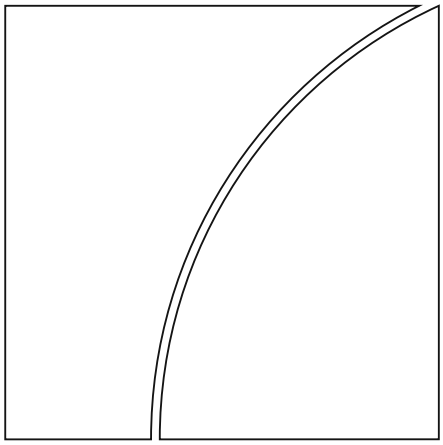
Markets Committee



# Monitoring of fast-paced electronic markets

Report submitted by a Study Group established by the Markets Committee

The Group was chaired by Imène Rahmouni-Rousseau (Bank of France) and Rohan Churm (Bank of England)

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# Preface

Foreign exchange and other fast-paced electronic markets (FPMs) have undergone significant structural changes in recent years. Trading has become increasingly electronic and automated, the use of machine learning is nascent but growing, incumbents are responding to the emergence of new participants, and activity has migrated across a range of trading venues. At the same time, the availability of data for market monitoring has increased substantially.

To explore how these developments affect central bank approaches to market monitoring, in September 2017, the Markets Committee established a Study Group chaired by Imène Rahmouni-Rousseau (Bank of France) and Rohan Churm (Bank of England).

This report presents the Group's findings. Among other sources, it is based on information from structured interviews with market participants, a Markets Committee workshop in January 2018, and a survey of central banks' current and planned initiatives in market monitoring. The report highlights key recent developments in market structure, includes statistics on notable trends, and outlines the priorities and approaches of central banks in undertaking near-time and medium-term market monitoring.

This study is of core relevance to central banking and I believe it could become a key reference on the impact of technology in financial markets. Together with the Markets Committee's recent report on Market intelligence gathering at central banks, it also provides unique insights into central banks' market-monitoring activities.

Jacqueline Loh

Chair, Markets Committee
Deputy Managing Director, Monetary Authority of Singapore

# Executive summary

Foreign exchange and other fast-paced electronic markets (FPMs) have undergone a wide range of structural changes in recent years. Trading has become increasingly electronic and automated, new participants have emerged, incumbents have evolved and responded, and activity has migrated across a multitude of trading venues. This evolution in market structure has implications for central banks' approaches to market monitoring, including the range of participants with which they engage, the types of data they collect, and the tools and technologies they utilise.

Market monitoring is a core component of central banks' mandates. Many are active participants in FPMs, either for monetary policy implementation or for reserves management purposes. As a result, being able to understand market developments and obtain an accurate view of market conditions is of paramount importance. And even for central banks not actively participating in these markets, the significant pace of change in recent years underlines their importance for financial stability mandates. Recent episodes of market dysfunction, such as the sterling flash event of 7 October 2016 and the flash rally in US Treasuries on 15 October 2014, as well as similar events in other markets, highlight the importance of close monitoring and timely analysis of underlying drivers.

To enhance central banks' capacity to monitor FPMs, particularly the foreign exchange (FX) market, the Markets Committee (MC) created a study group to explore aspects of structural change that have immediate relevance for monitoring approaches by central banks. This report provides a summary of this work.

The report identifies three key structural trends that have intensified in recent years, affecting approaches to market monitoring:

1. **Technological advances have changed the nature and location of trading** across a range of FPMs. In spot FX, the share of trading volume executed electronically has almost doubled over the last decade. One result is that trading activity is increasingly fragmented across a range of new venues, while the proportion of trading on so-called primary venues with transparent central limit order books has dwindled over time. Another is that the frequency of activity and speed of information flows in FX markets has increased drastically.

2. **As technology has changed, so too has the nature of participation** in FPMs. The business models of traditional bank intermediaries have come under increasing pressure. On the one hand, liquidity provision has become more concentrated among the largest banks, which reap the benefits of a large electronic network of client relationships to internalise a large part of their customer flows. Many other banks, however, have found it hard to compete and have resorted to an agency model of market-making or have exited the business altogether. The amount of risk-bearing capacity that traditional intermediaries bring to the market has arguably declined.

   At the same time, a new set of non-bank intermediaries, most notably principal trading firms (PTFs), has gained a stronger footing. In recent years, a number of PTFs have moved from high-speed trading on an anonymous basis (eg for so-called latency arbitrage) to the direct, disclosed provision of liquidity to a network of clients. How much additional risk-bearing capacity these firms bring to the market and how their trading affects overall market quality remains subject to debate.

3. **Greater electronification has led to the creation and commoditisation of large quantities of high-frequency data**. This can raise costs and erect barriers to entry. But it has also opened up a range of opportunities for market participants. Liquidity providers can rely on a wider range of inputs to build a quoted price for clients, and end-users can utilise new data to benchmark and improve the quality of their trade execution. The use of artificial intelligence and machine learning in trading algorithms, while nascent, also has the potential to introduce new market dynamics and increase complexity.

Against this backdrop, market participants in both the public and private sector have undergone a significant process of evolution with regard to their market-monitoring capacities. In many cases, this has involved significant investment in data, tools and analytical capabilities. For example, end-users are increasingly monitoring a wider range of trading venues (sometimes using aggregators), trading and interacting with new counterparties, and developing new approaches to collecting, storing and analysing market data.

Central banks have made significant efforts to adapt their monitoring approaches to these changes. Monitoring needs naturally vary according to central banks' mandates and the degree of electronification of the relevant markets. Their monitoring requirements will also naturally differ from those of the private sector, given that central banks have different needs and responsibilities. The monitoring activities of central banks can be broadly categorised according to their time frames:

1. **Near-time monitoring** of market conditions and market drivers supports core central bank functions such as policy implementation. Near-time monitoring of market impact and transaction costs, in turn, also supports the foreign exchange reserves management functions of central banks.
2. **Medium-term monitoring** of structural trends in FPMs and ex post event analysis supports financial stability monitoring functions of central banks, as well as broader market intelligence. While monitoring structural trends is crucial in identifying financial market vulnerabilities, event-driven analysis is designed to gain a deep understanding of episodes of severe market dysfunction so as to minimise the chances of their recurrence.

To fulfil these core functions, the overall trend among central banks has been towards greater usage of high-frequency, transaction-level data, in particular for the monitoring of market conditions in near time or to aid the analysis of specific events. Central banks with a mandate to trade in FPMs have also acted to maximise the quality of their trade execution, including through an increased use of transaction cost analysis (TCA) tools. As market structure continues to evolve further, central banks stand ready to continue adapting their approaches to market monitoring as necessary to fulfil their individual mandates.

# 1. Introduction

Foreign exchange (FX) and other fast-paced electronic markets (FPMs) have undergone a wide range of structural changes in recent years. Trading has become increasingly electronic and automated, new participants have emerged, incumbents have evolved and responded, and activity has migrated across a multitude of new trading venues. These developments have come in response to a combination of new technology, regulation and end-user demand.

As market structure evolves, central banks are adapting their monitoring approaches, especially for markets that are central to the fulfilment of their policy mandates, such as FX.[1] To enhance central banks' capacity to monitor FPMs, the Markets Committee (MC) launched a study group at its September 2017 meeting to explore the aspects of structural change that are of immediate relevance for central banks' monitoring. This report provides a summary of the study group's work. While broader issues around the impact of technological change on market quality and functioning are touched upon where relevant, they are only examined insofar as they help explain why and how central banks' monitoring approaches are adapting to this new environment.

The structure of this report is as follows. Section 2 provides a definition of FPMs and motivates efforts on behalf of central banks to closely monitor these markets. Section 3 identifies core market structure themes (eg technological advancements, new participants and changing intermediation patterns) that may have implications for market monitoring. Section 4 discusses how market participants, including central banks, have adjusted to these changes. And Section 5 outlines some of the core components (in terms of data, tools and analytics) of effective FPM monitoring.

# 2. Definition, scope and motivation

This section briefly provides a definition of FPMs, before turning to a discussion of why monitoring of these markets is of importance to central banks. It also distinguishes between two broad types of monitoring activity according to their time frames and provides some brief background on how such activities are typically organised within central banks.

## 2.1 What are fast-paced electronic markets?

For the purposes of this report, fast-paced electronic markets are broadly defined as markets where the price discovery process predominantly occurs via electronic means and which are characterised by a sizeable penetration of high-speed, algorithmically driven order placements.

[1] FX represents the OTC market with the largest penetration of electronic and automated trading (BIS (2016b, p 9)). Historically, technological developments in FX markets have often been adopted in other key OTC markets after certain time lags. And while largely exchange-traded markets such as equities and futures have also undergone significant structural change, FX (and fixed income) markets remain uniquely important for central banks given their close links to central banks' mandates.

Examples include spot FX in liquid currency pairs, most futures and equity markets and some government bond markets. This report focuses primarily on developments in spot FX, given its central importance for central banks' mandates and the extent of technological change in FX markets in recent years. Developments in fixed income markets (in particular cash sovereign bonds and government bond futures) are also covered to the extent that they shed light on FX market themes.[2]

## 2.2 Why do central banks monitor fast-paced electronic markets?

Market monitoring serves as an important input for many core central bank functions. Many central banks are active participants in FPMs, either for monetary policy implementation or for reserves management. As a result, being able to understand market developments and obtain an accurate view of market conditions is of paramount importance. And even for central banks not actively participating in these markets, the significant pace of change in recent years underlines the importance of monitoring FPMs, since market fragility arising from the erosion of liquidity could undermine financial stability. Recent episodes of market dysfunction, such as the sterling flash event of 7 October 2016 and the flash rally in US Treasuries on 15 October 2014, as well as similar events in other markets, highlight the importance of timely and in-depth market monitoring.

Based on their typical time frames, this report distinguishes **two main forms of market monitoring:**

1. The first concerns market monitoring conducted in or close to real time, typically as a continuous process with an intraday or end-of-day/next-day horizon. For the purposes of this report, such types of monitoring activities are collectively referred to as ***near-time monitoring***.

   When monitoring FPMs in near time, the most important objectives are to gain a better understanding of current market liquidity and market functioning conditions, and to identify key market drivers. Where central banks are transacting in FPMs, near-time monitoring is also an important input into high-quality trade execution.[3]

2. The second set of monitoring activities is focused on analysing structural changes in financial markets or on conducting ex post event analysis, and is referred to *as* ***medium-term monitoring*****.** It serves as an important ingredient not only for policy implementation decisions, but also for the assessment of financial system vulnerabilities.

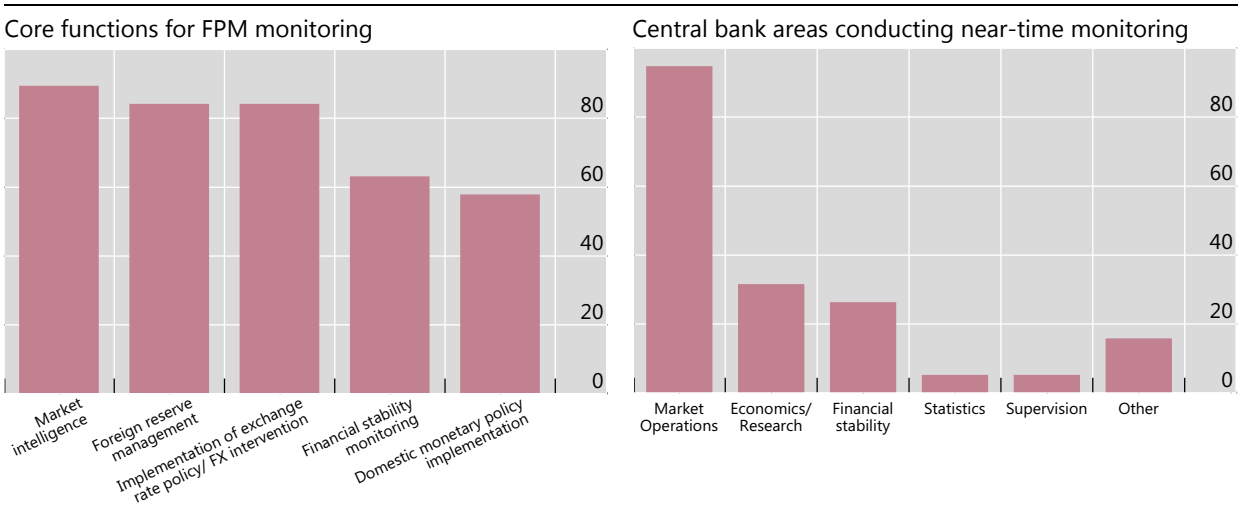
According to a survey of central banks conducted by the Study Group, FPMs are monitored to support a wide array of core functions, including market intelligence gathering to support monetary policy formulation and execution, foreign exchange

[2] See BIS (2016a) for a detailed discussion of the electronification of fixed income markets and the impact on market quality.

[3] When monitoring FPMs in near time, central banks with managed FX regimes or active quantitative easing (QE) programmes often prioritise operational objectives alongside market-monitoring objectives. Specifically, these central banks tend to prioritise identifying appropriate instances to enter the market, including seeking best execution.

Why do central banks monitor fast-paced electronic markets?

In per cent of respondents Graph 1




Source: Markets Committee FPM Study Group Survey.

reserves management and implementation of exchange rate policy (Graph 1, left-hand panel).[4] Domestic monetary policy and financial stability are also common core mandates that rely on monitoring FPMs, particularly as financial markets continue to trend in the direction of greater electronification.

Monitoring needs naturally vary according to central banks' mandates and the degree of electronification of the relevant markets in which central banks operate. Central banks' monitoring requirements will also naturally differ from those of the private sector given their different needs and responsibilities. Central banks generally place more emphasis on the analysis of market conditions and structural changes, consistent with policy objectives, such as market monitoring to support policy implementation and financial stability monitoring.

In terms of organisation, it is common for central banks to carry out FPM monitoring efforts within their market operations functions (Graph 1, right-hand panel). This may largely reflect the fact that market monitoring often serves as a key input for trading decisions, for the purposes of either policy implementation or reserves management. Some central banks also conduct additional FPM monitoring in other areas such as economics, research, and financial stability.

## 3. Structural developments in financial markets

This section explores structural changes in FX and other fast-paced electronic markets and their implications for market monitoring (both by the public and private sector). It is split into three subsections, covering the implications of new technologies, the migration of trading activity, and the advent of new participants.

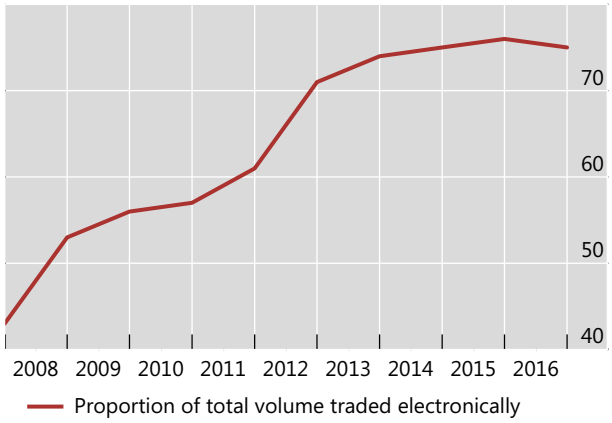
[4] The results presented in Graph 1 draw on the Study's Group's survey of 19 central banks. The survey explored the objectives, structures and tools used to monitor developments in FPMs.

Electronification of foreign exchange markets

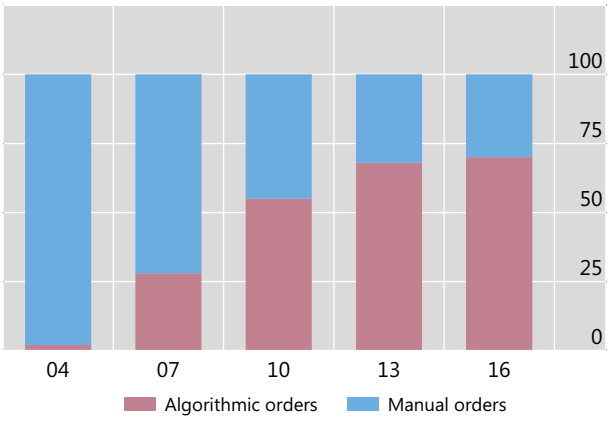
In per cent

Graph 2

Shares of 2016 spot FX turnover executed electronically




Share of algorithmic activity in spot FX on EBS




Sources: BIS Triennial Central Bank Survey; EBS; Greenwich Associates.

## 3.1 Technological developments

Technological advances that have changed the face of trading across a range of financial markets include greater processing power, lower storage costs and the ability to transfer data almost instantly. These changes have enabled participants to respond to developments in near-real time and have opened the door to deeper analysis, significant efficiency gains and new business models. The cost of trading, as measured by bid-ask spreads, has fallen notably, as a result.[5]

In spot FX, end-users can now access liquidity via a range of electronic platforms and participation is increasingly automated (see Annex A for a schematic of market structure). Survey data suggest that, since 2013, over 70% of spot trading is executed electronically (Graph 2, left-hand panel), while an estimated 70% of orders on EBS, a primary central limit order book (CLOB) and a major inter-dealer platform for spot FX, are now submitted by algorithms, rather than manually (Graph 2, right-hand panel). Some other OTC markets have undergone a similar transformation, including US Treasuries where the reliance on traditional voice trading has also diminished over time.

The speed at which new market data are becoming available has also increased. For instance, the frequency of pricing updates on the EBS platform was raised from every 100 milliseconds (ms) to every 20ms in September 2016, and further to every 5ms for select participants in February 2017 (Graph 3, left-hand panel).[6] Other platforms such as Reuters Matching also increased the frequency of their updates. The rise in the frequency of data feed updates on primary venues for spot FX had immediate spillovers to the wider set of trading venues and instruments, such as quoting activity for Chicago

[5] See, for example, Ding and Hiltrop (2010) and Rime and Schrimpf (2013). Note, however, that the structural changes discussed in this report have reduced the informative value of traditional indicators of transaction costs, such as top-of-book bid-ask spreads. See Section 5 and the monitoring showcase in Annex B for detailed information on more sophisticated metrics.

[6] The 5ms EBS Ultra data feed has been made available to EBS clients fulfilling certain criteria regarding liquidity provision and at an additional cost.

Mercantile Exchange (CME) currency futures which tends to track that of the pulse for spot FX quotes in some currencies on EBS (Graph 3, right-hand panel).[7]

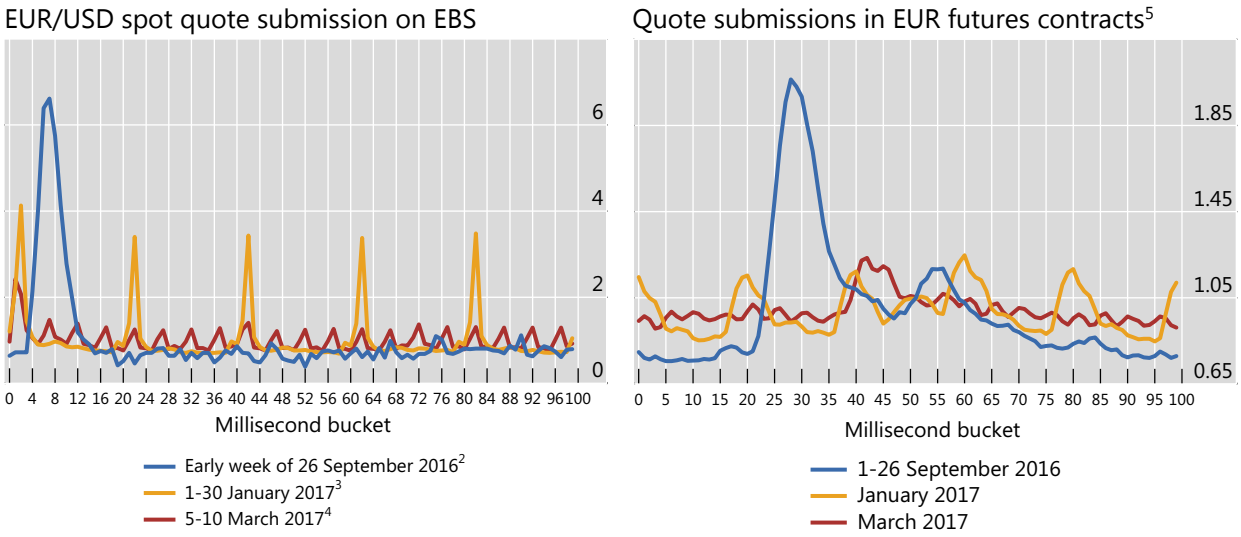
Participants looking to keep up with the pace of change often invest considerably to maintain market access and to enhance their monitoring, execution and risk management capabilities. The following three developments have created some of the biggest challenges for market participants from the public sector and private sector alike:

- **Higher speed** and, relatedly, the rapid increase in the **quantity of available data** can make market monitoring in near time, as well as collecting, storing and processing vast amounts of data for ex post analysis, more challenging.
- **Greater electronification of trading** can make it harder to keep track of and understand trading activity and market moves. Algorithmic execution designed to minimise market signature (eg by decomposing orders into multiple smaller blocks) can mask trading patterns and volume while prime brokerage on electronic communication networks (ECNs) masks the identity of the economic counterparty to the trade. Traditional market contacts (such as voice dealers) may have less visibility over flows that are driving short-term price formation.
- The **commoditisation of market data** that goes hand-in-hand with electronification, as participants attempt to monetise the data they produce, can increase the costs of monitoring market developments.

Increased speed of information flow and electronic "activity pulse"[1]

In per cent of messages

Graph 3




[1] All quotes generated within a given time period are allocated based on a 0 to 99 millisecond cycle, summed up, and divided by the total number of quotes to generate the distributions shown in the graphs. [2] Customer messages when 100ms EBS Live XML has been in effect, just prior to switching to 20ms EBS Ultra. [3] Quote submissions when 20ms EBS Ultra has been in effect for four months. [4] Quote submissions when 5ms EBS Ultra has been in effect for a week. [5] Underlying instruments are CME futures, but the data on quotes are sourced from Thomson Reuters Tick History. The pulse of quote submissions on the CME itself is expected to track the EBS pulse closer, in particular when sourced via co-location.

Sources: NEX Markets; Thomson Reuters Tick History; BIS calculations.

[7] The graph shows CME futures quotes data sourced from Thomson Reuters Tick History rather than directly from the CME itself. Therefore, the pulse signature is slightly "diluted" because it is not based on co-location.

## 3.2 Migration of trading activity

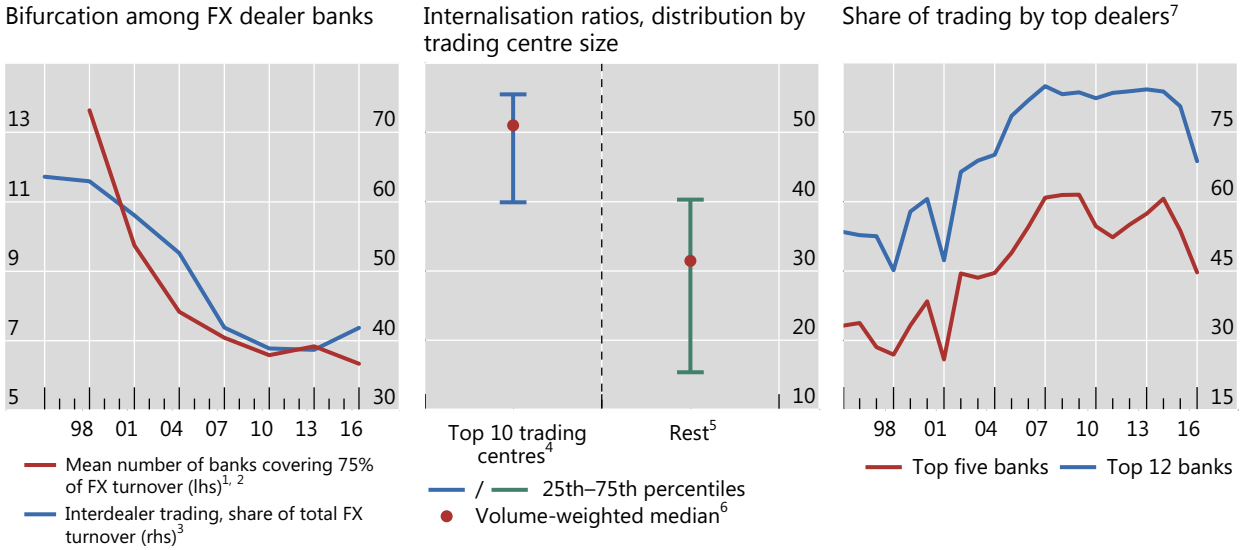
Alongside the developments described above, the FX market has simultaneously seen both a *fragmentation* of trading across venues and a *concentration* of liquidity provision among the largest dealers (both banks and a small number of PTFs).

Survey data collected by the BIS clearly illustrate these trends. Among dealer banks, there has been an increased concentration of liquidity provision among the largest banks (Graph 4, left-hand panel), which continue to take risks onto their balance sheets as principals. In contrast, many other banks have moved primarily to an agency-based model of market-making, and serve mainly as conduits of liquidity between clients and the large FX liquidity providers.

As a further sign of fragmentation, the proportion of electronic trading volume on the primary venues – namely Thomson Reuters Matching and EBS Spot – has declined. Volume has migrated to a combination of single-bank platforms and other ECNs (see BIS (2016c)). The former allow dealers to employ automated pricing and risk management technology to provide their clients with streaming prices, executable liquidity and customised pricing and execution for different client types. Still, despite this fragmentation, there is evidence that primary ECNs remain important for the spot FX price discovery process (see Box A).

### Changing inter-dealer trading and the entry of non-bank market makers

In per cent — Graph 4




[1] Across the following jurisdictions: Australia, Brazil, Denmark, France, Germany, Hong Kong SAR, Japan, Singapore, Sweden, Switzerland, the United Kingdom and the United States (simple average). [2] Spot, outright forward and FX swap turnover reported to BIS Triennial Central Bank Survey. [3] Adjusted for local and cross-border inter-dealer double-counting, ie "net-net" basis; daily averages in April. [4] Australia, Denmark, France, Germany, Hong Kong SAR, Japan, Singapore, Switzerland, the United Kingdom and the United States. [5] Remaining 40 jurisdictions that supplied internalisation ratios. [6] Weighted by each reporting dealer's trading volumes, excluding zeros and non-reporting. [7] Based on Euromoney overall rankings.

Sources: BIS Triennial Central Bank Survey; Euromoney Foreign Exchange Survey 2016.

Box A

## The role of "primary" ECNs for price discovery in a fragmented FX market

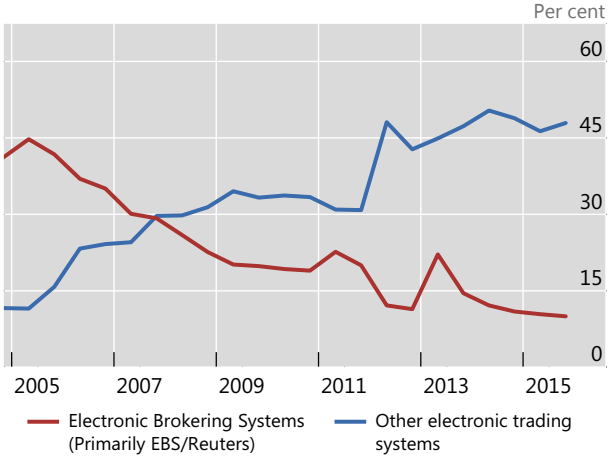
Fast and accurate price discovery (ie the process of how new information gets incorporated into asset prices) is a cornerstone of efficient and smoothly functioning markets. In FX, electronic brokering systems originally geared towards inter-dealer trading were long thought to dominate this process. Specifically, since the late 1990s, two "primary" ECNs, Thomson Reuters Matching and EBS Spot, have played a key role for inter-dealer trading in the liquid currencies and hence in the price discovery process.①.

These primary ECNs have been integral to price discovery for several reasons. First, because they provide real-time data on prices and trades, thereby enhancing transparency. Second, because of the high precision of the price signal, given that limit orders on these platforms are firm (as opposed to indicative quotes). Third, because pre-trade anonymity prevents price discrimination. And, finally, because inter-dealer flows directed to primary ECNs are an important aggregator of information stemming from dealers trading with clients.②

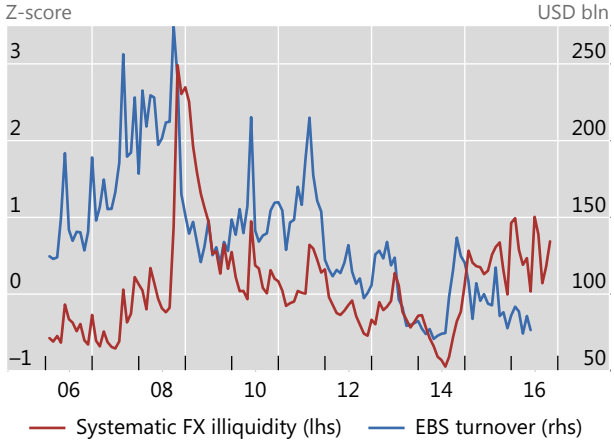
### Trading on primary vs secondary ECNs, and EBS turnover and FX illiquidity

Box A

ECN shares of trading in spot FX




FX illiquidity and trading on EBS[1]




[1] The systematic (market) FX illiquidity measure is from Karnaukh et al (2015) and is a standardised indicator based on a composite measure of relative bid-ask spreads and bid-ask spreads adjusted for the currency variance, covering 30 currency pairs.

Sources: Karnaukh et al (2015); US Foreign Exchange Commission; EBS.

Yet, over recent years the share of trading executed on primary ECNs has been falling (Graph A, left-hand panel), raising questions about how much they still contribute to price discovery. The reasons for this decline are discussed in detail in the main text. However, it is notable that trading volumes on the primary ECNs are still in the hundreds of billions as measured in dollar equivalents per day. And, both EBS and Reuters Matching remain the main point of reference for many financial market benchmarks, such as the WM/Reuters 4pm benchmark rate.

Academic research and market contacts generally suggest that EBS and Reuters Matching have remained the primary reference sources for benchmark pricing of major currency pairs and for many emerging market currencies.③ Indicative of its importance for price discovery, as the speed of feed updates on EBS Spot was increased to five milliseconds in 2017 (EBS Live Ultra), a visible change in the frequency of activity occurred not only on the platform itself, but also on other electronic venues including futures exchanges (see Graph 2 in main text). And, although bid-ask spreads can differ materially compared to secondary ECNs or single-dealer platforms, it appears that the primary ECNs continue to be the main reference for mid-prices.

There are several potential reasons why the role of primary ECNs in price discovery has remained fairly robust, even as volumes have declined. First, price discovery continues to take place on such venues because hedging activity by dealers aggregates the information from their client trades.④ In other words, the tendency towards greater trade internalisation may have led to an increase in the informational content of the flow that is directed to the primary

ECNs, in turn enhancing their contribution to price discovery (per unit traded).⑤ Second, FX dealers operate on multiple platforms simultaneously. Hence, the best quotes on primary ECNs are transparent to all market participants. Once dealers adjust their limit orders in one market, this information is almost instantaneously reflected on other venues.⑥ The rise of PTFs focused on electronic market-making and exploitation of short-lived arbitrage opportunities across different electronic platforms simultaneously would have further contributed to such integrated price discovery across otherwise fragmented venues.

Finally, the primary ECNs provide a crucial backstop during periods of market stress. Hence, FX trading activity typically reverts onto the primary venues during episodes of stress (Graph A, right-hand panel), as these platforms provide the highest concentration of liquidity and pre-trade anonymity. While dealers can internalise large FX flows and quote narrow spreads to their clients in normal times, their need to hedge inventory risk rapidly in the inter-dealer market rises sharply when volatility is elevated and client flow tends to come in the same direction. Primary ECNs thus have an important role to play in price discovery during periods of increased FX market volatility and are likely to take on an increased importance in the ex post analysis of periods of stress.

① See King et al (2011) ② Indeed, there is evidence that the growth of trading on such anonymous electronic limit-order book venues has been associated with the spot market becoming the dominant source of price discovery over FX futures markets in the 2000s for euro, yen and pound sterling. See Rosenberg and Traub (2008) and Wang and Yang (2008). ③ See Chen and Gau (2015). ④ See Osler et al (2011) and Menkhoff et al (2016). ⑤ See Zhu (2014). ⑥ See D'Souza (2007).

**Increasing fragmentation** of trading **reflects a number of factors**:

1. First, **demand from end-users** for more competitive pricing and reduced market impact has spurred the growth of new types of venue, including electronic single and multi-bank platforms and other venues designed to allow end-users to compare and/or aggregate quotes from a number of dealers.
2. A second driver has been the growth of **latency arbitrage by higher-speed participants**, including so-called principal trading firms (PTFs).[8]
3. A third factor has been the **rise of trade internalisation** among top-tier dealers, whereby dealers offset risk arising from client transactions against risk arising from transactions with other clients (Graph 4, centre panel). Trade internalisation has been facilitated by the proliferation of single-bank and multi-bank trading platforms. This bifurcation of liquidity provision has meant that a limited number of top tier FX dealers have retained a strong position as so-called "flow internalisers".[9]

As a result of these developments, market participants (central banks included) face the challenge of monitoring activity across a larger number of venues, some of which, such as single-bank platforms, are often opaque by design. Even discounting the technological issues and financial costs associated with collecting, cleaning and storing high-frequency data, the sheer number of active venues complicates both

[8] The increased share of high-frequency trading on Reuters Matching and EBS Spot that emerged during 2009–12 incentivised dealers to reduce their activity on primary venues due to the increased risk of being adversely selected. In 2013, these concerns led several large dealer banks to support the launch of the trading platform ParFX, which applied randomised pauses (measured in milliseconds), known as latency floors, to orders entered on the platform. Other ECNs, including the primary venues, then followed with their own variants of order processing delays and randomisation mechanisms.

[9] According to the results of the Triennial survey, around half of all spot FX volume in the largest trading centres is internalised (Graph 4, centre panel); although many report much higher internalisation ratios and the willingness to hold the other side of clients' trades for several minutes in the most liquid currencies. See Moore et al (2016) for an analysis of internalisation based on the Triennial Survey data and Butz and Oomen (2017) for theory and empirics characterising major FX dealers' internalisation strategies.

near-time monitoring and ex post analysis. A judgment is needed as to which platforms are sufficiently representative of the state of the broader market. The inability to monitor activity across all venues increases the risk that key pieces of evidence may be missed out in analyses conducted.

## 3.3 The rise of non-banks

The past decade has seen the rise of a new class of participants in FPMs: non-bank PTFs. These participants trade on a proprietary basis, often at high frequency and using sophisticated technology, and can be liquidity providers and/or consumers. Their size is often difficult to quantify, but they are thought to account for roughly 50% of trading in both US equities and on-the-run US Treasuries.[10] In FX, the daily trading volume for the largest individual PTFs is in the tens of billions of US dollar equivalents per firm.[11]

PTFs play a variety of roles. Most have traditionally operated on a largely anonymous basis, taking advantage of both their prime broker sponsorship and the opacity provided by centralised trading venues to generate profits on the back of their superior technology and speed. Their strategies include market-making, statistical arbitrage, latency arbitrage and momentum or trend-following.

PTFs have long acted as *indirect* providers of liquidity, for example on anonymised CLOBs. But more recently, some have also grown market share in the *direct, disclosed* provision of liquidity via a network of client relationships (see Annex A for a schematic description of market structure evolution). When non-banks appeared in the *Euromoney* magazine rankings for the first time in 2016, their share was already 6% of the market-maker segment. And, given that most non-bank market-makers do not disclose their trading volumes, their actual market share is most likely higher. In contrast, the share of top dealer banks in total FX trading with clients has fallen in recent years (Graph 4, right-hand panel).

The growth of direct, disclosed provision of liquidity by PTFs has derived from their ability to deploy their technology to provide liquidity at reduced marginal cost, and to increase distribution across currencies, instruments and trading venues, and from their increasing capability to take on inventory risk and internalise client flow. At the same time, the counterparty risk assessment and provision of credit that support this activity rest with a small number of major FX prime broker banks, and PTFs engaged in FX market-making trade almost exclusively on prime broker credit.[12]

Notwithstanding their broader impact on market quality, the growth of PTFs in FX and other markets renders monitoring structural changes and ex post event analysis harder. Central banks have traditionally gathered market intelligence from a relatively homogenous group of end-users and liquidity providers. But the emergence of new entrants in key roles means that it is incumbent on the official sector to engage with and understand the impact of these participants.

[10] US Joint Staff Report (JSR) (2015).

[11] Moore et al (2016).

[12] Unlike other fast-paced electronic markets, FX trading is not conducted on exchanges, which leaves counterparty risk assessment and credit arrangements almost exclusively with prime brokers. Since the volatility jump in January 2015, there has been a further consolidation in FX prime brokerage among fewer institutions, as a number of banks have been reassessing their prime brokerage business in favour of greater focus on client credit quality, internal risk management and capital requirements.

# 4. How have market participants responded to changes in market structure?

This section briefly lays out some major changes implemented by various market participants in response to the structural developments in FPMs covered in the previous section. It first considers how traditional liquidity providers have adjusted their business models, with a particular focus on their market-monitoring capacity. Next, it examines how end-users in the FX market have utilised new data and analytical tools to keep up with the pace of change.

## 4.1 Changes to the traditional model of liquidity provision

To compete in FPMs, traditional liquidity providers have undergone significant changes. Some have exited or reduced their presence since the early 2000s. Those that have remained have made sizeable investments in staff and technology as they seek to keep pace with the evolving market structure. One estimate suggests that the development of a single-bank platform, which combines pre-trade analysis, execution, and post-trade analysis, required investment in the region of US$100–150 million around the time of their inception. But such investments have since allowed a handful of larger banks to significantly grow their market share, while also improving their ability to manage client flow. These costs have fallen in subsequent years, reflecting the emergence of off-the-shelf trading infrastructure and data storage solutions, primarily to second-tier banks who have struggled to keep pace with technological developments. The cost of these off-the-shelf products is reported to be closer to US$5–10 million, although this varies with the level of sophistication.

The larger liquidity providers can be linked to more than 20 ECNs. Yet, this can also create new challenges for ascertaining market depth, because the same readiness to trade is posted across different venues, potentially creating a false impression of liquidity (the so-called "liquidity mirage").

Ever-increasing speed and the multitude of trading venues have also required traditional liquidity providers to invest heavily in infrastructure including sophisticated software, and hardware that minimises system latencies. Hardware improvements include the latest microchip technologies, the introduction of fibre optic networks, and the co-location of pricing servers in order to be as close as possible to important trading venues.

A by-product of the acceleration in electronic trading and fragmentation in trading venues has been the creation of large quantities of data by liquidity providers and trading platforms. For example, one large bank's e-trading desk produces around one billion FX quotes per day for clients globally. In order to deal with these data volumes, firms have begun using cloud services, which reduce the need for hardware and physical data storage.

More sophisticated liquidity providers have been able to internally manage their connections to clients, platforms and other liquidity providers, but others have had to rely on external providers for connectivity. One increasingly common approach is

"teaming up", where a non-bank typically provides superior technology capabilities to a bank liquidity provider.[13]

## 4.2 End-users, new data and analytical tools

As technology and other structural changes have impacted markets, end-users have adapted in a number of ways. The general trend has been towards greater utilisation of technology, greater use of data and more sophisticated execution techniques. But the pace of adoption across end-users has varied from basic upgrades to large-scale technological advances. Table 1 presents a stylised ranking of market participants and level of engagement with FPMs on the spectrum from more rudimentary users of new technology to the most sophisticated.

Adapting to fast-paced electronic markets — Table 1

| ***Less sophisticated*** | | ***More sophisticated*** |
|---|---|---|
| • Retail and some slower-moving institutional investors, corporates | • Smaller banks, larger corporates and institutional investors | • Larger banks, PTFs, sophisticated hedge funds/asset managers |
| • Limited use of market data; access to basic platforms, "social" brokers | • More sophisticated market monitoring from several ECNs, and/or aggregators | • Near-time market monitoring across a multitude of venues |
| • Limited algorithmic execution capabilities or use of off-the-shelf algorithms | • Some development of customised algorithms | • Sophisticated algorithmic execution |

### Market monitoring

End-users are required to monitor market developments for a number of different reasons: to identify opportunities to trade at preferred prices, to monitor markets on behalf of clients, or to manage the risk of existing positions. In each case, the nature of these requirements will dictate the appropriate approach to and scope of market monitoring.

In FX markets, the fragmentation of trading activity across a multitude of venues has increased the costs of comprehensive monitoring. Sophisticated end-users are required to monitor a large number of market data feeds simultaneously on primary ECNs (Thomson Reuters Matching and EBS), relevant futures exchanges and a range of smaller platforms and venues. Many firms now also rely on externally provided aggregators to receive data from a wide range of sources.

This task is made more difficult as a result of the uncertainty surrounding reference prices. Unlike other FPMs, FX does not feature a consolidated tape – which would allow users to observe a centralised record of anonymised transactions.[14]

[13] For the non-bank, the tie-up provides a new revenue source on top of its existing strategies. Recent examples include JP Morgan and Virtu, and BNP Paribas and GTS.

[14] Industry efforts to develop such an initiative have so far struggled with some participants' unwillingness to share data. Some are unable to share their market data for compliance reasons, while others operate a business model that relies on the sale of data. The development of some form of transactional data repository might deliver a number of benefits for the FX market, including a single reference point as well as increased pre and post-trade transparency.

Box B

## Machine learning for trading in fast-paced markets

Artificial intelligence (AI) involves the display of human-like intelligence by machines, while machine learning (ML) is a particular approach to AI that is based on the idea that systems can continuously "learn" from incoming data. Both AI and ML have gained traction in recent years with the declining costs of data storage and processing, and the proliferation of tools for data analytics, as well as increasing evidence of successful applications (eg medical imaging, marketing personalisation and fraud detection).

The application of ML techniques in trading has increased, but has focused for the most part on uses in low-frequency trading and investment. Examples include algorithms analysing a broad range of macroeconomic data for the timing of cross-asset investing, and deep learning approaches for applications such as long/short investing in a currency portfolio, and the analysis of unstructured data sets such as social media feeds or satellite imagery.

Instances of the applications of ML techniques in high-frequency trading appear to be more narrowly focused. One explanation is that the use of computationally heavy algorithms becomes difficult as execution speed increases. Notwithstanding, ML techniques have been used to analyse market impacts – ie expected price slippage for a given transaction. For instance, a bank has used decision tree algorithms on central limit order book data to forecast order flow direction over the next 20 or more ticks. Reinforcement learning has also been used to train a robot to identify trading strategies that will reduce market impact in given market conditions. Another area of application has been in optimising spread and skew in price-making to clients. These require data from FPMs, for example, order book and transactions data, but may not be conducted in real time. Instead, these provide additional electronic tools for market-makers to review the profitability and volume of transactions with clients, and to decide which tier to put clients in.

Most of the applications in high-frequency trading have been focused on equity markets, some on fixed income, while applications in FX are at an early stage. This is due partly to legacy issues, as algorithmic trading started and is most widely used in equity markets. Applications in FX markets are also complicated by the decentralised and fragmented nature of these markets. Nevertheless, research and experimentation is afoot, and lessons from equities will carry over to FX markets.

Similar ML techniques can be used at central banks for their core market functions in monetary policy implementation, reserve management and market monitoring. The evolution of FPMs has resulted in larger and more varied data sets, which may necessitate the use of ML techniques. In policy implementation and reserves management, it is conceivable that ML can be implemented in trading decisions, eg to optimise market impact. In monitoring, ML might be used to identify drivers of currency moves from broad and heterogeneous data sets (eg macro indicators, flow data, microstructure data etc).

Broader application of ML in fast-paced trading could lead to more efficient markets, particularly the timely incorporation of diverse sources of data in market pricing. But the application of ML could widen the technology divide, pushing lower-tier banks even further towards an agency approach to risk management. The application of commercially available third-party off-the-shelf technologies heightens the risk of application by less sophisticated market participants, who may not have sufficient controls and governance in place. Multiple participants using similar algorithms simultaneously could lead to herd-like behaviour. A good understanding of such developments is increasingly important for the effective monitoring of FPMs.

Risk management techniques will have to evolve with the adoption of such technologies in the market. In particular, traditional approaches to model validation will be challenged by the task of evaluating ML algorithms, particularly the more opaque and model-free approaches, whose outputs cannot be modelled or easily analysed. Some market participants have also highlighted a need to shift from a focus on model validation to the managing of risks through segregated controls, both within the complex events processors where trading algorithms reside, and through the use of market access controls. Market access controls can act as kill switches, but are usually applied on a graduated basis, imposing limits such as on price or aggregate volume, as well as the number of, duplication and size of orders being sent to trading venues. Some institutions have already started to enhance their model validation and risk functions, which increasingly demand technical expertise in programming and analytics.

Moreover, the decline in the market share of primary ECNs and the rise of internalisation ratios of large dealers have led to greater uncertainty around the relevance of the primary ECNs in, for example, determining the high or low-point in a volatile market move, or whether a specific price level has been reached in order to settle a derivatives contract or client or retail order. Much more activity now takes place on single-dealer platforms, where not only the bid-ask spreads but also the mid prices can vary substantially depending on both the dealer and the client being priced. From the perspective of many end-users, this has also increased the demand for a wider set of market data.

### Trade execution and analysis

Faced with bigger volumes of market data and greater pressures to achieve "best execution", end-users are now placing significant weight on the efficiency of their method of transaction, beyond simple bid-ask spread metrics. Focus has shifted from securing best price to achieving minimal market impact and reducing information leakage. As a result, the use of algorithmic trading has increased dramatically for both sophisticated, high-frequency participants, and for slower-moving ones as well. In fact, most single-bank platforms now come with a suite of client execution algorithms. And, as discussed in Box B, machine learning techniques and artificial intelligence are making in-roads in FX markets, although the applications are still in their infancy in terms of technological sophistication.

From a monitoring perspective, increased focus on best execution has led to the development of transaction cost analysis (TCA) tools which allow end-users to monitor the efficiency of their method of transaction both pre and post-trade. This can include a comparison of different algorithms, venues and/or liquidity providers on metrics such as price impact and the depth or firmness of available liquidity. Many end-users rely on externally provided TCA solutions, but more sophisticated participants are increasingly developing their own technology in-house.[15]

## 5. Fast-paced markets monitoring by central banks

This section explores some of the main ingredients that can serve as useful inputs for the monitoring of FPMs by central banks.[16] It looks at data and tools for the purposes of near-time monitoring, the analysis of medium-term structural trends, as well as the ex post analysis of market dysfunction. In line with the primary focus of this study, the

[15] Market contacts estimate that around 75% of the asset management industry (measured by AUM) now uses some form of TCA. By contrast, only around 20–30% of corporate trading activity and 5–10% of institutional investors' activity is thought to rely on TCA. In many cases, pressure to deliver greater transparency, reduced market impact and firmer liquidity have had their intended effect on dealers as they compete to win business from a better educated client base.

[16] Of course, FPM monitoring needs naturally differ across central banks. On top of this, relevant markets may have different degrees of electronification. For example, when it comes to policy implementation, some central banks may heavily operate in FPMs, such as spot FX, US Treasuries or bond futures. A close monitoring of these markets is hence paramount for their fulfilment of policy objectives. Others, by contrast, will operate in markets that currently exhibit a lower degree of electronification, such as corporate credit, other government bond, and FX derivatives markets. This heterogeneity naturally leads to differences in central banks' FPM monitoring needs.

section focuses on the spot FX market. However, many of the conclusions are applicable to other asset classes that have progressed towards greater electronic trading, such as fixed income (BIS (2016b, p 9)).

Table 2 provides an overview of the main monitoring needs arising from different central bank mandates as well as the general timeframe for deliverables. Following the categorisation outlined in Section 2, a distinction is made between near-time monitoring and medium-term monitoring of structural trends or past events.[17]

**Near-time monitoring** is particularly relevant for trade execution. Some central bank mandates can require active participation in FPMs, and therefore an up-to-date view of prevailing market conditions. For reserves management in particular, *best execution* is increasingly important, with demanding data implications. The deliverables based on near-time monitoring should be available with minimal time-lag on the same (ie intraday) or latest next day.

The primary aims of **medium-term monitoring** relate to market functioning and financial stability. For example, high-frequency or more granular data can be used to assess how market liquidity conditions have changed over time and in response to structural changes (eg changing business models of intermediaries or regulation). Fragility in market conditions can undermine investor confidence and hence impact the real economy. For policy implementation and reserves management, medium-term monitoring can further be used to assess how structural changes affect the optimal venue, time and method for trade execution.

Monitoring needs in central banks' functions and timeframes for deliverables Table 2

| | Policy decision and implementation | Reserves management | Financial stability |
|---|---|---|---|
| Monitoring in near time (intraday or EoD / t+1) | • What are key market drivers?<br>• What are current market conditions? Is it an adequate time to intervene?<br>• On which venue, at what time and with which method to trade to achieve the desired market impact? | • What are key market drivers?<br>• What are current market conditions? Is it an adequate time to execute?<br>• On which venue, at what time and with which method to trade to have best price and minimal market impact?<br>• What is the quality of trade execution (TCA)? | • What are current market conditions? In particular, are liquidity conditions adequate? Is there evidence of stress or dysfunction? |
| Medium-term (weeks to months): structural trends and event-based analysis | • How do market conditions evolve over time? In particular, is market functioning orderly such that the price adequately reflects information?<br>•How does market structure change over time? Where and how is price discovery happening? | • How do market conditions evolve over time?<br>• How does market structure change over time? Which venues offer best liquidity? Which execution method(s) to choose? | • How do market conditions evolve over time?<br>• How are market conditions affected by changes in technology and market structure?<br>• What happened in a specific event of market dysfunction?<br>• Do disorderly market movements spill over between asset classes?<br>• What spillovers exist from derivatives to spot markets? |

[17] In the following, near-time monitoring includes continuous monitoring during the day as well as end-of-day/next day (EoD/t+1) reporting.

The indicators used for the purposes of medium-term monitoring are also useful for ***ex post event analysis***, particularly as it relates to incidents of extreme market dysfunction (eg a flash crash). Given the extent of market fragmentation, ex post event analysis would ideally integrate granular data from various sources, while accounting for cross-market spillovers (especially from closely-linked derivatives markets). And, it is commonly complemented with qualitative information, such as market intelligence. While event-driven analysis may require less immediacy compared to near-time monitoring, in many cases it generally necessitates greater depth and breadth of analysis. Having the data and tools for near-term monitoring in place can help shorten the horizon at which periods of market dysfunction can be investigated and drivers identified.

The next two sections discuss a range of indicators and data sources that can support an in-depth monitoring of the spot FX market. This has emerged from the expansion of data collection and market intelligence gathering by central banks from new venues and intermediaries. Clearly, the value of constructing such indicators depends on a number of factors, including the importance of specific mandates and the degree of electronification of relevant markets for different central banks.

## 5.1 Data and indicators for near-time monitoring

Near-time monitoring covers three broad, yet interrelated, areas: market conditions, market drivers, and market impact/transaction costs.[18]

**Market conditions** are best captured by indicators based on high-frequency (eg millisecond sampling) or even tick-by-tick data from primary venues. These data vary in granularity and depth, ranging from simple price or top-of-book (TOB) quote metrics to richer data covering the entirety of a CLOB. Price data from trades or mid-prices can be used to analyse the occurrence of price gapping or broader dysfunction, while bid-ask spreads can be used to measure market liquidity. Volume data such as quoted depth are required to proxy the resiliency of the market, while order flow data can be used to measure the asymmetry between buying and selling interest. Combined price and volume measures can be used to measure the price impact of trades. A showcase on near-time monitoring in Annex B illustrates how these measures provide value in monitoring and understanding market functioning.

For spot FX, the most important near-time data are likely to come from the primary venues, EBS and Reuters Matching. Anecdotal evidence further suggests that liquidity providers often rely on CME traded futures for an additional reference price for their spot FX quotes. In an increasingly fragmented market, complementing information from primary venues with CME data and/or information from secondary venues is thus becoming more important.

The need for multiple data sources to get an adequate picture of price discovery is not a theme unique to spot FX. Secondary market trading in on-the-run US Treasuries is split between the cash market, which predominantly comprises centralised electronic trading platforms, and the electronic futures market, which is mainly hosted on CLOBs of regulated exchanges like the Chicago Board of Trade

[18] See Annex B for a list of relevant indicators to monitor fast-paced markets and the associated data requirements. The areas are mutually interrelated. For example, market impact depends on market conditions, and, furthermore, is itself a factor that can disrupt the prevailing market conditions.

(CBOT) or the CME. As such, a fully representative picture can only be drawn utilising multiple data sources from both segments and multiple trading venues therein.

The analysis of **market drivers** requires a richer set of data in addition to qualitative market intelligence, but sampling frequency can generally be lower. Adequate identification of market drivers often requires information on relevant positioning and/or flows. For example, flows by location or customer group can be used to glean information on the origin and motivation of a market-moving transaction.

Swap data repositories (SDRs), which collect mandatory transaction reporting under the implementing acts of Dodd-Frank/MiFID, constitute a particularly valuable data source to analyse possible spillover and amplification effects due to investors' positioning in derivatives markets.[19] Auxiliary data sources might also include data sets from central counterparties (CCPs), FX settlement service providers such as CLS, or central securities depositories (CSDs).

Monitoring of **market impact and transaction costs** can require additional data on timestamps and characteristics of own trade executions. A liquid and well functioning market is characterised by the ability to absorb trading activity without a

Box C

## Monitoring based on data collected under MiFID II/MiFIR

The entry into force of MiFIR and MiFID II in January 2018 has created a range of new granular data collected by authorities, platforms and data repositories. The use of these data seems promising for the purposes of market monitoring. However, it faces three challenges: the limitation due to the scope of the legislation, the frequency of the collection and the lack of centralisation of aggregated data.

First, the potential utilisation is limited to fixed income and FX derivatives only, whereas the spot FX market is out of the scope of the legislation. Second, the frequency of the reporting is not well defined, with many exemptions in place. Such exemptions aim at mitigating the potential side effects of excessive transparency in financial markets, specifically when someone is executing a block trade that may represent a big relative share of a specific product or is trading an illiquid financial instrument. This prevents accurate intraday analysis. Finally, the most serious limitations arise from the lack of centralisation and aggregation of the data. Two sets of data are being collected: market activity data (based on so-called "Trade Reporting" requirements) and transaction data ("Transaction Reporting"). The market activity data set captures the order book (pre-trade), prices and volumes of transactions carried out (post-trade reporting); the transaction reporting data instead includes a wide range of transaction related details (such as, for example, the client on whose behalf a transaction has been carried out). A major difference is that "Trade Reporting" needs to be sent in near real-time and is to be made public, while transaction-level data are highly sensitive and remain non-public. After being submitted at a t+1 requirement, transaction data are stored at a very high level of disaggregation.

With regards to the first set ("Trade Reporting"), private initiatives to store and make the post trade data available centrally are currently emerging (Consolidated Tape Providers, CTPs) and may eventually allow this issue to be overcome. Such data will probably not be available free of charge and a 100% coverage is unlikely to be achieved. On the "Transaction Reporting" set, the European Securities Market Authority (ESMA) is acting as a switch, receiving data from one National Regulatory Authority (NRA) to be sent to another NRA if necessary, rather than as a central processing unit storing data, which could then be used by the central bank community and other interested parties. Therefore, the access to data would require the approval from all the NRAs prior to receiving, storing and aggregating the data. Provided the challenges can be overcome, on a medium to long-term time scale, these data could be used for assessing the overall market activity or liquidity on fixed income and FX derivatives products, such as swaps and options.

[19] Under Dodd-Frank, SDRs are obliged to publish data on the transaction level in an anonymous form. Examples of SDRs include DTCC, CME, and BSDR. See Box C on coverage and public availability of data from euro zone/MiFID SDRs.

Indicators and possible data inputs for monitoring of market structure Table 3

| | | Market data | Market intelligence |
|---|---|---|---|
| **Market structure** | Trading technology (eg degree of electronification, share of algorithmic trading, new order types, matching mechanisms) | • BIS Triennial Survey (every three years)<br>  ○ Share of electronic trading<br>• Regional FXC surveys (semiannual)<br>  ○ Share of electronic trading<br>• Data from primary and secondary venue (hourly, daily)<br>  ○ Share of algorithmic trading<br>  ○ Share of trading of a specific order type | • Central bank-led intelligence gathering (including with new participants and technology providers)<br>• Published reports and commentaries from market participants (eg platform vendors, connectivity providers, sell and buy side)<br>• Market research industry conferences and workshops |
| | Composition of market participants (eg volumes by counterparty) | • BIS Triennial survey (every three years)<br>  ○ Turnover by counterparty<br>• Regional FXC surveys (semiannual)<br>  ○ Turnover by counterparty<br>• Flows by customer group (daily up to weekly) | |
| | Migration of trading activity (eg primary venue's share of total turnover, disclosed vs undisclosed trading, direct trading vs central matching) | • BIS Triennial Survey (every three years)<br>  ○ Turnover by execution method<br>• Regional FXCs (semiannual)<br>• Data from primary and secondary venues and/or connectivity providers (hourly, daily)<br>  ○ Turnover by platform<br>• CLS settlement volumes (hourly, daily)<br>  ○ Total turnover to calculate a platform's share | |

FXCs=Foreign Exchange Committees.

disruptive price response. From the perspective of a single institution trading in FPM, liquidity can be most simply defined as the cost associated with executing a trade (see eg the joint report on the October 2014 US Treasury flash rally). Hence, market impact is an important aspect of transaction costs and thus a key question not only in the context of policy implementation, but also for reserves management.

## 5.2 Data and indicators for monitoring of structural trends and event-driven analysis

Monitoring how market conditions evolve in the medium term broadly requires the same indicators to be tracked as are used for near-time monitoring, but resampled to a lower frequency. In some cases, it will also benefit from a wider breadth of data and a further underpinning by market intelligence.

**Structural trends** can affect liquidity conditions in crucial markets for central banks, and are important when monitoring financial market vulnerabilities. Following Section 3, three relevant areas of structural change are considered: changes in trading technology, changes in the composition of market participants and migration of trading activity. Monitoring structural trends requires integrating a broad set of numerical data and qualitative information (Table 3).

The notable aspects of changes in trading technology are the rise in the share of electronic and algorithmic trading, changes in order types and matching mechanisms on trading venues, all of which the BIS Triennial Survey seeks to shed light on.

The BIS Triennial Survey provides a snapshot of the share of electronic trading of total turnover.[20] More detailed aspects of market structure, such as the share of algorithmic trading, can be monitored for specific trading venues, who along with technology vendors, can provide qualitative information on changes in order types or venue-specific matching mechanisms. On changes in the composition of market participants, the BIS Triennial Survey provides a breakdown of turnover by reporting dealers, other financial institutions and non-financial clients.[21] This can be complemented by flow data, broken down by customer group. In addition, qualitative information is particularly important to keep up with new market participants or changes in business models of existing participants.

Tracking the migration of trading activity requires monitoring changes in market shares across venues (eg indirect, anonymous trading on CLOBs across the primary and secondary venues needs, and turnover distribution between direct and indirect trading venues). The BIS Triennial Survey is again the prime source for such data, but only every three years. Turnover data from primary and secondary venues and CLS settlement volumes can be used as a proxy for total turnover between the publication dates of the Triennial Surveys.[22]

An **event-driven analysis** often requires combining data from various sources (Table 4). A case in point is the October 2016 sterling flash event where dealers' dynamic hedging of options positions as well as developments in the closely linked futures market played a potentially key role as shock amplifiers (BIS (2017) and Noss et al (2017)). These events highlight the importance of monitoring changes to the structure of the market to deepen the understanding of episodes of severe market dysfunction.

Indicators and possible data inputs for event-driven analysis Table 4

| | Trade repository data | Customer flow data | Positioning data | Market intelligence |
|---|---|---|---|---|
| Option expiries and market maker positioning: resistance/support levels, dampening/amplification of FX rate moves due to option expiries and market maker delta hedging activity. | Trade-by-trade | | | |
| Positioning of speculative-oriented investors: information of buying/selling interest of speculative-oriented investors. | | | Low-frequency (daily up to weekly) | |
| Flows by customer group or by location: information on the origin/motivation of a market transaction | | Low-frequency (daily up to weekly) | | |
| Anecdotal evidence: Explanations and interpretation gathered from market contacts and research to enhance understanding. | | | | Low-frequency |

[20] See BIS (2016c), detailed tables, Table 26.

[21] See BIS (2016c), Table 5.

[22] A complementary approach is to apply statistical benchmarking techniques to monthly CLS data in combination with semiannual surveys of regional foreign exchange committees (FXCs) in order to obtain a higher frequency picture of the evolution of FX trading volume across currencies and instruments (Bech (2012); Bech and Sobrun (2013)).

Foreign exchange and other fast-paced electronic markets have undergone a wide range of structural changes in recent years, with implications for central banks' market-monitoring activities. Notable changes include increasing market fragmentation, a rise in non-bank market intermediation, significant increases in the speed and complexity of execution, and rapid growth in market data. Against this backdrop, market participants in both the public and private sector have undergone a significant process of evolution with regard to their market monitoring capacities. End-users are increasingly monitoring a wider range of trading venues (sometimes using aggregators), trading and interacting with new counterparties, and developing new approaches to collecting, storing and analysing market data. Increasing use of data is reflected in the increasing commercialisation of and investment in data, tools and analytical capabilities. Central banks have already made significant advances on these fronts, and stand ready to continue to adapt their approaches to market monitoring as necessary to fulfil their individual mandates.

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# Glossary

**Aggregator:** Technology that allows a participant to receive prices streamed from several liquidity providers/pools simultaneously.

**API:** *Application Programming Interface* is an interface allowing the connectivity between several data feeds or trading tools. In the context of FX trading, API often refers to an interface that enables software used by counterparties to connect in order to obtain real-time pricing data or place trades.

**Ask:** The *ask price* is the price at which a market-maker is willing to sell an asset. Equivalently, it is the price at which one is able to buy the asset from a market-maker.

**AUM:** *Assets under management,* total assets managed by a financial institution.

**Bid:** The *bid price* is the price at which a market-maker is willing to buy the asset. Equivalently, it is the price at which one is able to sell the asset to a market-maker.

**Bid-ask spread:** Ask price minus bid price. It is a measure of the cost of a round-trip transaction, ie the price of buying and selling the same asset. The bid-ask spread represents the transaction cost of a specific asset.

**BSDR:** Bloomberg SDR is a swap data repository (compare SDR).

**Buy-side:** Investment firms, such as mutual funds or pension funds, which purchase securities and other assets for money-management purposes, for themselves or for their clients.

**CBOT**: *Chicago Board of Trade* is a futures and options exchanges (merged with the CME on July 2007).

**CCP:** *Central counterparty clearing house* is an entity that interposes itself between counterparties to financial contracts, as the buyer to every seller and the seller to every buyer, thereby guaranteeing the terms of a trade even if one party defaults on the agreement.

**CLOB:** *Central limit order book* is a trading protocol in which outstanding offers to buy or sell are stored in a queue and are filled in a priority sequence, usually by price and time of entry. Orders to buy at prices higher than the best selling price and orders to sell at prices lower than the best buying price are executed. CLOBs are common for highly standardised securities and markets in which trade sizes can be small.

**CLS:** *Continuous Linked Settlement* is a service provided by CLS Bank International to its members in order to manage settlement risk of FX contracts.

**CME:** *Chicago Mercantile Exchange* is a futures and options exchange (Merged with the CBOT on July 2007)

**CSD:** *Central Securities Depository* is an entity that provides securities accounts, central safekeeping services and asset services, which may include the administration of corporate actions and redemptions, and plays an important role in helping to ensure the integrity of securities issues (that is, to ensure that securities are not accidentally or fraudulently created or destroyed or their details changed).

**Consolidated Tape:** is an electronic program that provides continuous, real-time data on trading volume and price for exchange-traded securities.

**Data feed:** an electronic data stream that transmits market information.

**Dealer:** A financial intermediary whose primary business is to enter both buy and sell transactions and which seeks profit by taking the associated inventory risk.

**Depth:** Amount of outstanding orders pending (possibly at different prices) on either side of the market.

**DTCC:** *Deposit Trust & Clearing Corporation*, is a post-trade financial services company providing clearing and settlement service to financial market participants.

**ECN:** *Electronic communication network* is a system that electronically matches buy and sell orders for securities.

**FXC:** *Foreign Exchange Committee* is an industry group that provides guidance and leadership to foreign exchange market participants.

**Inter-dealer platform:** A trading platform access to which is restricted to banks and large financial institutions.

**Internalisation:** A process by which dealers offset risk (open positions) arising from client transactions against risk (open positions) arising from transactions with other clients.

**Latency:** The time (delay) between the transmission of an order to a trading platform and the execution of the order on the platform. A lower latency implies faster order processing and execution.

**Limit order:** Order to buy a specified quantity up to a maximum price, or sell subject to a minimum price.

**Market-maker:** A dealer obliged to quote buy and sell prices in return for certain privileges on a trading platform or an exchange.

**MBP:** *A multi-bank platform* connects a set of dealers' clients with the dealers and enables electronic negotiation and execution in competition (also called **multi-dealer platform, MDP**).

**Off-the-shelf:** Off-the-shelf trading products are ready-made solutions for clients rather than tailor-made for individual plans and needs.

**On-the-run:** An on-the-run bond is the most recently issued bond for a certain maturity. On-the-run bonds are more liquid than off-the-run bonds. An off-the-run bond is no longer the most recently issued bond for a certain maturity.

**OTC:** *Over-the-counter* refers to bilateral transactions not conducted on a formal exchange.

**PB:** *Prime-brokerage* is a service offered by banks that allows a client to source funding and market liquidity from a variety of executing dealers while maintaining a credit relationship, placing collateral and settling with a single entity.

**Primary dealer:** A dealer that buys government securities at issuance. In many countries, primary dealers are the only parties allowed to buy government debt directly from the government when it issues new debt. In some countries, primary dealers are obliged to maintain a liquid market in these securities.

**PTF:** A *principal trading firm* is a firm that invests, hedges or speculates for its own account. This category may include specialised high-frequency trading firms as well as electronic non-bank market-making firms. Sometimes referred to as a proprietary trading firm.

**PV:** A *primary [trading] venue* is a classical exchange for settling trades in a transparent manner. For spot FX, primary venues traditionally include electronic communication networks like EBS or Reuters Matching.

**RFQ:** *Request for quote* is a query issued by a trading platform member to another member to request price quotations. Systems for sending RFQs vary according to: whether the sign of the order (buy or sell) is revealed; how many participants and what kind of participants may receive an RFQ; and whether the quotes are executable or indicative. In most fixed income RFQ systems, clients query only a limited number of dealers. A related trading protocol is request for market (RFM). RFM refers to a request for quote where the client does not reveal the sign of the desired trade (buy or sell). An RFM is a request to see a two-sided or "market" quote rather than a one-sided quote.

**RFS:** *Request for stream* is a query, in which market makers provide continuous streams of firm quotes with available size, and client receiving the quotes can click to trade.

**SBP:** *Single-bank platform* is a proprietary trading platform provided by a single dealer to its clients that connects the dealer with its clients and enables electronic negotiation and execution (also called **single-dealer platform**).

**SDR:** The *Swap Data Repository* is an entity created by the Dodd-Frank Act in order to provide a central facility for swap data reporting and recordkeeping.

**TCA:** *Transaction cost analysis* tools allow end-users to monitor the efficiency of their method of transaction both pre and post-trade.

**Tick-size:** Tick size is the smallest increment by which the price of financial instruments can move.

**Tick-by-tick:** Tick-by-tick data sets provide data points for every single event. Physical time between data updates is not constant but depends on the occurrence of events (so called "event time").

**TOB:** *Top-of-book* data displays the best bid and ask prices for each market participant in a given security. The difference between the highest bid and the lowest ask is the top-of-book bid-ask spread.

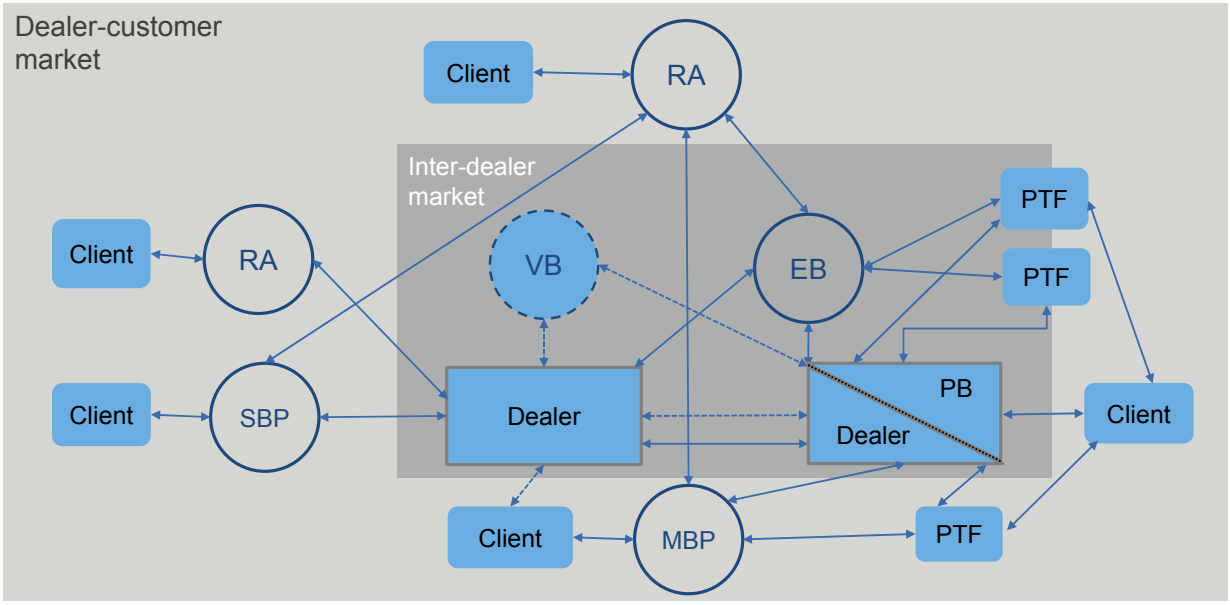
**VB:** A *voice broker* is a financial intermediary that acts as a negotiator between buyers and sellers via telephone. A broker acts as an agent and is not a party to the transaction.

## Annex A: Schematic representation of the evolution of FX market structure

The FX market structure has evolved rapidly in recent years due to greater electronification and the advent of new players. Annex Graph 1 is an updated version of the schematic of FX market structure shown in King et al (2011) and BIS (2011). As described in detail in King et al (2011), electronic brokers (EBs) that allow dealers to trade anonymously, such as Thomson Reuters Matching and EBS, appeared in the early 1990s, and began to dominate trading in liquid currencies by the late 1990s, displacing voice brokers (VBs).

The late 1990s and early 2000s also saw the rise of prime-brokerage (PB) arrangements, whereby dealers' clients, such as hedge funds, could transact in the inter-dealer market either directly or via EBs. In addition, there was a rapid growth in other electronic means for dealer-to-client trading. One area consisted of multibank trading platforms (MBPs), which allowed clients to request quotes from dealers via proprietary computer networks.[23] Another development was the rise of single-bank platforms (SBPs), which are proprietary electronic trading platforms of major FX dealers that allow them to provide customised price streams to their clients and tailor trades to other client-specific needs.[24]

Trading network topology in FX markets — Annex Graph 1




A = aggregator; EB = electronic broker; MBP = multi-bank platform; PB = prime broker; PTF = principal trading firm; RA = retail aggregator; SBP = single-bank platform; VB = voice broker.

Note: dashed lines indicate voice execution; solid lines indicate electronic execution.

[23] Examples include Currenex, Hotspot FX, and FXall.

[24] Examples include Citi's Velocity, Deutsche Bank's Autobahn, Barclays' BARX and UBS's Neo.

By 2010, algorithmic execution accounted for about half of all trading via EBs such as EBS and Reuters Matching (BIS (2011)). Much of this activity stemmed from high-frequency strategies employed by proprietary trading firms (PTFs). Around 2013, in an attempt to insulate themselves from being adversely selected by PTFs employing such strategies, dealers shifted greater amount of activity to dealer-client venues, while EBs introduced speed bumps in the form of latency floors.

By 2015, a number of PTFs have also entered into direct electronic trading with clients. Such more direct market-making activity of select PTFs has partly displaced traditional dealer banks as major liquidity providers and has become a fast-growing segment.[25] While the vast majority of PTFs engaged in such disclosed trading with clients in their own name still requires the PB services of a major dealer, business models that may entirely dispose of a PB have started to emerge.

[25] Annex Graph 1 depicts the dominant operating models of PTFs, whereby they trade with dealer banks (or prime-brokered clients of dealer banks) via electronic brokers (EBs, primary ECNs) and with their clients on multibank platforms (MBPs, secondary ECNs), also on a prime-brokered basis. However, some PTFs are also expanding other forms of disclosed bilateral trading with clients via application programming interface (API) feeds or a single-bank platform. One example of a business model whereby a PTF trades directly with its client using a single-bank platform is known as the "ISDA-carve out model". Under this model, the price-taker is a bank client whereas the non-bank market-maker is a prime brokerage client of the same bank.

# Annex B: Near-time monitoring of market conditions

This showcase illustrates how *high frequency data*, *analysis tools* and *quantitative skills* provide value in monitoring fast-paced electronic markets and assessing market functioning in near time.

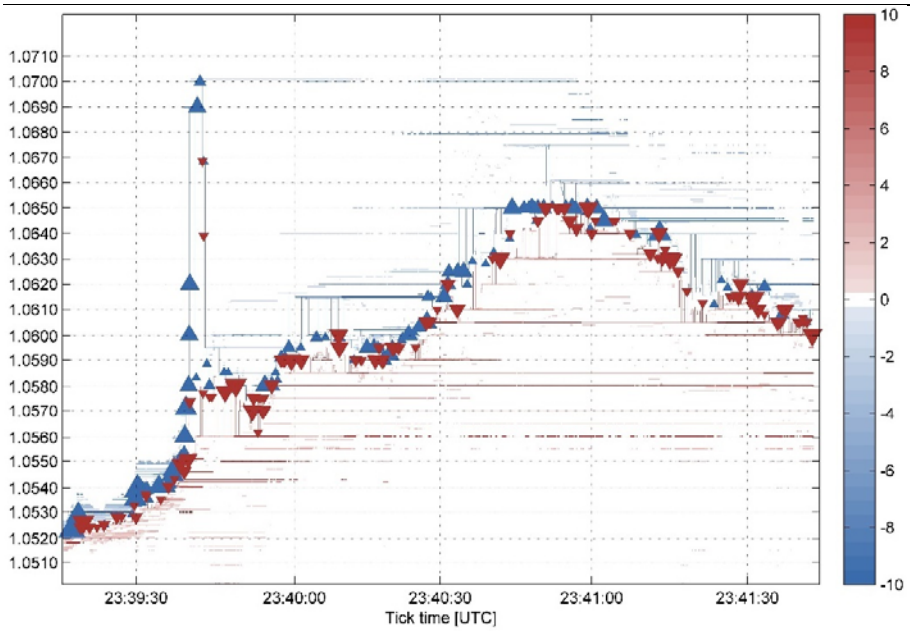
Such information about current market conditions is important as input for policy decisions and for the implementation of policies in fast-paced electronic markets. It also serves as an important source of information for reserves management.

Microstructure indicators can add colour to market moves. On 29 December 2016 shortly after 23:39:30 (UTC), the EURUSD cross-spiked almost 2% within seconds to a traded high of 1.0700 during the Asian trading session. No fundamental news was released during this time that could have caused this exchange rate move.

Annex Graph 2 shows the limit order book of EURUSD on the primary venue EBS from 23:39 until 23:42 UTC. The red (blue) bars illustrate the quoted bid (offer) volume whereas the triangles show the deals. The chart uses tick-by-tick order book data up to 10 levels. For each tick, the quoted volumes for the bid and the offer side are plotted where darker colours indicate more quoted volume on a specific level.

The graph clearly illustrates the deterioration in market quality over this period of temporary dysfunction. After 23:39 UTC, several buy orders were executed and quoted volumes evaporated rapidly on both sides of the order book. Up to 23:40 UTC, almost 200 trades were recorded. The intraday pattern of turnover (red line) shown in Annex Graph 3 reveals excessive trading during this time of the day compared to the historical average (blue bars).

EURUSD order book — Annex Graph 2

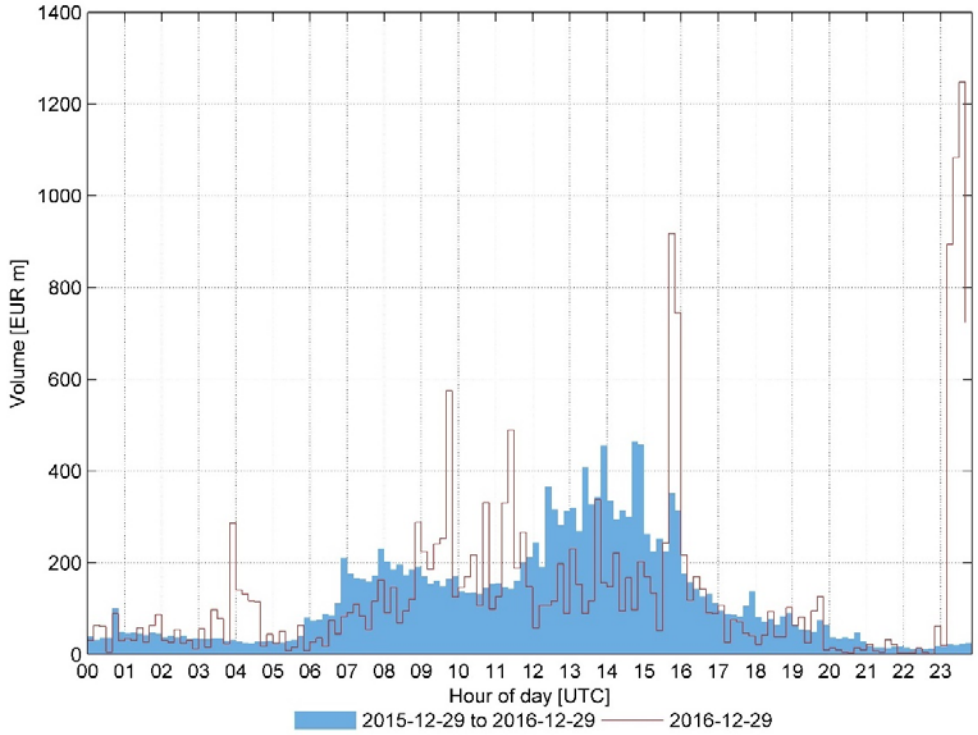



The figure shows the best bid (red line) and offer (blue line) as well as quoted volumes (in millions of base currency) for EURUSD on 29 December 2016 from 23:39 until 23:42 UTC. Triangles correspond to given (red) and paid (blue) transactions. The size of the triangle indicates the size of the transaction.

Sources: EBS; Markets Committee FPM Study Group calculations.

EURUSD intraday pattern of turnover

Annex Graph 3




Note: The figure shows the intraday pattern of turnover in 10-minute buckets. The blue bars indicate a historical average whereas the red line show the intraday volume pattern for 29 December 2016.

Sources: EBS; Markets Committee FPM Study Group calculations.

The evidence in both charts suggests that the EURUSD spike was caused by very aggressively executed buy orders. The market-making interest started to come back well after EURUSD had come off its highs several minutes later. Market liquidity conditions were still thin with relatively large bid-offer spreads and a sparsely populated order book.

Annex Graph 4 provides consolidated information on several transaction cost measures that have been introduced in the main text.[26] The measures are based on the Asian trading session (23:00 until 6:00 UTC) and are aggregated over this session. The red diamond indicates the transaction cost for the Asian trading day December 29–30 UTC, whereas the reference period (0–100% quantile values) goes back one year.[27]

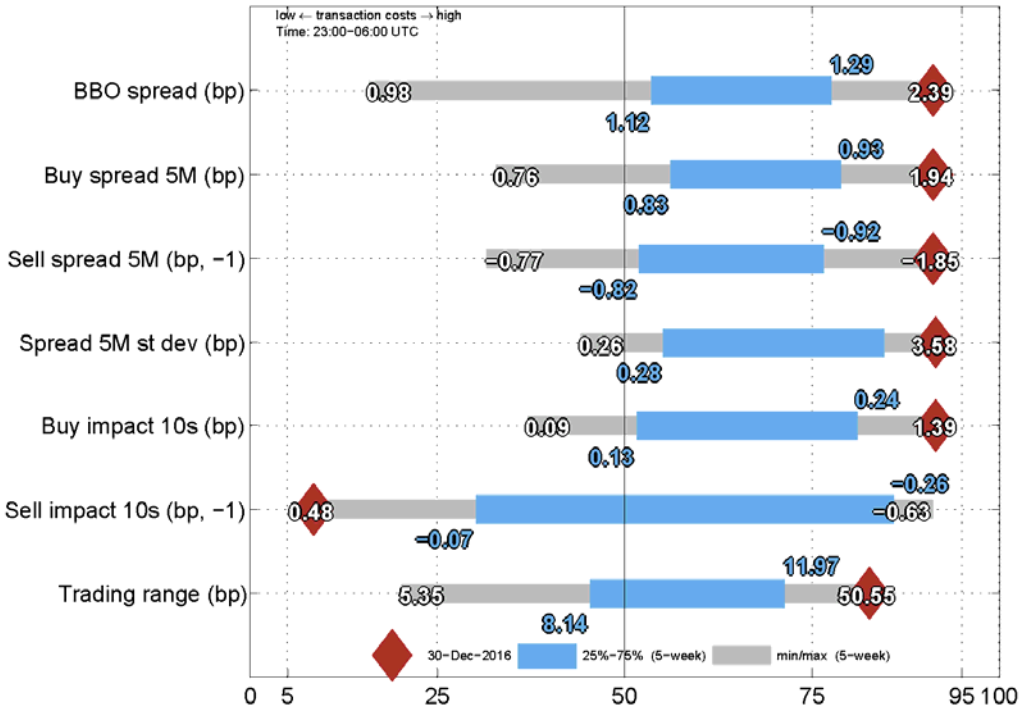
[26] Detailed information on the data needs to construct monitoring indicators of this kind are reported in Annex Table 1.

[27] The *BBO spread* (in bp) is computed as the log(best bid price) – log(best offer price), averaged in quote tick time. This is the cost of turning around the minimum order amount immediately and hence a measure of tightness. The *Buy spread 5M* (in bp) is a measure of offer side depth. For every tick, the volume weighted price of buying 5M with an aggressive market order is computed. The buy spread is then computed as the difference between the volume weighted price to buy 5M and the prevailing mid-price. Thus, for this measure order book information about quotes deeper in the book are needed. *The Sell spread 5M* (in bp) is calculated symmetrically. The *Spread 5M st dev* (in bp) is the standard deviation over quote ticks of the sum of buy spread 5M and sell spread 5M. If the order

As can be expected, a significant move in a relatively less active trading hour goes hand in hand with higher transaction costs (Annex Graph 4). The liquidity measures on this day were close to their historical 95%-quantile. That is, compared with the reference period, the indicators indicate highly elevated transaction costs. Specifically, the best bid-offer spread was 2.39 bp on average, which is more than twice as large as usually observed. The thin liquidity conditions after the spike are reflected in the measures that take the order book into account, ie the *Buy* and *Sell spread* as well as *Spread 5M st dev*. For example, the *Buy spread* shows that the volume-weighted price of buying 5M with market orders deviates significantly from the prevailing mid-price as indicated by the 1.94 bp. The same conclusion holds for the *Sell spread*. Overall, the order book was on average significantly less stable throughout the whole Asian trading session relatively to the reference period as highlighted by *Spread 5M st dev*.

EURUSD transaction costs

Annex Graph 4




Note: The figure shows transaction costs measures for December 29–30 (23:00– 6:00 UTC, 2016). BBO spread refers to the relative best bid-offer spread. Buy (sell) spread 5M is a measure of the offer (bid) side depth. Spread 5M st dev is a measure of order book stability. Buy (sell) impact 10s is the relative impact of a paid (given) deal. Trading range is a measure of the volatility of the price. All measures are in basis points. (–1) indicates that the measure is inverted for better interpretability.

Sources: EBS; Markets Committee FPM Study Group calculations.

book is completely stable, the standard deviation would be zero. It can be interpreted as a measure of resiliency. Another measure of resiliency is the Buy and Sell impact 10s (bp), defined as the relative impact of a paid (given) deal after 10 seconds. Finally, the trading range is the highest transaction price relative to the lowest transaction price. This is a measure of the volatility of the price.

## Some useful academic references on FPM monitoring indicators

### Volatility

*Squared return-based estimator:*
Zhang, L, P Mykland and Y Aït-Sahalia (2005): "A tale of two time scales: determining integrated volatility with noisy high-frequency data", *Journal of the American Statistical Association*, no 100, pp 1394–11.

*Range-based estimator:*
Parkinson, M (1980): "The extreme value method for estimating the variance of the rate of return", *The Journal of Business*, vol 53, no 1, pp 61–5.

*Quantile-based estimator:*
Christensen, K, R Oomen and M Podolskij (2010): "Realised quantile-based estimation of the integrated variance", *Journal of Econometrics*, vol 159, no 1, pp 74–98.

### Depth/quoted volume imbalance

Chordia, T, R Roll and A Subrahmanyam (2000): "Commonality in liquidity", *Journal of Financial Economics*, vol 56, no 1, pp 3–28.

### Price impact of trades

Kyle, A (1985): "Continuous auctions and insider trading", *Econometrica*, vol 53, no 6, pp 1315–35.

Amihud, Y (2002): "Illiquidity and stock returns: Cross-section and time-series effects", *Journal of Financial Markets*, vol 5, no 1, pp 31–56.

### Traded volume/deal flow imbalance

Chordia, T, R Roll and A Subrahmanyam (2001): "Market liquidity and trading activity", *The Journal of Finance*, vol 56, no 2, pp 501–30.

Hasbrouck, J and D Seppi (2001): "Common factors in prices, orderflows and liquidity", *Journal of Financial Economics*, vol 59, no 3, pp 383–411.

### Price jumps

A good overview on parametric and nonparametric jump identification can be found in:

Bera, A, S Ivilev and F Lillo (2015): *Financial econometrics and empirical market microstructure,* Springer, Chapter 4, pp 81 ff.

### Option expiries

Cinar, E and J Vu (1987): "Evidence on the effect of option expirations on stock prices", *Financial Analysts Journal*, vol 43, no 1, pp 55–7.

### Meta order market impact

Bershova, N and D Rakhlin (2013): "The non-linear market impact of large trades: evidence from buy-side order flow", *Quantitative Finance*, vol 13, no 11, pp 1759–78.

# Data requirements for FPM monitoring indicators

## Indicators and required data

Annex Table 1

| **(i) Market conditions** | **Traded prices** | **Traded volumes[1]** | **ToB data[2]** | **LOB data** |
|---|---|---|---|---|
| *Volatility*: measure of price stability. | Trade-by-trade (PV) | | | |
| *Spread*: measure of market tightness or roundtrip costs. | | | Millisecond (PV) | |
| *Depth*: measure of market resiliency. | | | | Millisecond (PV) |
| *Quoted volume imbalance*: measure of market-making balance. | | | | Millisecond (PV) |
| *Price impact of trades*: measure of resiliency and transaction cost (eg Kyle lambda, Amihud, sweep-to-fill cost). | | Millisecond (PV) | Millisecond (PV) | |
| *Traded volume*: notion of market activity and possibility to find opposing interest. | | Millisecond (PV, SV) | | |
| *Deal flow imbalance*: notion of symmetry between buying/selling interest. | | Millisecond (PV, [SV]) | | |
| *Arbitrage potential*: frequency/PnL of arbitrage or least-cost situations. | Trade-by-trade (PV, [SV]) | Trade-by-trade (PV, [SV]) | Tick-by-tick (PV, [SV]) | |
| *Jump frequency*: indicator for the regularity of price evolution. | Trade-by-trade (PV) | | Tick-by-tick (PV) | |
| **(ii) Market drivers** | **Forward prices** | **SDR data** | **Option vols** | **Customer flows** |
| *Flows by location or customer group*: informs about the origin/motivation of market moving transactions. | | | | Hourly |
| *Option expiries*: in-the-money expiries of large options might induce sizeable spot trades. | | Trade-by-trade | | |
| *Market maker delta hedging activity*: depending on the position of the MM (long/short) prices might be "sticky" or "slippy". | Seconds/Minutes | Trade-by-trade | Seconds/Minutes | |
| *News releases*: surprises in economic indicators might impact prices. | | | | |
| **(iii) Market impact** | **ToB data** | **Traded volumes** | **Traded prices** | **Own trades** |
| *Block impact*: measures the expected cost incurred due to price response to executing a series/block of trades. | Millisecond (PV, [SV]) | Trade-by-trade (PV, SV) | | Trade-by-trade |
| *Effective spread*: measure of the difference between prices obtained on trade vs prices just before a transaction. | Millisecond (PV) | Trade-by-trade (PV) | Trade-by-trade (PV) | |
| *Price response*: measure of expected short-term (eg 30s) price change after the execution of one trade. | Millisecond (PV) | | | Trade-by-trade |

PV = Primary venue; SV = Secondary venue.

[1] Signed volumes are required. [2] Quoted prices and volumes are required.

## Members of the study group

| | |
|---|---|
| Chair, Bank of England | Rohan Churm |
| Chair, Bank of France | Imène Rahmouni-Rousseau |
| Reserve Bank of Australia | Jason Griffin |
| Bank of Canada | Rhonda Staskow<br>Jun Yang |
| People's Bank of China | Wei Xu |
| European Central Bank | Istvan Mak |
| Bank of France | Alexis Laming<br>Sophie Perez |
| Deutsche Bundesbank | Yvonne Winkler |
| Reserve Bank of India | Manoranjan Padhy |
| Bank of Italy | Eleonora Iachini<br>Alfonso Puorro |
| Bank of Japan | Masao Fujiwara |
| Bank of Korea | Namhyun Cho |
| Bank of Mexico | Raúl Álvarez del Castillo<br>Edna Lopez Avila |
| Netherlands Bank | Evertjan Veenendaal |
| Monetary Authority of Singapore | Harry Lee<br>Alvin Teo |
| Bank of Spain | Marta Kuhnel Tormo |
| Swiss National Bank | Thomas Maag<br>Tanja Zehnder |
| Bank of England | James O'Connor<br>Liam Crowley-Reidy |
| Federal Reserve Bank of New York | Angela O'Connor<br>Alex Cohen |
| Bank for International Settlements | Andreas Schrimpf (Secretary)<br>Vladyslav Sushko |