2K and 9/11 caused the spread to widen significantly. The impact of the financial crisis of 2007-08 was strong, though. As a percentage of the FX spot price, the spread quadrupled from 0.01% to around 0.04%, and the collapse of Lehman Brothers resulted in a temporary bid-ask spread of over 0.55%. Although the market quickly recovered in 2009, following extraordinary monetary policy measures by a range of central banks, the Eurozone sovereign debt crisis and policy measures linked to 'Abenomics' (leading to concern about the ability of banks to raise USD funding in the FX swap market) led to renewed uncertainty in 2011 and 2015 respectively. The development of the bid-ask spread in the smaller 3-month USD/NOK FX swap market has been rather different. Having previously been very tight, the currency turbulence in 1998 and the subsequent adoption of a floating exchange rate regime caused the spread to widen to around 0.10% of the spot price. The impact of the financial crisis of 2007-08 was substantial, yet the recovery process slower.

Naturally, there are several measures of liquidity, and the bid-ask spread is only one of them. For the FX market, however, it tends to be a good proxy (King, Osler and Rime, 2013). Seen from the perspective of the bid-ask spread, in the long run, both

FX swap markets present themselves as very liquid. Despite the differences, however, both FX swap markets seem to be similarly affected by stress, or perceived stress, in the financial system. To some degree, parallels can be drawn to the FX spot market, where bid-ask spreads have been found to widen because of higher inventory risk (Bassembinder 1994; Glassman 1987). However, as an FX swap involves an FX spot transaction with a simultaneous FX forward transaction in the opposite direction, contracts also contain elements of credit risk and funding liquidity risk (see, for instance, Brunnermeier and Pedersen, 2009; Baba and Packer, 2009). It could, therefore, be argued that the FX swap market, being more closely connected than the FX spot market to the unsecured money market, could be more affected by funding liquidity than market liquidity. As these not only tend to be time-varying but also closely connected, it might be difficult to draw conclusions from episodes of financial crises. For instance, surveys conducted among banks in the Eurozone during 2003-2015 suggest that the FX swap market has been perceived to be less efficient and liquid than the interest rate derivative market which is subject to minimal credit and funding liquidity risk (e.g. for overnight index swaps and forward rate agreements), but considerably more efficient and liquid the unsecured money market (ECB, 2016). In other words, although such risk is smaller than in the uncollateralised money market, a severe credit and/or liquidity crunch ought to widen the FX swap bid-ask spread for longer maturities, such as 3 months. The occasionally wide (crisis-related) spreads depicted in Figure 1 confirm this logic.

Both FX swap markets are comparable to their relative FX spot markets in terms of size. The wider spreads in the 3-month USD/NOK FX swap market seem consistent with the fact that despite being large, the market is substantially smaller than the world's second most traded currency pair. As can be seen from Table 9, BIS estimates that the *daily* turnover involving the Japanese yen swaps and forwards surpassed $600 billion in 2016, a four-fold increase in two decades. This helps to explain the immensely tight, and seemingly competitive, bid-ask spread. With a daily turnover of around $50 billion, the USD/NOK FX swap and forward markets are far behind, consistent with the notion that trading volume has a negative effect on the bid-ask spread in the long run (Hartmann, 1988).

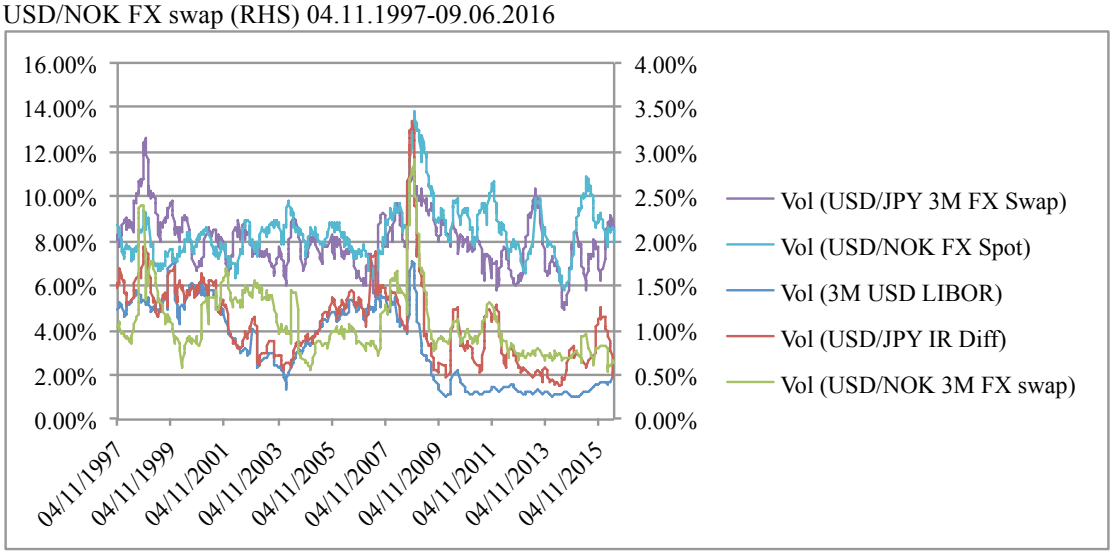
Table 9: Daily average turnover in the JPY and NOK FX markets (USD mio, April)

	1995	1998	2001	2004	2007	2010	2013	2016
JPY FX Spot	109,039	142,863	100,624	130,381	205,958	300,214	612,341	394,931
JPY FX Forwards	28,353	34,586	33,257	47,135	61,453	115,111	122,686	151,068
JPY FX Swaps	136,696	122,614	132,169	181,715	242,319	278,897	331,876	457,929
NOK FX Spot	N/A	N/A	2,605	4,741	12,326	12,335	21,395	29,022
NOK FX Forwards	N/A	N/A	1,187	2,543	6,498	6,153	10,096	8,320
NOK FX Swaps	N/A	N/A	13,909	18,430	48,140	31,602	42,913	43,849

Sources: BIS (1996, 1999, 2002, 2005, 2007, 2010, 2013, 2016).

FX price volatility has also been found to have a direct impact on the bid-ask spread. However, as FX swaps are premia or discounts quoted in pips, it is useful to compare the volatility of the FX spot price with the components that drive the premium or discount, following the covered interest rate parity. As an FX swap can be seen as the interest rate differential between two currencies expressed in FX pips, the 60-day historical volatility for the difference between the 3-month USD LIBOR and implied 3-month JPY and NOK interest rates from the FX market should serve as very close approximations.

Figure 2: Volatility of USD/JPY and USD/NOK FX Spot (LHS); 3-month USD LIBOR, USD/JPY and USD/NOK FX swap (RHS) 04.11.1997-09.06.2016



Sources: Bloomberg and author's calculations. Notes: the 60-day volatility is calculated using the 3-month USD LIBOR and end-of-day mid quotes for USD/JPY and USD/NOK FX spot (composite) as well as 3-month USD/JPY and USD/NOK FX swap quotes (Tullett and DNB respectively). The implied interest rate differential follows the covered interest rate parity (see Footnote 1).

As can be seen from Figure 2, the volatility of both 3-month FX swap currency pairs has been low, or even extremely low, since 1998: ranging between 0.5% and 3.5% and more comparable to that of 3-month USD LIBOR than their respective FX spot markets (which have ranged been 6% and 14% during the period). Again, notable exceptions are the Japanese banking crisis, the Norwegian currency turbulence in 1998 and the 2007-08 financial crisis.

In sum, both FX swap markets have been subject to considerably lower volatility their FX spot markets. Both markets are also as large, or larger than the respective FX spot markets. Finally, although the bid-ask spread in the USD/NOK FX swap market has been wider than in the USD/JPY FX swap market, Figure 1 suggests that both markets could be considered as very liquid (with tight bid-ask spreads even during times of volatility and crisis). Over the long-run both markets appear competitive and it would seem as if any attempts to engage in manipulative or collusive practices ought to, in theory, be unsuccessful.

5.2 An Anti-Competitive Market?

Despite being astonishingly large and liquid, however, the global FX market is remarkably concentrated within a relatively small group of very large banks. According to a survey conducted by Euromoney (2012), which captures client price taking activity only and not any interbank or interdealer broking volumes, the top 15 banks had a total market share of 87% in 2012. In the FX swap market, the top 10 banks had a total market share of 78%. Most currency pairs have experienced an increase in concentration during the last two decades. For instance, with regards to the FX turnover in Japan, the number of banks accounting for 75% of decreased from 19 in 1998 to just 8 in 2010 (BIS, 2010).

A considerable proportion of trading between banks takes place via interdealer brokers. The FX interdealer broker market is even more concentrated than the overall market, with a handful of dominant firms. Tullett Prebon, BGC, ICAP, GFI and Tradition collectively obtained 88.5% of the votes in the latest Risk Interdealer Ranking (Risk, 2015), which serves as a reflection of how banks view brokers in

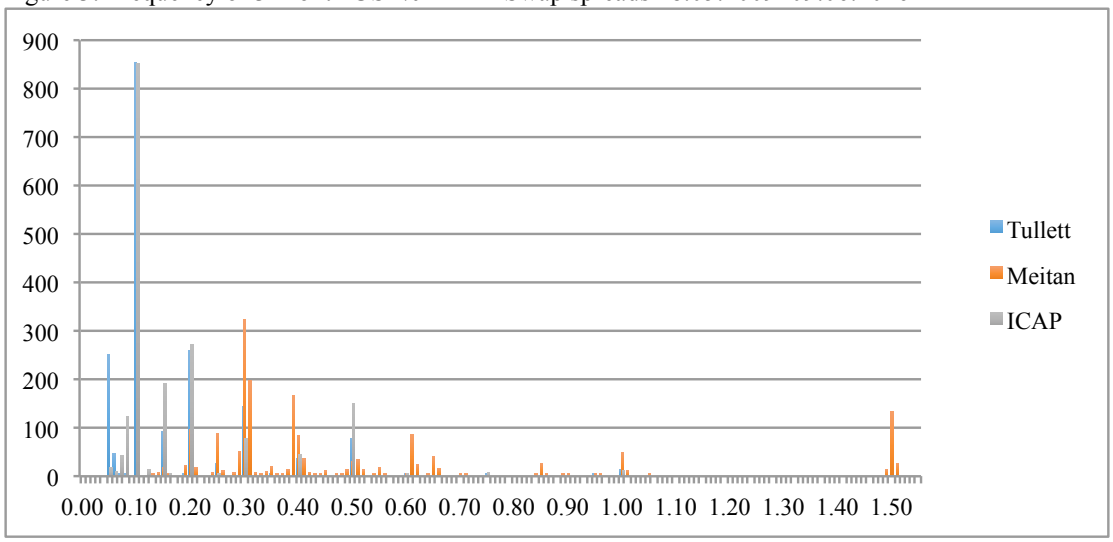
terms of overall quality of service. Although their individual volumes are not reported, the figure confirms anecdotal evidence that FX traders at banks typically speak to 3-5 of the major competing interdealer broker firms.[4]

The empirical results in Section 4 can be summarised as follows. A screening test for collusion in the 3-month USD/JPY and USD/NOK FX forward market (Table 1 and Table 2) do not suggest any suspicious activity. However, when looking at an individual *price component*, the FX swap bid-ask spread, the pattern is strikingly different. Table 3 and Table 4 show extreme clustering around the numbers 0 and 5 for the USD/JPY FX swap bid-ask spread and the number 0 for USD/NOK. Thus, the round number effect, which has been shown to exist in the FX spot market and other OTC markets, is also prevalent in the FX swap market.

Interestingly, however, for all three interdealer brokers studied, the change in the USD/JPY FX swap bid-ask spread tends to be *zero*, regardless of the change in the actual FX spot or FX swap price. In other words, the spread tends to be characterised by an extremely high degree of price clustering around a few numbers through a behavioural pattern that, between the two dominant interdealer brokers (ICAP and Tullett), is based on coordination and *repetition* of such coordination (see Table 5). Figure 3 shows the frequency of the individual USD/JPY 3-month FX swap bid-ask spreads during the same period. We can see that the two dominant interdealer brokers, Tullett and ICAP, consistently quoted more competitive bid-ask spreads than third-ranked Meitan. It also appears as if the individual broker quotes have clustered around spreads of 0.05, 0.1, 0.2, 0.3 and 0.5, rather than, say, 0.08, 0.13 or 0.7. Theoretically, such behavioural pattern is consistent with Ball *et al.* (1985) and could suggest that a form of bid-ask spread matrix has been used - which then has been 'recalibrated' over time.

[4] The survey is not designed to capture market share. Rather, the banks are supposed to 'base their decisions on a variety of criteria, including cost, liquidity provision, technology support and reliability' (Risk, 2015).

Figure 3: Frequency of 3-month USD/JPY FX Swap spreads 28.05.2009–09.06.2016



Sources: Bloomberg and author's calculations. Notes: The 3-month USD/JPY FX swap bid-ask spreads are calculated using end-of-day bid and ask quotes from Tullett, ICAP and Meitan. The number of observations is 5,441 (for the sake of clarity, 19 observations where the bid-ask spread is higher than 1.52 have been excluded).

This pattern is even more pronounced among the three banks in the USD/NOK FX swap market. As Tables 7-9 demonstrate: DNB, SEB and DDB have clearly harmonised their indicative 1-month, 3-month and 6-month USD/NOK FX swap bid-ask spreads throughout the period studied. Whereas the financial crisis of 2007-08 acted to break down the pattern to some degree, the coordination behaviour has since returned almost to pre-crisis levels.

Thus, even though the empirical results do not provide any evidence as to whether the USD/JPY and USD/NOK FX swap markets have been susceptible to collusion among interdealer brokers or banks, the patterns are nonetheless striking. The results are even more extreme than those detected by Abrantes-Metz, Judge and Villas-Boas (2011) using a similar methodology on the US dollar LIBOR, as well as the findings by Christie and Schultz (1994ab) on actively traded NASDAQ stocks. In the latter case, the authors found that odd-eight quotes were more or less non-existent among 70% of the stocks. Instead, individual stocks were quoted in increments of $¼ and $½ rather than, say, $3/8 or $5/8 - prompting the question as to whether a large number of market makers on NASDAQ tacitly colluded to maintain wide bid-ask spreads.

5.3 A Harmful Convention?

We have seen how screening methodologies, such as Benford's Law, can be useful tools in detecting potential price-fixing conspiracies in financial markets. However, although it has successfully been applied to LIBOR (Abrantes-Metz, Judge and Villas-Boas, 2011), it is questionable whether it is an appropriate methodology for markets involving uncollateralised borrowing and lending in any form. As Stiglitz and Greenwald (2003, p. 26) point out, 'interest rates are not like conventional prices and the capital market is not like an auction market'. Prices in markets involving uncollateralised borrowing and lending (such as Eurodollars and FX swaps) depend on judgements on creditworthiness and access to funding liquidity, which deviates from the anonymous nature of markets in the Arrow-Debreu model. Instead, prices (and consequently also bid-ask spreads) in these markets are highly dependent on the *relationships* between the counterparties involved. This has two important consequences.

First, given the role of banks in the first stage of the monetary transmission mechanism, prices involving borrowing and lending have a natural 'anchor': the official central bank rate. This, rather than any form of price conspiracy, explains the observation why the interest rate benchmarks tend to observe an extreme level of clustering and 'stickiness'. Therefore, unless there is a change in the projected central bank rate, or the assessments of credit and/or liquidity risk, prices submitted by competitors may remain stable and identical even in the absence of improper communication.

Second, given the requirement to continuously assess creditworthiness and funding liquidity, transparency in the form of tradable prices becomes difficult to obtain. This is particularly obvious with regards to LIBOR, where individually submitted quotes are not binding or tradable prices. Instead, banks are asked, without being able to see each other's quotes, to submit their rates according to the following criteria: 'At what rate could you borrow funds, were you to do so by asking for and then accepting interbank offers in a reasonable market size just prior to 11 am?' (IBA, 2014, p. 12). Therefore, LIBOR (but also its equivalents elsewhere) can be seen as benchmarks for where the selected panel banks *argue* prices in the money market are.

Prices in the FX swap market cannot directly be compared to LIBOR, which is an interest rate *benchmark*. However, there are important similarities. Although electronic trading has become standard in the FX spot market, market-making banks do not continuously supply the market with firm and tradable two-way prices in FX swaps. Consequently, banks and end-users remain overwhelmingly reliant on *indicative* quotes for price discovery and valuation. Indicative prices from Bloomberg or Reuters might, naturally, over- or understate the magnitude of the actual bid-ask spread at any moment in time. However, they should serve as a good approximation because of the reputational damage caused by repeatedly submitting prices deviating from the actual market price (Bollerslev and Melvin, 1994; Cheung and Wong, 2000). A similar approach could be taken with regards to interdealer broker quotes. If the broker spread were to be too wide, banks would turn to competing brokers for price discovery and possibly future business. With reference to the empirical results in Section 4, this logic could, of course, be applied to explain to continuing dominance of Tullett and ICAP in the USD/JPY FX swap market. If the indicative spread were to be unreasonably narrow, however, banks would be disappointed when placing firm buy or sell orders. Therefore, an indicative interdealer broker bid-ask spread matrix ought to serve as a 'best guess' of what brokers *perceive* banks would expect as a reasonable bid-ask spread for various maturities - in other words, which bid-ask spreads banks expect of other banks. It could be argued that interdealer brokers should have nothing to gain from colluding to set bid-ask spreads, as their business model is based on matching buyers and sellers in the interbank market. However, given the large market shares held by only a few firms, antitrust authorities could equally argue that competition more widely could be harmed should two or more interdealer brokers decide to harmonise their behaviour towards banks. This mirrors the concern raised by the UK Competition and Markets Authority in June 2016 with regards to oil products, following the announcement of a planned merger between the rivals Tullett Prebon and ICAP (Stafford, 2016). In sum, then, indicative (i.e. non-tradable) prices, benchmarks and bid-ask spreads remain, and are likely to remain, paramount in the price discovery process for FX and interest rate instruments for banks and end-users alike. At the same time, however, screening methodologies are likely to find evidence of a high likelihood of communication or signalling between firms that ought to compete with each other.

The empirical results in Section 4, both with regards to USD/JPY and USD/NOK FX swaps, also seem to challenge traditional market microstructure theory, where market makers are assumed to quote two-way prices *competitively* following the original Bertrand analysis. Instead, they seem consistent with survey-based research conducted by Cheung and Wong (2000) and Cheung and Chinn (2001). Having found that a majority of FX dealers rely on 'market conventions' rather than 'costs' when determining bid-ask spreads, the overriding reason for following the prevailing convention appears to have been to maintain an 'equitable and reciprocal trading relationship' (60.2% among Tokyo-based banks), 'firm policy' (12.5%) and 'market image' (14.8%). Interestingly, only 5.7% of the FX dealers in Tokyo cited 'trading profits' as being the main reason for following the market convention. The responses in the other financial centres were fairly similar. Thus, it appears as if market makers feel, and continue to feel, a long-term 'sense of duty' towards the bank and its competitors with regards to the liquidity provision. The bid-ask spread is key to this mechanism and is, *in practice*, seen as a social norm or market convention, rather than a function of a hypothetical mid-price and various costs in a competitive environment. Hence, the determination of the FX swap bid-ask spread in practice seems more consistent with the theoretical approach offered by Post-Keynesians (Carvalho, 1983-1984; Harvey, 2009; Lawson, 1985).

Even if banks or brokers do not *explicitly* communicate, a form of signalling automatically takes place through the submission of indicative prices such as LIBOR or bid-ask spreads in the FX swap market. Seen from this perspective, the process depicted in Tables 5-8 in Section 4 is more akin to a type of Keynesian Beauty Contest modelled by Stenfors (2014b) on the LIBOR fixing mechanism. Deviations of prices (or bid-ask spreads) from what could be regarded as their 'fundamental value' (the competitively determined equilibrium bid-ask spread) can be long lasting and also be surprisingly sticky as market participants incorporate the reputational effects of deviating from a particular financial market convention or social norm. This suggests that bid-ask spreads in the FX swap market might develop following some kind of convention, rather than overwhelmingly being a function of various costs. Spread clustering can be commonplace and persistent even in seemingly large, liquid and competitive markets. Only extremely sharp market movements seem to cause the

conventions to break down. Even then, however, market makers gravitate towards a coordinated behaviour around a new spread: a new convention or norm. This, for instance, clearly appears to have been the case in the USD/NOK FX swap market during the turbulent years of 2007-08.

As Harvey (2006, p. 781) points out, 'individuals may participate in social norms in part because of an expectation that others will also participate'. This follows the definition by McAdams (1997) of a social norm as 'informal social regularities that individuals feel obligated to follow because of an internalised sense of duty, because of a fear of external nonlegal sanctions, or both'. The antitrust aspect comes into play when the social norm that benefits a few has an anticompetitive effect, and when communication between its participants enforces it. Empirically, the FX swap bid-ask spread determination process in this paper clearly contains *symptoms* of such anti-competitive behaviour. The crucial question, however, is whether indicative quotes by banks and/or interdealer brokers in any way might benefit some and have harmful effects on others.

The articles by Christie and Schultz (1994ab) on NASDAQ stocks prompted a regulatory investigation and ultimately resulted in significant financial settlements. New rules requiring the display of customer limit orders were imposed, and previous rules governing the publication of quotations were amended in order to enhance pricing efficiency and competition (SEC, 1996). Transcripts from the investigations reveal that market makers generally treated the convention as a 'pricing "ethic," "tradition," or "professional norm" that other market makers were expected to follow' (US Securities and Exchange Commission, 1996, p. 17). Some market makers testified that they had been trained by senior staff to follow this convention. Moreover, a failure to comply with the convention sometimes led to harassment or refusal to trade by other market makers. However, although the behaviour was seen as consistent with that of collusion, the outcome of the investigations by the Securities and Exchange Commission and the Department of Justice was not to refer to the convention as 'an express agreement reached among all of the market makers in a smoke-filled room'. Instead, the process generating the bid-ask spreads was seen as a convention that 'had anticompetitive consequences and was harmful to the interests of investors' (ibid, p. 3). More recently, the European Commission (2014) fined a

handful of market makers for agreeing 'to quote to all third parties wider, fixed bid-ask spreads on certain categories of short-term over-the-counter Swiss franc interest rate derivatives, whilst maintaining narrower spreads for trades amongst themselves'. The behaviour between RBS, UBS, JP Morgan and Crédit Suisse was classified as a cartel and Joaquín Almunia, Commission Vice-President in charge of competition policy, argued that '[…] the four banks agreed on an element of the price of certain financial derivatives. […] Cartels in the financial sector, whatever form they take, will not be tolerated'.

Hence, the bid-ask spread is considered a 'price component' or 'an element of a price' under competition law. By regarding it as such, the spread can be seen as, say, a computer keyboard. Price-fixing of computers is illegal, and so is price-fixing of computer components such as keyboards. Whereas the market makers in the European Commission case decided to quote narrower bid-ask spreads to each other than to others, the creating of such a 'two-tier' market is not a prerequisite for it to be considered as price fixing conspiracy. Neither is it necessary for the behaviour to follow a *formal* agreement agreed upon in person, in writing, over the phone or via an electronic chat room.

It is, of course, extremely difficult to assess what the prevailing 'fair' bid-ask spread should be for every instrument related to interest rates or FX at every moment in time. Different market makers use different methodologies, make different assessments and ultimately quote different prices and spreads. However, if they stand in competition with each other, market makers should not collude to agree upon a pre-defined bid-ask spread. The spread, or the 'price component', should be determined competitively. Although the rule seems clear and similar in the two different cases above, the question is how and whether it is applicable to the hitherto largely unregulated FX market. According to the Fair and Effective Markets Review (FEMR, 2015, p. 98), the message is clear: a new regulatory requirement is that 'no distinction is made between wholesale and retail markets, or between fixed income, currency and commodity (FICC) and non-FICC markets' with regards to UK and EU competition law. The report specifically stresses that it 'also applies to financial markets, including FX spot, which may currently fall outside of the direct scope of financial market regulation'.

Indeed, a class action has been filed in the US (New York Southern District Court, 2015), where the claimants (end-users in the FX market) allege that the defendants (banks) have conspired to fix bid-ask spreads for various currency pairs in the FX spot market. Such collusive practises, it is argued, have acted to deprive end-users of active price competition, resulting in higher prices. Moreover, given that FX spot prices often are used as *components* in a range of other FX instruments, clients having entered into for instance FX forward or FX futures contracts would also have been harmed. In the OTC markets, different categories of market participants may face different bid-ask spreads (Duffie, Gârleanu and Pedersen, 2005; Harris and Piwowar; 2006; Green, Hollifield and Schürhoff, 2007). Thus, key elements of the alleged conspiracy above are the anti-competitive processes and the usage of market power among the market-making banks in the FX spot market.

Paradoxically, however, the assumption (or, indeed, the regulatory requirement) that the bid-ask spread ought to be determined competitively in FICC markets at all times seems at odds with the guidelines published by the ACI (The Financial Markets Association), which since 1955 has acted as the trade organisation for banks and central bank dealers in the FX and money markets around the world. The latest version of the ACI (2015, p. 103-104) Model Code, published in February 2015, states that 'bilateral reciprocal dealing relationships are common in the OTC markets and often extend to unwritten understandings between Dealers to quote firm two-way dealing prices'. Further, the Model Code states that such informal reciprocal dealing relationships are to be 'encouraged' and are 'a logical development in the OTC markets and play an important role in providing support and liquidity'. Hence, the trade organisation sees conventions, such as informal agreements regarding bid-ask spreads, as natural, logical and something that should be encouraged to maintain to maintain trust, reciprocality and liquidity in the marketplace. This approach is fundamentally different from the exchange-traded securities market and particularly relevant for OTC instruments that involve credit and/or liquidity risk. Problematically, the logic not only seems to *encourage* mutual understandings between competitors, it also seems to *contradict* the recent regulatory reform proposals and compliance changes aimed at radically restricting the ability of traders to communicate with each other.

To illustrate this contradiction, and the relevance of indicative quotes, it is useful to refer to Stenfors' (2014a) discovery how an *informal* rule change to the Norwegian Interbank Offered Rate (NIBOR) by six panel banks in 2008 not only came to change the decomposition of the benchmark but also increase the susceptibility of the benchmark to manipulation. Individual NIBOR quotes had traditionally been submitted following the covered interest rate parity, in other words using an implied NOK money market rate derived from the USD LIBOR and USD/NOK FX swaps. However, the NIBOR panel banks chose to change the convention of using the USD LIBOR (which was no longer perceived to reflect the actual USD funding cost of the banks) to *indicative interdealer broker quotes*. The impact of the rule change on NIBOR was substantial and thus harmful to a certain group of end-users. Although the governance structure of NIBOR has radically changed in the aftermath of the manipulation scandals (the regulation has moved from the panel banks themselves to Oslo Børs and Finans Norge), the submission methodology remains unchanged (Tafjord, 2015). An *indicative* interdealer broker screen is used for the USD money market rate, and individual *indicative* USD/NOK FX swap prices are then used to derive an implied NOK money market rate (which becomes NIBOR). Moreover, as Stenfors (2014a, p. 455) points out, 'a tighter bid-offer spread used for the USD/NOK FX swaps in the fixing mechanism would, *ceteris paribus*, result in a lower NIBOR. Measured in terms of basis points, the bid-offer spread is wider for shorter maturities, implying greater scope for deception for these maturities'. In other words, the choice of the *indicative* bid-ask spread matters greatly for the NIBOR fixing, which in turn determines the value of a range of derivatives instruments and other financial contracts.

A calculation exercise aiming to determine the harmful impact of collusive bid-ask spread matrices in the FX swap market is beyond the scope of this paper. However, even though the average maturity is short (around three-quarters of the turnover consists of trades of less than one week), and the bid-ask spreads tight for major currency pairs, the impact of the sheer scale of the market can hardly be overestimated. With a daily turnover of more than $3 trillion in the directly affected FX swap and FX forward markets, a 'recalibration' of just one basis point would result in increased gains (for market makers) or losses (for end-users) amounting to

billions of US dollars per year. Such recalibrations by market-making banks would, as the analysis shows, not necessarily be purely be determined by competitive processes, but also by the submitted bid-ask spreads as *indicated* by competing firms.

In sum, the determination of bid-ask spreads in interest rate and FX swap markets tend to follow conventions. These conventions also include the usage of indicative prices and spreads from banks and interdealer brokers, which are central to the price discovery process and often serve as inputs for other benchmarks (or even become benchmarks themselves) in the absence of transaction data. Problematically, however, conventions in interest rate and FX swap markets fall back on trust and reciprocality – which is difficult to obtain without human communication.

6 Concluding Remarks

This paper has investigated the drivers behind bid-ask spreads in the USD/JPY and USD/NOK FX swap markets. At the outset and over the long-run, the markets appear to be sufficiently large, stable and liquid, giving the impression that the bid-ask spread ought to be competitively determined – in line with traditional market microstructure theory. The empirical results from a screening methodology based upon Benford's Law, on the other hand, suggest that the bid-ask spread determination is characterised by fundamentally anti-competitive processes. As Stenfors and Lindo (2016) demonstrate, the large turnover (and tight bid-ask spreads) in the LIBOR-indexed derivatives market played an important role in sustaining an 'illusion' that the underlying benchmark reflected a large, liquid and competitive Eurodollar market. The LIBOR came to appear as an objective and competitively determined price, which served to delay the discovery that it always had been susceptible to manipulation. Although there are fundamental differences between the FX swap market and LIBOR, there are also important similarities. Both are dominated by the activities of a homogenous group of players (large and global banks), and both have until recently largely managed to escape regulatory scrutiny. Both are also inherently linked to the money market and the unique interconnectedness of the banking system. Banks act as market makers of FX swaps, but can only provide liquidity as long as they are confident that other banks will also continue to do so. Theoretically,

therefore, it seems like the classification between competitive and anti-competitive bid-ask spreads in markets related to borrowing and lending, including FX swaps, might be too narrowly formulated. Crucially, it fails to capture the importance of *conventions*.

A key response by regulators and policy makers in light of the recent findings of widespread misconduct in the largely unregulated OTC markets has been to seek to establish some kind of 'correctness' in how important financial benchmarks are generated. The first set of reforms, or reform proposals, have been aimed at achieving greater 'formalisation and professionalism' (IBA, 2014, p. 3). For instance, the regulation and supervision of LIBOR have shifted from the LIBOR-panel banks themselves and the British Bankers Association to the UK Financial Conduct Authority. LIBOR-manipulation has been made a criminal offence, and a specific Code of Conduct ('the LIBOR Code') sets out practice standards that LIBOR panel banks are expected to follow. These changes follow a string of fines imposed on banks that have been found having manipulated, or attempted to manipulate, the benchmark. All in all, these set of measures strive to eliminate, or at least greatly reduce, the incentives of benchmark-manipulation. The second set of reforms has been aimed at making benchmarks more 'market-like'. For instance, the window for calculating the WM/Reuters 4 pm London Closing Spot Rate, a widely used FX benchmark, has been widened from 1 to 5 minutes to include more trade and order data (FEMR, 2015). Although many interest rate benchmarks, such as LIBOR, are not based upon actual transactions, such data shall be used 'if available and appropriate' (European Council, 2105, p. 79). However, acknowledging that the underlying market might, at times, be illiquid or even non-existent, provisions have been made allowing LIBOR-banks to use their 'expert judgement' when submitting quotes during periods of 'market turmoil and inactivity when inter-bank offers are absent' (IBA, 2014, p. 12).

The reaction by the banks themselves is echoed by a statement by UBS Chairman Weber and CEO Ermotti from May 2015 (in reaction to the bank being fined by regulators for its involvement in the FX manipulation scandal): 'The conduct of a small number of employees was unacceptable and we have taken appropriate disciplinary actions. We made significant investments to strengthen our control

framework and compliance programs. We self-detected this matter and reported it to the US Department of Justice and other authorities. Our actions demonstrate our determination to pursue a policy of zero tolerance for misconduct and a desire to promote the right culture in our industry' (Business Wire, 2015). Following the revelations of widespread manipulative and collusive practices, banks have imposed firmer Chinese Walls on their trading floors (particularly with regards to the benchmark submission process) and substantially increased the number of compliance officers to monitor traders' activities. Numerous dealing room conventions have been banned or become subject to strict internal oversight (such as the usage of mobile phones and multi-bank electronic chat rooms) with the intent to limit the possibilities of improper communication between traders and their competitors, interdealer brokers and clients (see, for instance, Verlaine and Finch, 2014; Martin and Stafford, 2015; Finch, Detrixhe and Choudhury, 2016). Thus, an underlying assumption is that traders in these markets often have had the means, opportunities and incentives to act anti-competitively. By eliminating, reducing and monitoring various forms of communication, end-users in the market can be reassured that prices are determined competitively.

Thus, the findings in this paper illustrate a challenge in light of recent changes in regulation and compliance aimed at eliminating, reducing or monitoring communication between traders at banks that ought to compete with each other. What banks and central banks could interpret as logical and necessary conventions to maintain market liquidity; lawyers, regulators and antitrust authorities might regard as collusive practices to extract rents – ultimately having harmful effects on end-users in the global FX market.

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