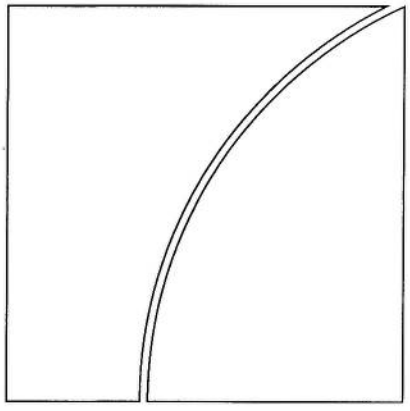
Markets Committee



The sterling 'flash event' of 7 October 2016

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Executive summary[1]

This report presents an analysis of the 7 October 'flash event' during which sterling depreciated by around 9% versus the dollar in early Asian trading, before quickly retracing much of the move. It draws on detailed analysis conducted by the Bank of England as well as intelligence gathered by the members of the BIS Markets Committee.

This analysis points to a confluence of factors catalysing the move, rather than to a single clear driver. Furthermore, it concludes that the time of day played a significant role in increasing the sterling foreign exchange market's vulnerability to imbalances in order flow.

The event can be split into three distinct phases. First, the early phase of the move, during which sterling depreciated rapidly from 1.26 to around 1.24 against the dollar in response to significant selling flow, but in an orderly fashion and with broad participation on key venues. Second, a period of a number of minutes of extreme dysfunction during which sterling fell further, rebounded and then traded in a wide range. This phase involved lower volumes and narrower participation, pointing to a greater role for the actions of individual market participants as a driver of the sharp moves. And finally, the gradual recovery in market liquidity over the hours that followed.

A number of factors are likely to have contributed to and amplified this market dysfunction. In particular, significant demand to sell sterling to hedge options positions as the currency depreciated appears to have played an important role. The execution of stop-loss orders and the closing-out of positions as the currency traded through key levels may also have had an impact. A media report released shortly after the move began, which would have been interpreted as somewhat sterling-negative, is only likely to have added marginal weight to the move as it did not contain new information. These factors appear to have contributed to the mechanical cessation of trading on the futures exchange and the exhaustion of the limited liquidity on the primary spot FX trading platform, which encouraged further withdrawal of liquidity by providers reliant on data from those venues.

The presence, outside the currency's core time zone, of staff less experienced in trading sterling, with lower risk limits and risk appetite, and with less expertise in the suitability of particular algorithms for the prevailing market conditions, appears to have further amplified the movement. Other factors such as 'fat finger' errors and potential market abuse cannot be ruled out, but there are little, if any, hard data to substantiate them.

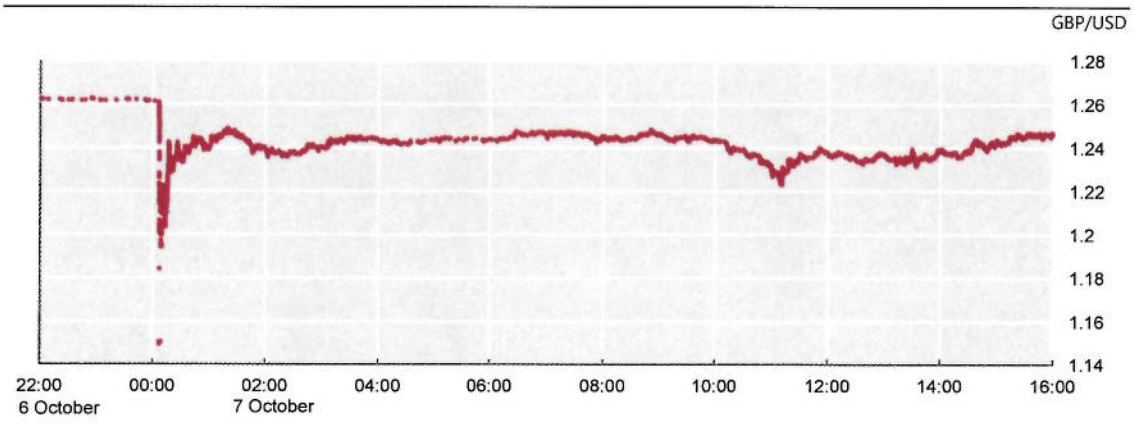
This event does not represent a new phenomenon but rather a new data point in what appears to be a series of flash events occurring in a broader range of fast, electronic markets than was previously the case in the post-crisis era, including those markets whose size and liquidity used to provide some protection against such events. There are a number of commonalities with previous flash events and similar

[1] This report has been prepared by an ad-hoc working group led by Rebecca Jackson, Liam Crowley-Reidy (Bank of England) and Andreas Schrimpf (Bank for International Settlements, Secretary) with input from Markets Committee central banks.

episodes. Unusually, there were few spillovers to other currencies or asset classes. And no systemic financial institutions incurred material financial losses in this instance. This might point to market participants having learnt lessons from past episodes.

Flash events to date have generally proved short-lived and without immediate consequences for financial stability. And the same appears to have been true of the sterling event. However, such events have the potential to undermine confidence in financial markets and hence impact the real economy. Therefore it is important for policymakers to continue to develop a deeper understanding of modern market structure and its associated vulnerabilities.

GBP/USD traded prices on Thomson Reuters Matching on 6–7 October — Graph 1



Sources: Bank of England calculations; Thomson Reuters.

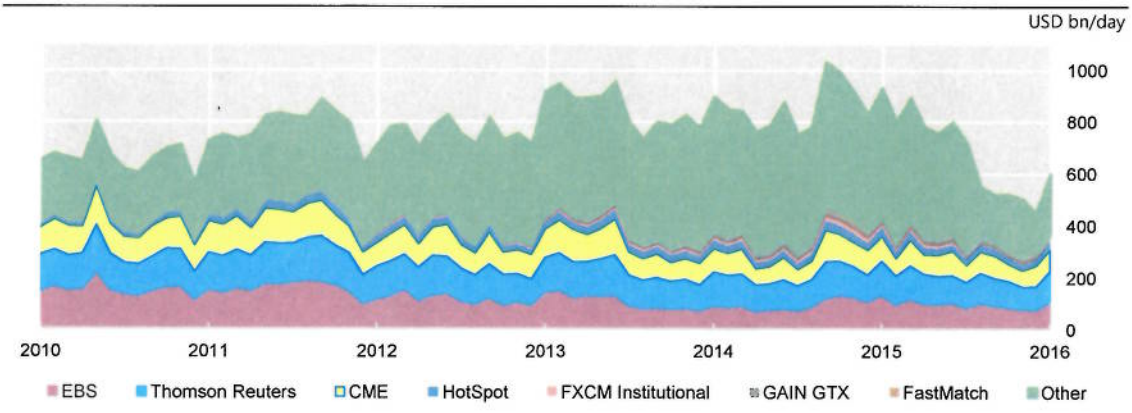
Introduction

On 7 October 2016, the BIS Markets Committee confirmed that it would, with input from the Bank of England, look into the events surrounding the so-called flash event in sterling (notably the sudden and large fall in the dollar exchange value of sterling, commonly referred to as cable) during early Asian trading on that day (Graph 1).

In line with the core responsibilities of the Markets Committee, this report focuses on the event primarily from the perspective of market functioning. It does not consider specific issues around market conduct during and around the event.

Given the fragmented nature of trading in the foreign exchange (FX) market (Graph 2) and the fact that the vast majority of trading is over the counter (OTC) and currently lacks a consolidated tape, analysis of currency movements will typically struggle to offer a complete view of market activity. This analysis focuses on activity on Thomson Reuters Matching, an inter-dealer platform, and the Chicago Mercantile Exchange (CME) futures exchange, drawing on market depth and anonymised transaction-level data – further supplemented by UK supervisory data on client orders and options-related hedging needs from the 12 most active banks in sterling FX. As such, the analysis can only provide a window into the trading activity during this period. And while these platforms are likely to have been the two most important for this event, the fact that these data are anonymised further limits the extent to which it is possible to draw conclusions on a number of points.[2]

FX spot volume,[1] by electronic trading platform — Graph 2



[1] Includes all FX trading activity, not just sterling FX pairs.

Source: MarketFactory.

Section 1 of this report presents a detailed analysis of price movements and market functioning during the event window, drawing on data and intelligence gathered from market contacts; Section 2 compares the event with similar large intraday moves in the FX market and other asset classes; and Section 3 concludes,

[2] Thomson Reuters Matching and the CME are each thought to account for around 5–10% of trading in sterling FX during normal times, and these proportions are thought to increase during periods of thin liquidity and stress, according to market participants.

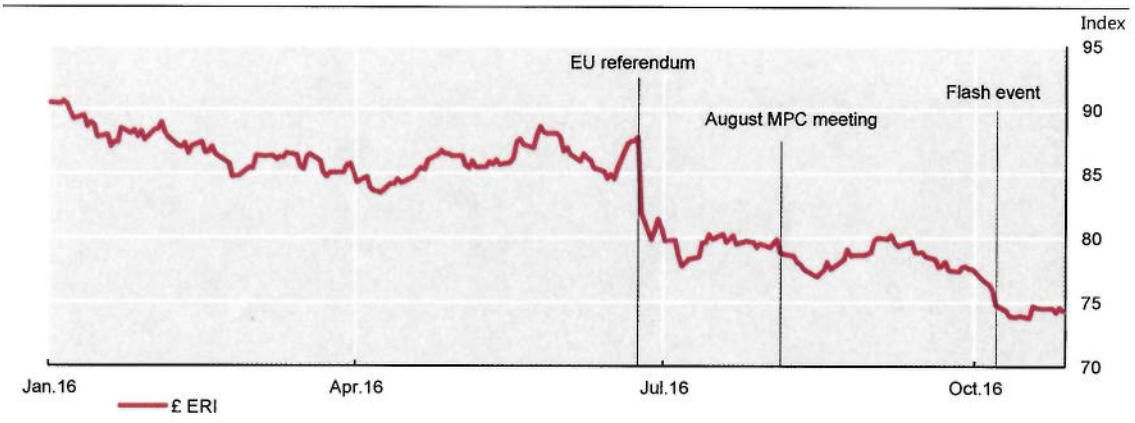
drawing out the lessons from 7 October and the possible policy consequences. Further background information is provided in the Appendix. Appendix A provides background information on the structure of the FX market, Appendix B presents a simple econometric analysis of trends in intraday FX market liquidity, and Appendix C provides a more detailed comparison of the sterling flash event with the so-called 'flash rally' in US Treasuries in October 2014.

1. Event window analysis

Before looking in detail at the moves of 7 October, it is important to provide context on broader moves preceding the event, the time of day and the structure of the FX market.

During the week prior to 7 October, sterling had trended lower against most major currencies, with the sterling exchange rate index falling from a level of around 77.5 to 75.9 (Graph 3) and GBP/USD falling from 1.285 to just over 1.26 at the 6 October London close. Over this period, moves in sterling were largely uncorrelated with other currencies, pointing to idiosyncratic drivers. But, despite their magnitude, these moves had been relatively orderly. And measures of implied volatility had ticked up only slightly from their post-EU referendum lows.

Sterling exchange rate index[1] Graph 3



[1] Exchange rate index (100 = January 2005).

Sources: Bank of England calculations; Bloomberg.

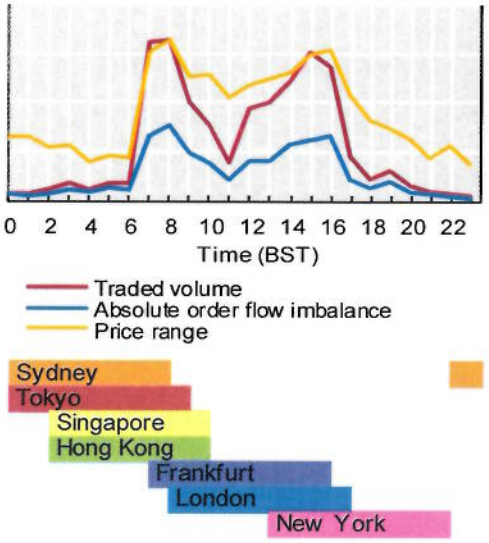
Activity in GBP/USD is highest in the morning (around 7–9 am UK time), as well as in the afternoon (1–5 pm UK time) when the London and New York markets are open. And despite occasionally large imbalances between buying and selling order flow during the day, this is when measures of liquidity are also the highest. Conversely, both trading volumes and measures of liquidity are observed to drop off outside these periods – particularly during the early hours of Asian trading. Appendix B provides further details on these dynamics.

Graph 4 shows a number of key measures of activity and liquidity averaged for each hour of the day, based on data from 3–6 October, the four days before the flash event. The coloured bars show when the large FX trading jurisdictions are open

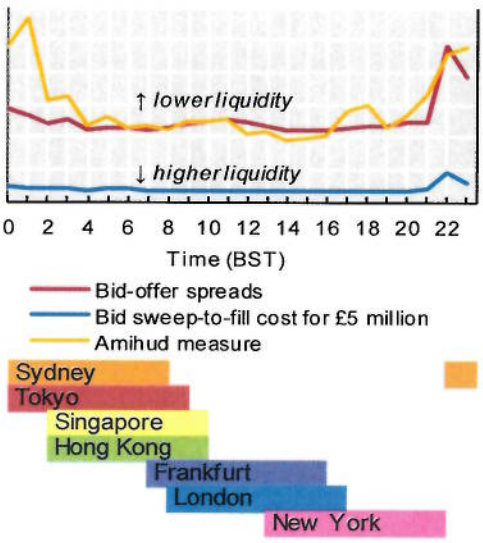
(although some trading in the jurisdictions in question does take place outside the marked hours).

Intraday GBP/USD activity on Thomson Reuters Matching (3–6 October) Graph 4

Intraday activity in GBP/USD and trading hours[1]



Intraday GBP/USD liquidity and trading hours[1, 2]



[1] These measures are presented without scale for confidentiality reasons. [2] Sweep-to-fill costs are calculated as the weighted average spread (from the implied mid-price) required to buy or sell a given quantity of sterling (£5 million here) versus the dollar.

Sources: Bank of England calculations; Thomson Reuters.

1.1 A flash event in three stages

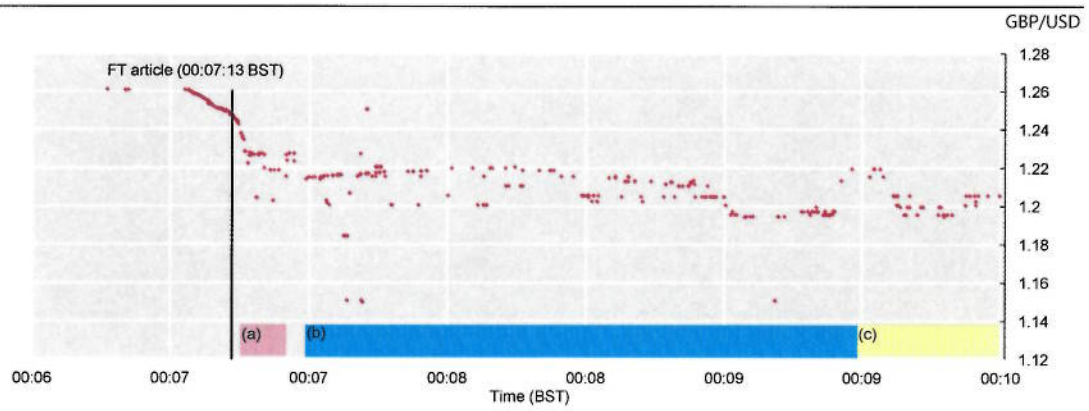
The sterling flash event of 7 October can be broken down into three stages: an initial sharp, but orderly depreciation of sterling that lasted for a matter of seconds; a period of less than 10 minutes of extreme dysfunction that saw sterling fall further, rebound and then trade in a wide range; and a relatively slower recovery as liquidity returned to the market. Graph 6, based on Thomson Reuters Matching order book data, maps this process over a 20-minute window.

Stage 1: Shortly after midnight British Summer Time (BST), equivalent to Greenwich Mean Time (GMT) plus one hour, on 7 October, trading volumes picked up sharply and sterling began to depreciate against other currencies (Graph 5). Over a period of around eight seconds (00:07:03 to 00:07:11 BST), sterling fell from 1.2600 to 1.2494 against the dollar, based on the Reuters mid-price.[3] During this time, around £252 million of GBP/USD (Graph 7) and €52 million of EUR/GBP was traded on Reuters, of which the vast majority represented so-called 'aggressive' sales of

[3] Calculated as the mid-point between the best bid and offer prices.

sterling – pointing to a very significant imbalance in order flow.[4] Despite the magnitude of the move and the volumes transacted, GBP/USD bid-offer spreads remained little changed until around 00:07:14 BST and measures of the price impact of transactions over this period were relatively low.[5]

Thomson Reuters Matching GBP/USD trades[1] and CME trading halts on 7 October Graph 5



[1] Each dot here represents a traded price on Thomson Reuters Matching.

[(a)] 00:07:15 BST: sharp price movements over a two-second window trigger a velocity logic event which pauses trading on the CME for 10 seconds.
[(b)] 00:07:29 BST: the futures price reaches its lower limit of 122.17 (based on the change on the day). The exchange remains open, but transactions cannot take place below this price on the CME. A two-minute monitoring period begins.
[(c)] 00:09:29 BST: as the futures price has not rebounded from the lower limit by the end of the monitoring period, a further two-minute trading halt is triggered on the CME. At 00:11:29 BST, the exchange reopens with a new (lower) price limit.

Sources: Bank of England calculations; CME; Thomson Reuters.

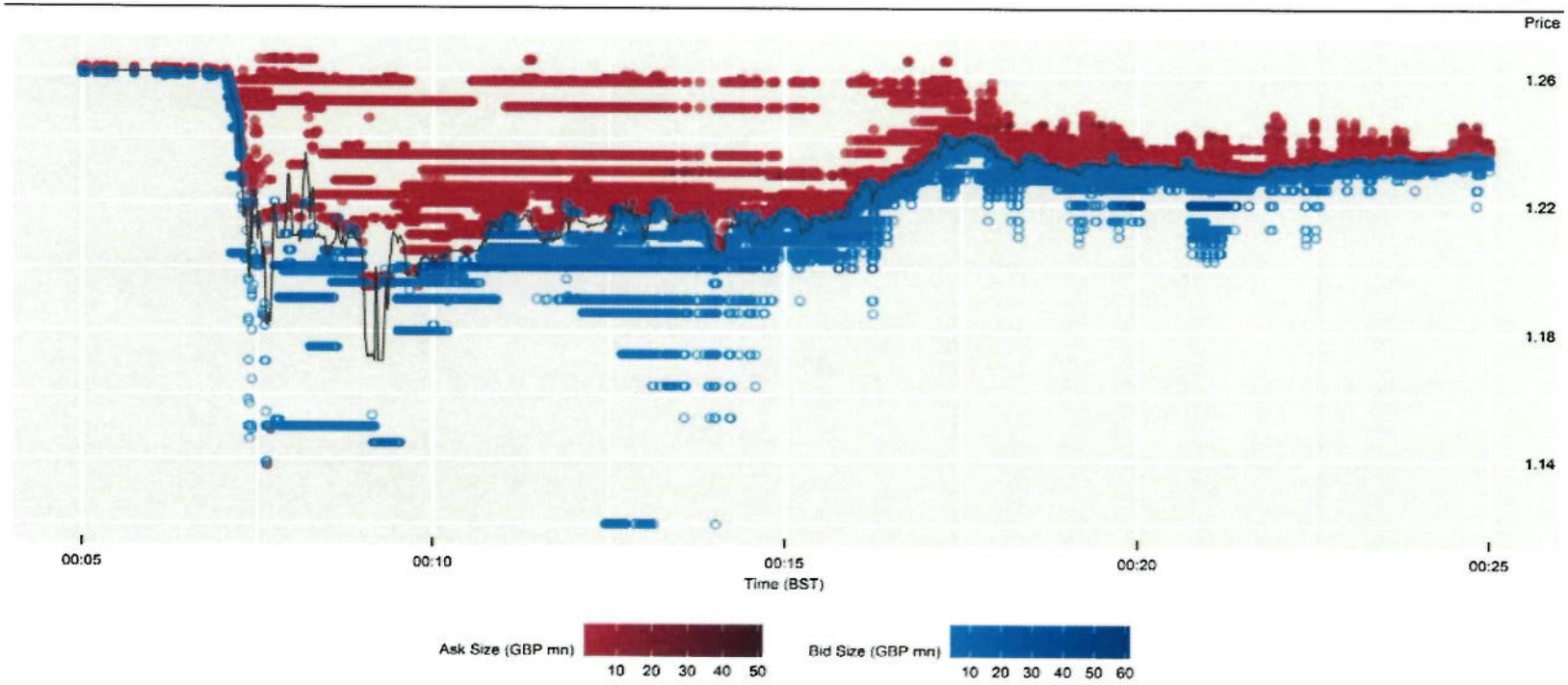
At 00:07:13 BST, the *Financial Times* (FT) published an article entitled "Hollande demands tough Brexit negotiations" on its website. The story was repeated on a variety of news wires. Market participants note that this release would have been interpreted as somewhat sterling-negative, but it did not represent new information. The comments from President Hollande were made at a widely attended event earlier that evening and had featured in similar form on a variety of well known news websites (including in English) prior to the publication of the FT article. Indeed, as can clearly be seen in Graph 5, the initial moves preceded its release. However, in the midst of the broader moves, it is conceivable that at the margin this may have acted to exacerbate the existing volatility.

4 Every trade in a central limit order book (CLOB), such as Thomson Reuters Matching, consists of an aggressive buy or sell order matching against a limit order. The aggressive order represents a drain on available liquidity, whereas inputting limit orders (at a pre-specified price) adds to the available depth of liquidity. An uneven balance between aggressive buying and aggressive selling, referred to as an order flow imbalance, is often linked to sharp price moves.

5 For example, the Amihud measure of price impact, which calculates the ratio between price moves and volumes traded.

Thomson Reuters Matching GBP/USD order book behaviour[1] on 7 October

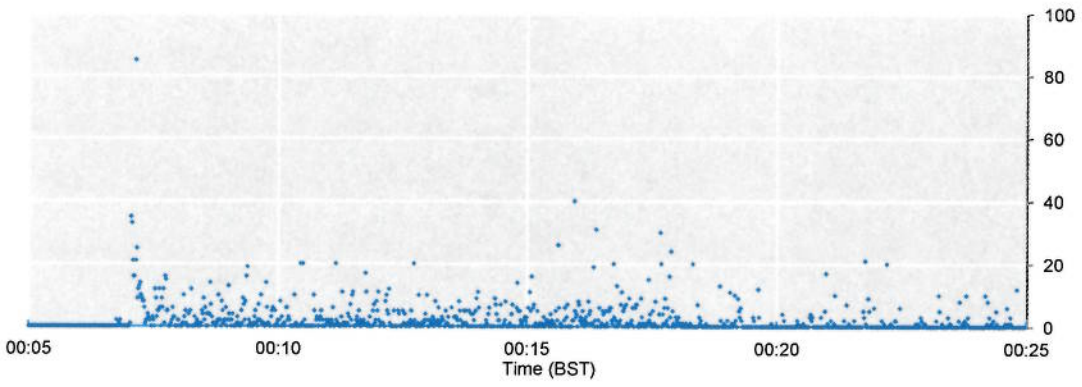
Graph 6



[1] The blue and red circles here represent resting bid and offer limit orders, respectively, in the order book. The black line represents the implied mid-price, and the intensity of the blue and red colours signifies the size of the order.

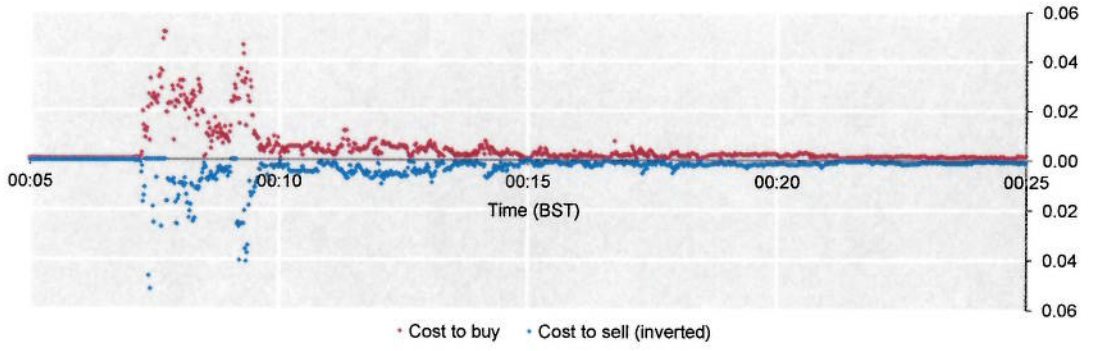
Sources: Bank of England calculations; Thomson Reuters.

Thomson Reuters Matching GBP/USD trading volumes on 7 October — Graph 7



Sources: Bank of England calculations; Thomson Reuters.

Thomson Reuters Matching GBP/USD £5 million sweep-to-fill-costs[1] on 7 October — Graph 8



[1] Sweep-to-fill costs are calculated as the weighted average spread (from the implied mid-price) required to buy or sell a given quantity (£5 million here). Gaps in the series represent periods where there is insufficient depth in the order book to complete a transaction of this quantity in the respective direction.

Sources: Bank of England calculations; Thomson Reuters.

Stage 2: At 00:07:15 BST, the CME triggered its velocity logic mechanism, which pauses trading for 10 seconds on the futures exchange, in response to the large moves in the preceding two seconds. At this point, bid-offer spreads in the spot market widened significantly. It is not possible to disentangle the impact of the trading pause on the CME, if any, on spot market liquidity from the impact of the preceding large price moves. After reaching 1.24 on Reuters (at 00:07:15 BST), GBP/USD accelerated its fall and market functioning continued to deteriorate. From this point onwards, and particularly past the 1.22 level in GBP/USD, price gapping between trades is increasingly visible (Graph 5). And by 00:07:34 BST, 19 seconds later, GBP/USD had reached 1.20 and the move had exhausted the resting sterling bids across a variety of electronic trading platforms' order books. This unusual

phenomenon occurred at several points during this period, with EUR/GBP also affected by an intermittent evaporation of offers to sell euros (and buy sterling).

While bids quickly returned to the market, overall depth in the order book remained extremely low for several minutes. Those wishing to trade could only execute in relatively small sizes and at prices at a wide spread to the implied mid-price (Graph 8). For example, on Reuters prices as low as 1.1491 in GBP/USD traded at 00:07:41 BST – which represented a fall of almost 9% from the pre-event level of 1.26. Other platforms reported transactions at even lower prices. In EUR/GBP, the highest traded level on Reuters was 0.9403, at 00:09:49 BST – representing a 6.3% appreciation of the euro relative to sterling from the level around three minutes prior.

During this period, it is likely that the trading activity of individual participants could have had a significant impact on market functioning and prices traded, given the lack of depth. Indeed, UK supervisory data point to a significant increase in certain market participants' share of trading activity as others withdrew – suggesting a role for idiosyncratic factors in driving the extreme dysfunction observed as sterling traded at levels well below 1.20 against the dollar.

It is worth noting that some of the trades executed during this period were subsequently torn up or had their prices revised, but this was often the consequence of bilateral agreements or specific contractual arrangements as there is no single methodology for determining the low in FX markets. Market contacts suggested they did not feel able to co-ordinate in determining a low point (which is relevant for certain derivatives contracts) as they feared this would breach competition and/or conduct requirements.

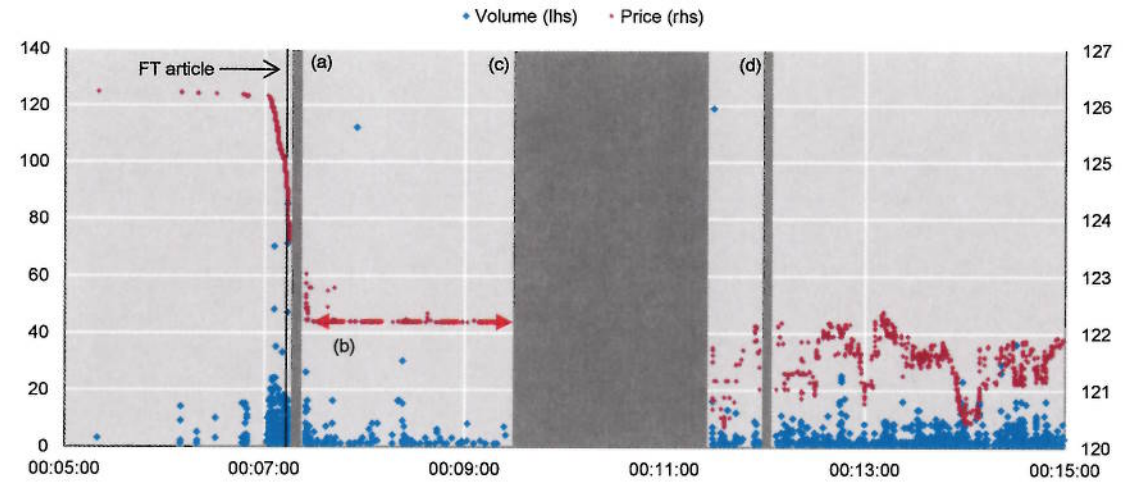
The lows in sterling were extremely short-lived. Between 00:08:00 and 00:09:00 BST, GBP/USD traded at levels between 1.20 and 1.22 – still a wide range. Market functioning took longer to recover. Sweep-to-fill costs (a measure of market depth) on Reuters remained volatile until nearly 00:20:00 BST, a period over which the CME triggered a number of further trading halts (Graph 9). Shortly after the first pause in trading on the CME ended, the futures price hit the daily lower limit of 122.17.[6] At this point, futures trading was floored at this price for a period of two minutes. Some transactions were completed on the CME over this period, despite the spot price continuing to fall on other platforms. But when prices had not risen by the end of the two-minute window, a two-minute trading halt was imposed at 00:09:29 BST. The market reopened at 00:11:29 BST with a new lower limit, but conditions remained impaired (for example, as seen in measures of the price impact of trades). Finally, amid the continued heightened price volatility, a second velocity logic event was triggered at 00:11:57 BST, again halting trading for 10 seconds on the futures exchange.

Stage 3: Over time the market began to recover, although it is difficult to identify a clear shift to the recovery phase. By around 00:20:00 BST, prices in both the futures and spot market had settled around 2.2% lower against the dollar than their levels immediately prior to the event, although relatively high trading volumes (for the time of day) persisted for a period of three to four hours. Bid-offer spreads on Reuters remained wider than usual, but not at extreme levels, for the rest of the night.

[6] Futures prices are not directly comparable to spot FX prices, but the two should move closely in line, absent large changes in relative interest rates or the cross-currency basis.

CME GBP/USD futures volumes (blue) and traded prices (red) on 7 October

Graph 9



(a) 00:07:15 BST: sharp price movements over a two-second window trigger a velocity logic event which pauses trading on the CME for 10 seconds.

(b) 00:07:29 BST: the futures price reaches its lower limit of 122.17 (based on the change on the day). The exchange remains open, but transactions cannot take place below this price on the CME. A two-minute monitoring period begins.

(c) 00:09:29 BST: as the futures price has not rebounded from the lower limit by the end of the monitoring period, a further two-minute trading halt is triggered on the CME. At 00:11:29 BST, the exchange reopens with a new (lower) price limit.

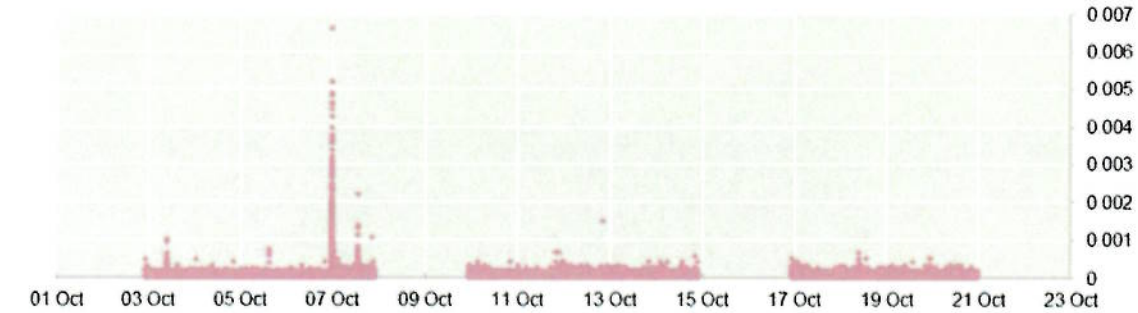
(d) 00:11:57 BST: a second velocity logic event is triggered by sharp price movements over a two-second window, again pausing trading for 10 seconds

Sources: Bank of England calculations; CME; Bloomberg.

Higher than usual GBP/USD volumes were observed on Reuters during the day on 7 October, and measures of market illiquidity were slightly elevated (see Appendix B for more details). But broader spillovers were generally limited. UK government bonds registered a relatively large move as trading opened on 7 October, but the moves were orderly. And there appeared to be little impact on risky asset prices. GBP/USD closed in London on 7 October 1.7% lower than on the previous day.

In the weeks following the event, there was little observable evidence of a lasting impact on market functioning. Option-implied volatility in sterling FX pairs remained elevated for a number of days before retracing, but it is difficult to determine whether or not this reflected factors other than the flash event. Bid-offer spreads appeared to quickly recover to around normal levels, with no evidence of impaired market functioning when trading recommenced on the evening of Sunday 9 October. And measures of the price impact of trading activity showed no signs of any persistent impact on liquidity in the futures market in the weeks that followed (Graph 10).

Liquidity in CME GBP/USD futures[1] Graph 10



[1] Liquidity is measured via the Amihud measure, which calculates the price impact of individual trades as the ratio of the associated price move (measured since the last trade) to the traded volume. Higher values are typically associated with illiquid trading conditions.

Sources: Bank of England calculations; Bloomberg.

1.2 Triggers, vulnerabilities and amplifiers

This analysis points to a confluence of factors catalysing the moves of 7 October, rather than to a single clear driver. In particular, it is important to recognise that this event occurred during a typically illiquid period of the trading day for sterling FX, further impaired by regional bank holidays, including in China. During this period, there is typically a shallower order book and a heightened sensitivity to increased volumes and/or volatility, which suggests that the market is likely to have been better able to cope with the large moves observed in the early stages of the flash event had they occurred during the core trading day.

Early commentary pointed to the publication of the FT article as the driver of initial sterling selling, but as described above, the timings do not match such an interpretation. Market contacts have since pointed to other candidate triggers: for example, a so-called 'fat finger' trade,[7] a deliberate attempt to move the price lower during a typically illiquid period, or Asian retail trading in sterling. But in each case market participants were unable to offer definitive evidence to substantiate these hypotheses.

As well as the time of day, contacts have identified a number of potential pre-existing vulnerabilities going into the event that appear to have amplified both the price movement and the deterioration in market functioning. Chief among these are dealers' options-related hedging flows and client orders, including stop-loss orders. Both represent a source of mechanistic demand for liquidity in response to changes in the level of the exchange rate. Broader metrics of speculative investor positioning in sterling were biased to the short side going into the event, seemingly ruling out an unwind of crowded speculative positions – as thought to have featured in the October 2014 flash rally in US Treasuries – as an exacerbating factor. But both options hedging and, to a lesser extent, the execution of stop-loss orders appear to have predominantly forced additional selling of sterling as the price fell.

[7] For example, a larger than intended trade input in error – which would not necessarily show up in this data set if initially executed on another platform.

Dealers usually seek to hedge options positions by buying or selling the underlying security,[8] in order to maintain a neutral position with respect to small further price movements. As these options positions feature non-linear payoffs, for larger price movements this can involve buying or selling large quantities of the underlying security. And this hedging may sometimes be undertaken in an automated manner, without respect to prevailing liquidity conditions or the likely market impact.

Similarly, client orders can prompt mechanistic selling (or buying) when prices reach a certain level. Both retail and institutional investors often leave such orders with dealers in order to close out positions quickly and thus limit potential losses or to initiate new trades at specific entry levels. It is notable that some intermediaries have suggested that the execution of such orders has become more indiscriminate with respect to the impact on market functioning – either because they are less confident in their ability to manage such orders with discretion or their interpretation of best execution requirements for retail customers does not allow for such discretion. Again, this has the potential to lead to trades being executed irrespective of the prevailing liquidity conditions or the likely market impact.

Relatedly, retail FX clients can sometimes also be automatically 'stopped out' by their brokers, mechanistically and without discretion, in the event of mark-to-market losses causing them to no longer meet their margin requirements. In some instances the entire position will be liquidated.

Retail aggregators and dealers may not be alone in feeling compelled to 'chase' prices lower. High-frequency market-makers, with limited risk appetite and capital may also feel the need to trade during a sharp market movement as they look to close out positions.

UK supervisory data gathered from 12 of the most active dealers in the sterling spot FX and options markets suggest that options hedging and, to a lesser extent, stop-loss orders may help to explain the significant order flow imbalance observed during the flash event. Graph 11 displays the potential cumulative impact of these mechanistic flows.[9] Not all of this volume is likely to have been transacted given the level of dysfunction and the fact that options hedgers in particular may retain a degree of discretion. But, taken at face value, it represents a significant proportion of the total value traded during the event window and would constitute sizeable volume even during the more active London trading hours.

The initial price move and sharp increase in selling flow on 7 October aligns closely with a breach of the 1.26 level in GBP/USD, potentially indicative of a role for mechanistic selling needs around this level. And it is striking to note that the largest net selling pressure observed in these data coincides with a fall in GBP/USD through 1.24 – the point at which there was a significant pickup in price gapping and broader dysfunction.

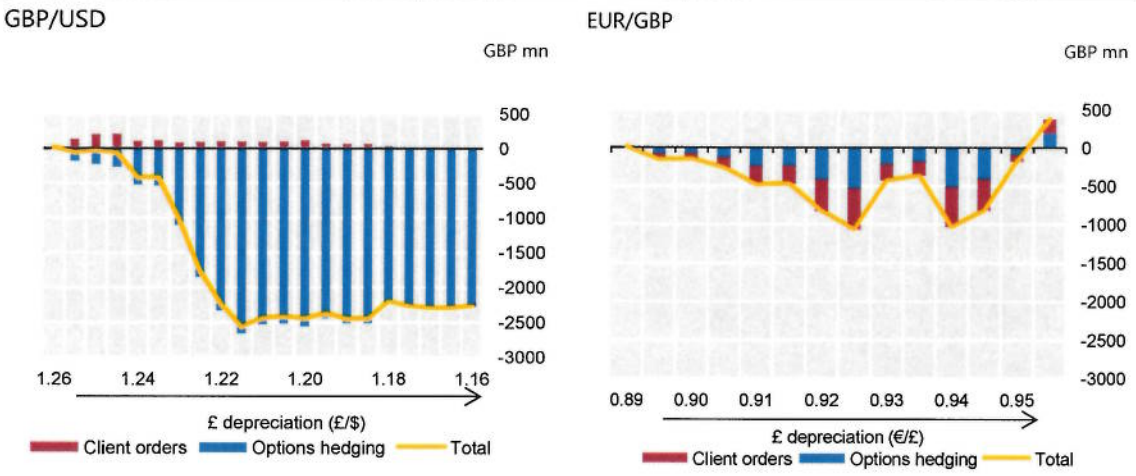
Across GBP/USD and EUR/GBP, the combined maximum potential selling needs of roughly £3.5 billion from the peak to trough price levels is significant compared with the volumes observed across the CME and Reuters, which totalled just over £2 billion between 00:05:00 and 00:15:00 BST. Furthermore, the potential selling pressure from these two activities flattens off at around the prices the market reached

[8] Or exchange rate pair in the case of FX.

[9] These data do not capture retail brokers and therefore may underestimate the role played by stop-loss orders left by such investors or automatic stop-outs.

Cumulative net potential selling needs from options hedging and client orders generated by a sterling depreciation[1]

Graph 11



[1] Data are as of New York close of business on 6 October.

Source: Bank of England calculations.

at its lowest point, indicating that the abatement of this pressure may have helped the market to stabilise.

The steep profile of GBP/USD options hedging demand (Graph 11) may reflect the fact that dealers were thought to have gone into the event with large positions in barrier options. These derivatives contracts feature so-called knock-outs or knock-ins based on the spot price which, once breached, can dramatically alter the risk profile (and hence the associated hedging needs) of the position – closing out the exposure in the case of a knock-out, or initiating a new exposure in a knock-in. These features can give rise to potentially destabilising hedging dynamics, whereby dealers are required to buy or sell large quantities of the underlying at certain price levels in order to neutralise their resulting delta risk.[10]

1.3 Liquidity withdrawal as an amplification mechanism

Automated (or algorithmic) market-makers often respond to stress in much the same way one might expect a human trader to (see Appendix A). Firms will naturally become more cautious in pricing risk during bouts of volatility and will widen prices before ceasing quoting altogether when certain thresholds are breached. These can include simple P&L limits, or when wide, stale or off-market pricing inputs are identified. For example, some market-makers are thought to rely on the CME to provide an additional pricing source, and so during the periods when the futures exchange was halted, this is likely to have made it more difficult for them to make prices in the cash market. And to the extent that such participants' provision of liquidity is keyed (indirectly) off that of their peers, any significant withdrawal of liquidity has the potential to become self-reinforcing.

[10] Delta represents an option holder's first-order exposure to price movements in the underlying, which options desks typically aim to avoid.

Market participants exhibited a variety of responses to the increasing market dysfunction on 7 October. Some remained active throughout, with automated pricing widening for a time in recognition of the increased volatility, while others widened initially and then halted as protection mechanisms kicked in. Some firms withdrew first from voice trading, others from e-trading. Such halts lasted anywhere between two and 30 minutes. Some recommenced trading automatically when conditions stabilised, but many required management override. For some it was their algorithmic trading that restarted first (although often with human intervention to allow the restart), for others their voice activity. Those withdrawing liquidity cannot be readily categorised by type of institution – various major dealers, principal trading firms and firms representing a retail client base confirmed that they withdrew liquidity provision from the market during the event.

According to market participants, this dynamic may have been further exacerbated by the presence, outside the currency's core time zone, of staff at some institutions who were less experienced in trading sterling. Such individuals were likely to have had lower risk limits and risk appetite, and may have had less expertise in the suitability of particular algorithms for the prevailing market conditions. Evidence in the UK also suggests that some traders' participation during the event may have been constrained as a result of concerns around potential market and conduct risks associated with trading in illiquid markets away from previous prevailing price levels. Both factors could have exaggerated the speed and dysfunctional nature of the price movement.

2. Comparison with previous flash events and similar episodes

There have been a number of episodes of intraday volatility associated with short-term illiquidity over the past few years – so called flash events. This section compares the sterling event of 7 October with a number of similar historical episodes and explores the possible impact on the real economy. Table 1 in the Appendix lists the characteristics of a range of sharp intraday moves in the FX market and Appendix C compares the sterling event with the so-called 'flash rally' in US Treasuries in October 2014. A number of commonalities can be drawn out from these events, many of which also played a role on 7 October.

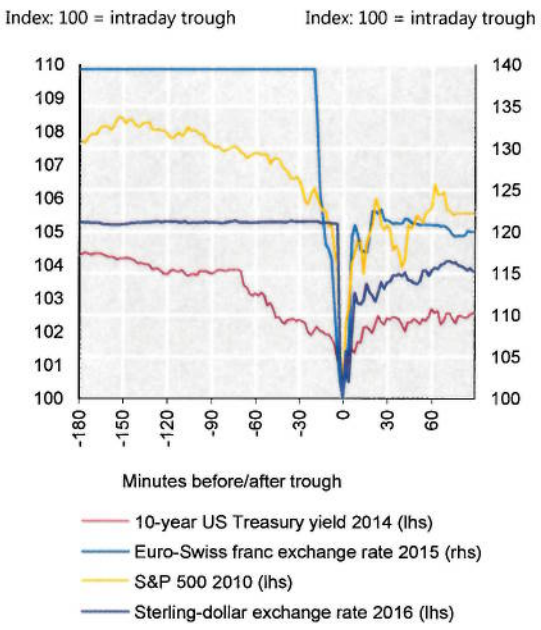
These episodes have been outwardly similar in a number of ways (Graph 12, left-hand panel). They typically feature a fast and exceptionally large v-shaped (or inverted v-shaped) movement in the price of a financial asset that cannot be fully explained by news or economic data. Trading volumes during such moves tend to be unusually high relative to typical liquidity for the relevant market in the relevant time window (in some events this volume spike results in truly exceptional levels of activity whereas in others volumes peaks are more modest). And the speed at which they unfold suggests a role for automated, high-frequency trading behaviour – either on behalf of end-investors, traditional intermediaries or other liquidity providers such as principal trading firms (PTFs).

Flash events have largely centred on fast, electronically-traded markets, including FX, US government bonds and equities. These markets are similar in that they allow for trading over central limit order books, often with a high degree of PTF activity, and offer a greater degree of price transparency than other markets.

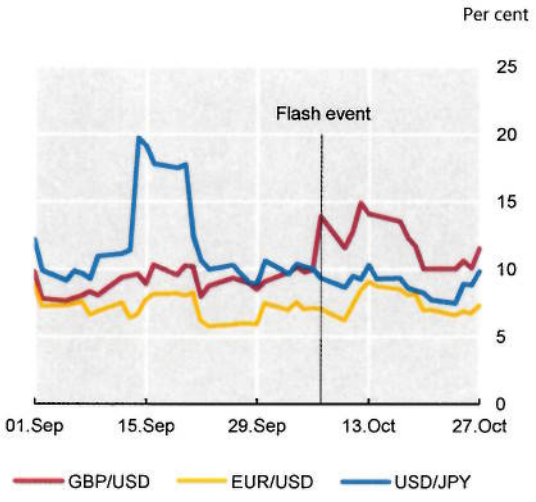
Fundamental economic news has acted as a trigger in some historical cases of sharp intraday moves. For example, the Swiss franc move in January 2015 had a clear driver. But most others appear to relate more to technical factors: imbalances in order flow that appear hard to explain, or outsized reactions to news releases that might otherwise be expected to be of little consequence.

Graph 12

Selected historic intraday moves



1-week option-implied FX volatilities around 7 October



Sources: Bank of England calculations; Bloomberg.

Such events often occur against a backdrop of already fragile market conditions. Order flow imbalances are more likely to destabilise markets if they occur during periods of thin liquidity. For example, many – like the sterling event – have occurred during quiet trading hours for the market in question, when the supply of liquidity is thinnest and most susceptible to a rapid withdrawal.

Correlated and mechanical responses to shocks, including an unwind of crowded positioning or derivatives hedging flows, can amplify price movements and jeopardise market liquidity. Such responses to the initial fall appear to act as amplifiers in some of the episodes of volatility described in Table 1. In particular, prices can move through levels at which options hedging amplifies moves, and investors may be mechanically forced to unwind positions as they hit stop-loss limits. Similarly, high-frequency market-makers and retail aggregators may be forced to 'chase' prices lower as they look to close out positions.

Weaknesses in trading infrastructure can become exposed under stressed circumstances. Given the reliance of liquidity providers on data inputs from public venues for their trading strategies and risk management, the quality of data is an important component to their ability to operate. During the Swiss franc event, several banks suffered from 'latency problems', meaning that pricing on their electronic platforms could not keep up with the pace of market developments. However,

infrastructure problems do not appear to have played a role on 7 October. Banks and major FX platforms did not report any operational or infrastructure issues over the course of the event.

Flash events in non-FX asset classes share a number of similarities with the 7 October sterling moves, but also exhibit notable differences – as detailed for the US Treasury flash event in Appendix C. Similarly, while the sharp moves in equity prices on 24 August 2015 were in part linked to specific technical issues around the opening of the cash market, both this and the sterling event appear to have been potentially exacerbated by the presence of circuit breakers, or trading halts, in some but not all trading venues or parts of the market.

Flash events to date have generally proved to be short-lived and without immediate consequences for financial stability. But if occurrences of heightened intraday volatility were to increase in frequency, or if disruption persisted for longer in future episodes (at the extreme this could involve a flash event that did not self-correct ie one which moved a market to a new, non-fundamental, equilibrium), confidence in these markets could be undermined, potentially impacting financial stability. In the FX market, this could manifest in a number of ways. Market-makers may demand additional compensation for liquidity provision, impairing market liquidity via wider bid-offer spreads and/or higher margin requirements. Or end-investors may show an increased reluctance to hedge due to concerns that their hedges will be crystallised not by the persistent changes in rates that would affect the terms of their real economy activity but rather by short lived market phenomena. Were these dynamics to play out, there could be knock-on consequences for the real economy.

Historical episodes provide relatively limited evidence of persistent effects on transaction costs or hedging. In some cases, market functioning appears to have been impacted for a short period of time. As detailed in Appendix B, US Treasury market liquidity took around a week to recover from the 2014 flash event. In other cases, including the 7 October sterling event, liquidity appears to have recovered more quickly. But in the weeks following 7 October it was notable that a number of retail trading platforms increased their margin requirements for clients trading sterling FX, which may encourage prudent risk management but at the cost of higher transaction costs.

Measures of forward looking volatility or uncertainty have also tended to increase in the aftermath of such events (Graph 12, right-hand panel). But this is not unusual following any volatile episode, and again the effects appear to be short-lived.

3. Conclusions and policy implications

This analysis does not point to the 7 October sterling flash event as a new phenomenon; rather, it represents an additional data point in what appears to be a series of flash events occurring in a broader range of fast, electronic markets than was previously the case, including those markets whose size and liquidity used to provide some protection against such events.[11] This section draws out a number of points for

[11] It is necessary to point out, however, that while flash events in fast, electronic markets appear to be a relatively modern phenomenon, historic episodes of significant price gapping and/or discontinuous liquidity provision also occurred in manual or voice-traded markets.

further consideration, while bearing in mind that many of the key dynamics at play have been observed in the past.

Based on the available evidence, this event appears to have been the product of a confluence of factors. Whatever the cause of the initial selling in sterling, the market was likely to be vulnerable at that time of day to sharp moves and an associated withdrawal of liquidity. It is possible to distinguish between three distinct phases of the event. First, the early phase of the move, during which sterling depreciated rapidly from 1.26 to around 1.24 against the dollar in response to significant selling flow, but in an orderly fashion and with broad participation on key venues. Second, a period of a number of minutes of extreme dysfunction during which sterling fell further, rebounded and then traded in a wide range. This phase involved lower volumes and narrower participation, pointing to a greater role for the actions of individual market participants as a driver of the sharp moves. And finally, the gradual recovery in market liquidity over the following hours.

These moves are likely to have been amplified by a variety of factors, including options-related hedging flows and, to a lesser extent, the execution of stop-loss orders and the closing-out of positions as the currency traded through key levels against both the dollar and the euro. Coincidental adverse news headlines could have, at the margins, added weight to the move. And less experienced traders deployed outside the core time zone for the currency, with lower risk limits and less expertise in the suitability of particular algorithms for the prevailing market conditions, may also have contributed to the movement and delayed the recovery.

The withdrawal of liquidity in response to these factors was rapid, though, given the time of day, not necessarily unexpected. That said, the complete erosion of resting orders to buy sterling (against both the dollar and the euro) for very short periods was highly unusual. And the fact that the futures exchange was halted for a large proportion of the event may have further amplified the dysfunction in the cash market, given the extent to which automated market-makers apparently rely on the CME as an additional pricing source and hedging tool.

Other factors such as 'fat finger' errors and potential market abuse cannot be ruled out given the incomplete data set, but there are little, if any, hard data to substantiate them.

It is important to consider what can be learnt from this event in order to inform relevant policy debates. Whilst acknowledging that such episodes may present risks to financial stability in future, a number of positives can be taken from the 7 October flash event:

- There appear to have been no material losses incurred by systemic financial institutions. A number of market participants highlighted the positive impact of the lessons they had learnt from the January 2015 Swiss franc event for the calibration of their risk appetite and trading methodologies.
- The initial sharp depreciation in sterling retraced rapidly, and market functioning recovered relatively quickly with it – indeed, faster than in some previous events, as highlighted in Section 2.
- Despite the seeming fragility of market liquidity, large volumes were able to be transacted around the event window.
- Spillovers to other markets were practically non-existent, a unique feature of the sterling event.

There are direct lessons from the 7 October flash event for the new FX Global Code. Among other things, these relate to market participants' obligation to consider the disruptive consequences of their trading activity (for example, in relation to best execution requirements during periods of poor liquidity); governance around algorithmic execution of trades, including possible controls to boost resilience to the loss of data from public venues; and, in conjunction with industry bodies, how market participants might best determine the low (or high) point of pricing in a flash event. These have already been taken on board by the Foreign Exchange Working Group (FXWG), which is responsible for the development of the Global Code.

How market participants react to and learn from events such as this is important for the likelihood of them occurring again and for the consequences thereof. A move by liquidity providers to further self-protect by increasing their sensitivity to emerging dysfunction could be individually rational but undesirable at an aggregate level. Indeed, many institutions noted that they were content to have withdrawn from the market despite the financial incentive to have offered liquidity to sellers of sterling at the extreme lows.

That said, it is possible that others more able to appropriately bear the associated risks will step in to take the place of some of these traditional intermediaries. Market participants may themselves alleviate some of the amplification channels identified in this report by fine-tuning systems and processes – and thus reducing the likelihood of flash events occurring with the same frequency in future.

While the events of 7 October do not appear to represent a new phenomenon, they reinforce the need to better understand modern market structure and its associated vulnerabilities. In particular, there is still a relatively limited understanding of the implications of widespread automated trading, the reduced role of traditional market-makers, and the increasingly important role of PTFs and other non-bank liquidity providers in FX and other markets. This combination of new participants, changes in market-making and the advance of technology raises important questions about the evolving nature of liquidity and resilience in financial markets – and the possible impact on the real economy – that policymakers should address.

Notwithstanding policymakers' ability to understand the dynamics of flash events ex post, limited progress has been made in terms of how one might predict or react to them. Building such capability is likely to require a combination of further research and better data collection.

Flash events have important consequences for both micro-supervisory policy (including prudential and conduct regulation) and macroprudential policy. Indeed, as detailed above, any response on behalf of market participants or the regulatory authorities has the potential to create trade-offs between these competing priorities – in particular, between the resilience of individual market participants and that of the liquidity of the market as a whole.

Appendix

A. FX market structure

The FX market is fundamentally based on OTC cash-for-cash transactions, primarily via risk transfer in principal-to-principal bilateral trading arrangements for: payment for goods and services abroad, investing in overseas assets, hedging foreign currency exposures, and active management of portfolios, including for speculative purposes. It trades 24 hours a day, five and a half days a week and comprises participants from a vast and diverse community.

FX is not a centralised, organised market. But trading in the major currencies has become more homogenised, moving the spot FX market towards a more 'equity-like' structure, with a hybrid of trading styles, including principal and agency activity, some of which can require the application of best execution guidelines.

The FX market, although highly fragmented, is technologically advanced, and is linked through a wide network of bilateral and multilateral connections. There exists a multitude of platforms (in the region of 60 or 70) that aggregate and advertise liquidity from providers to consumers, although price discovery is thought to primarily rely on a smaller number of key venues. Some platforms are simply matching buyers and sellers, others operate as exchanges or are exchange-like using a commercial bank as a central counterparty. There are often differences across platforms, for example in costs, rule books, latencies and connectivity.

Banks and principal trading firms (PTFs) increasingly use automated market-making tools and various communication channels to facilitate transactions at high speed. An algorithmic approach to both price-making and risk management enables participants to optimise market-making activity, improve efficiency and achieve higher proportions of internalisation of market risk than was traditionally achieved by voice-driven market-making. Participants will typically broadcast their interest to transact simultaneously on multiple platforms and withdraw as soon as their order on one platform is 'hit', giving the illusion of more trading interest than is actually present – sometimes referred to by market participants as a 'liquidity mirage'. Competition is intense, and price developments on one platform are quickly reflected on others. Therefore the provision and consumption of large quantities of high-speed data has become a key feature of today's market structure.

There are no compulsory requirements for spot FX platforms to have trading halt mechanisms: two of the main spot FX electronic broking platforms (EBS and Thomson Reuters Matching) do have some pre-trade controls, but not circuit breakers, although the CME futures exchange does. Each participant is therefore responsible for their own risk management and controls. Importantly, unlike some other markets, there is no formal obligation for market-makers to provide liquidity. To that end, each price-maker controls its own trading presence, in effect establishing their own bespoke circuit breaker, widening spreads or even withdrawing completely in much the same way a voice trader might choose to in response to stress.

B. Analysis of intraday liquidity

Liquidity conditions typically vary over the course of the trading day. This section attempts to quantify these fluctuations, and to compare the conditions during the 7 October flash event with those on a normal day.

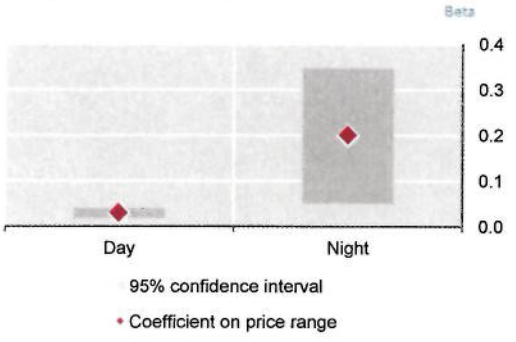
Though the FX market is open for 24 hours a day during the working week, the majority of trading in GBP/USD takes place between 7 am and 5 pm UK time, with volumes highest when both the London and New York markets are open. Accordingly, this is when measures of liquidity appear to be at their strongest.

On the night of 7 October, trading activity was significantly higher than usual. Volumes on Thomson Reuters Matching were several hundred times their average overnight rate. Bid-offer spreads were significantly wider than their usual overnight average. And other measures of liquidity, such as sweep-to-fill costs and the Amihud measure, the ratio between price moves and traded volumes, were also much higher than their usual overnight levels, indicative of lower liquidity. See Graph B for a comparison of these and other metrics on 7 October.

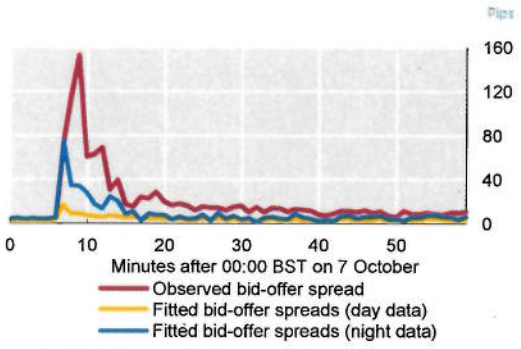
Statistical analysis by Bank of England staff provides evidence to suggest that liquidity, as measured for example by bid-offer spreads, is more sensitive to changes in realised price volatility and traded volumes at night, compared with during the day. The left-hand panel in Graph A shows the sensitivity of bid-offer spreads to realised volatility, as measured by the price range per minute, estimated on data from 22:00 BST on 2 October to midnight on 6 October. The data are divided into two subsamples covering 'daytime' (01:00–22:00 BST) and 'night-time' (22:00–01:00 BST). An increase in intra-minute volatility of 10 pips during the day is associated with a 0.3 pips higher bid-offer spread. But during the night this rises to 2.0 pips. Care should be taken when interpreting the results, however, given the fact that the two factors explain only a small proportion of the variation in bid-offer spreads in these data and the confidence intervals around the estimated sensitivities are wide.

Estimating the drivers of market liquidity[1] Graph A

Sensitivity of bid-offer spreads to realised price volatility during the day and at night



Bid-offer spreads observed around the flash event, compared with fitted model values



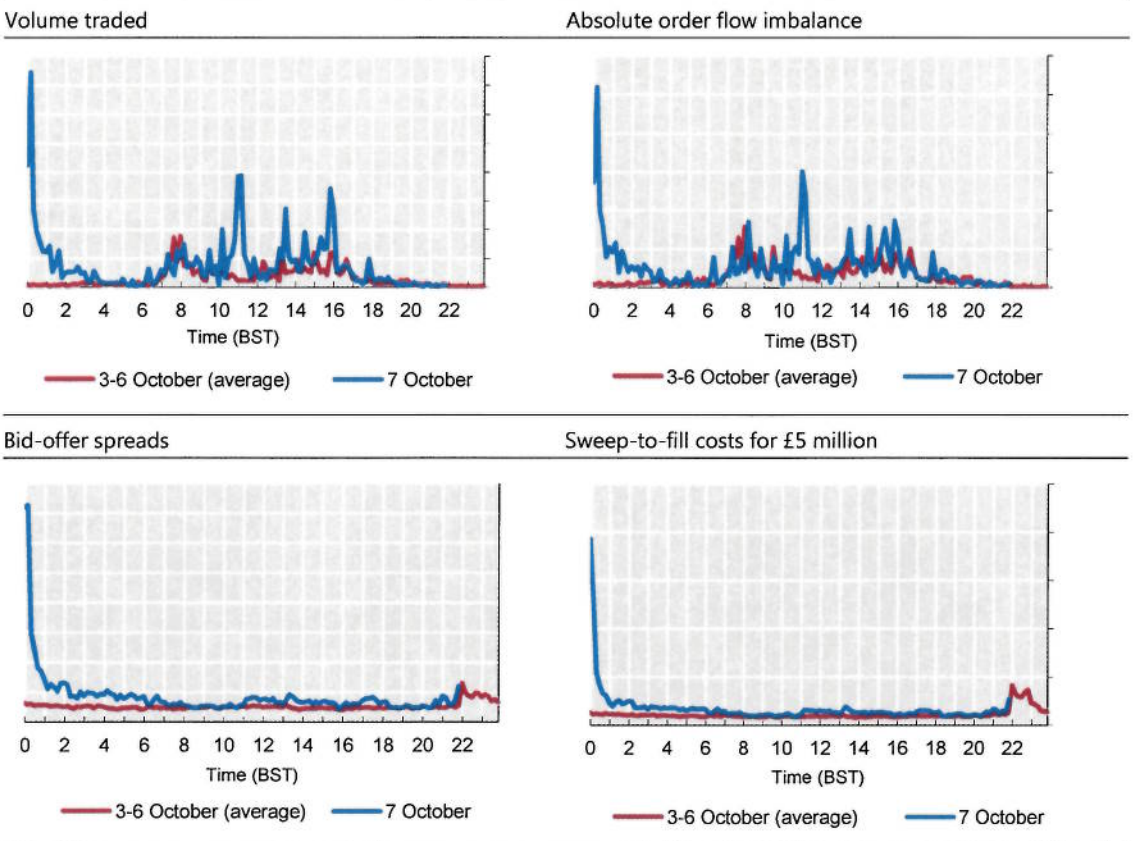
[1] Calculated using 3–6 October 2016 data from Thomson Reuters Matching and the following equation: $\text{bid-offer spread}_i = \alpha + \beta \cdot \text{price range}_i + \gamma \cdot \text{traded volume}_i + u$.

Sources: Bank of England calculations; Thomson Reuters.

The 7 October flash event took place during the night, when liquidity conditions appear to be more sensitive to price volatility. This may have played a role in amplifying the effect of the initial shock. The right-hand panel in Graph A compares the actual move in bid-offer spreads (red line) with the path predicted by the stylised model estimated using 'daytime' data (yellow line) and 'night-time' data (blue line). This comparison suggests that the deterioration in liquidity observed during the first minute of the event was broadly consistent with what might be expected at that time of night given the large price move. But after that the observed increase in bid-offer spreads is greater than what the model predicts.

Movements in bid-offer spreads over the event window are likely in practice to have reflected a more complex interplay between market participants' trading strategies, observable prices and order flows. Nevertheless, taking the model's estimates at face value, it is reasonable to conjecture that the initial shock might have had a significantly smaller impact had it occurred during the day – given the large difference between the blue and yellow lines in the right-hand panel in Graph A.

Thomson Reuters Matching trading activity and liquidity metrics[1] Graph B

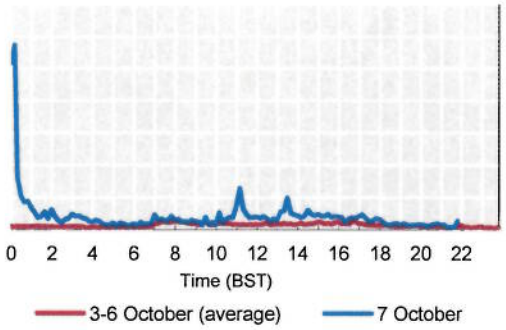


[1] The graph compares measures of trading activity and liquidity on October 7 to the average levels prevailing in the 3-6 October period. Note: these measures are presented without scale for confidentiality reasons.

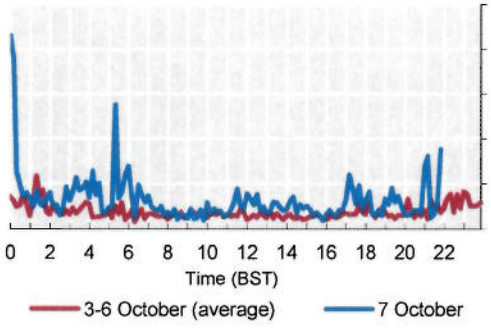
Sources: Bank of England calculations; Thomson Reuters.

Thomson Reuters Matching trading activity and liquidity metrics (Continued)[1] Graph B

Price volatility (max-min range)



Amihud measure of price impact



[1] The graph compares measures of trading activity and liquidity on October 7 to the average levels prevailing in the 3-6 October period. Note: these measures are presented without scale for confidentiality reasons.

Sources: Bank of England calculations; Thomson Reuters.

C. Comparison with the 15 October 2014 US Treasury event

On the morning of 15 October 2014, the US Treasury market, universally viewed as the deepest and most liquid government securities market in the world, experienced a short-lived episode of extreme volatility. During the event – which impacted Treasury securities across maturities, as well as futures and other interest rate derivatives – the yield on the benchmark 10-year Treasury note moved in a 37 basis points trading range, falling sharply, recovering quickly, and finally closing only a few basis points down on the day. Intraday movements of such magnitude had only been seen a handful of times in this market since the 1990s, and they had all been associated with important monetary policy announcements. In contrast, the 15 October flash event did not appear to be directly linked to a specific news release or economic announcement.

The staff of several US official sector entities jointly conducted an in-depth investigation of the event using non-public transaction-level data from the cash and futures Treasury markets. The report concluded that a confluence of factors is likely to have explained the event, rather than specific news, unusual trading activity or any other single cause. Importantly, the report highlighted relevant features in the structure of the Treasury market, including the increasingly electronic nature of the wholesale market and the prominent role of principal trading firms (PTFs) using automated trading strategies.

As with the 7 October sterling event, the US Treasury event shares a number of common characteristics with other flash events, including: the pattern of an initial sharp move and retracement; the prevalence of automated, electronic trading and the speed at which quotes, transactions and price movements occurred; and the high level of trading volumes over the event window, despite the deterioration of market depth and the price impact of trades.

However, the US Treasury and sterling flash events featured distinct market structures and prevailing market conditions. These structural and contextual differences may help explain the unique paths of each event. They include:

- The sterling event occurred at a time of day where trading activity and market depth is usually very low. The Treasury event occurred at a time of day that usually sees a very high level of trading activity and market depth.
- Data showed that, ahead of the Treasury event, speculative investors were mainly positioned for an increase in bond yields, the opposite of what happened. In contrast, in the sterling event, most speculative investors seemed to have been positioned for a depreciation of sterling, the event which came to pass.
- Both events began with a gradual deterioration in market depth. But the deterioration progressed much more rapidly in the sterling event.
- Liquidity in the Treasury market remained notably impaired for several days, while liquidity in sterling appeared to recover appreciably by the next day.
- During the entire Treasury event, bid-offer spreads remained fairly tight, prices showed very few gaps, and trading volumes remained high from beginning to end. In contrast, during the second phase of the sterling event, bid-offer spreads widened dramatically, trading volumes dropped during the most severe period of dislocation, and large gaps in prices were visible.
- Treasury futures on the CME were not affected by trading halts during the Treasury event. In contrast, sterling futures on the CME were subject to a series of such halts on 7 October.

Key features of selected sharp intraday moves in FX markets

Table 1

Episode	Date/Time	Description	Trigger	Amplifiers	Stabilisers	Parallels with 7 October
Removal of Swiss franc/ euro floor (EUR/CHF) *Fundamental economic news led to overshooting of prices*	15 Jan 2015 09:30 UK time (10:30 local time)	Ca 41% rise in the Swiss franc in 20 minutes. It retracted over 60% of this move within a further 20 minutes.	The Swiss National Bank (SNB) announced the removal of the floor under the Swiss franc against the euro – a fundamental driver that separates this event from most others here.	Automated liquidity providers **withdrew from two-sided market-making** and suspended streaming prices on public and bilateral platforms. The CME activated a trading halt.	The SNB stabilised markets by providing liquidity in a price range, giving market participants the confidence to re-enter the market. Market users initially reverted to more traditional transaction methods such as voice trading but resumed use of all methodologies once they had made the appropriate adjustments to their e-trading tools.	Withdrawal of automated liquidity provision and 'gapping' on key platforms.
Japanese yen (USD/JPY) *Scant economic news exposed crowded positions*	17 Mar 2011 21:20 UK time (06:20 local time)	Ca 4% rise in the yen in 25 minutes.	Uncertainty around capital flows related to the earthquake the previous week.	Because of daily system halts at retail aggregators, clients were not able to post additional margin or close positions to avoid triggering automatic **stop-losses**. Many liquidity providers also **withdrew from two-sided market-making.**	Intelligence suggests that hedge funds and new retail investors started to build up fresh USD/JPY long positions. Liquidity providers also resumed market-making.	The event occurred during a less liquid part of the global trading day, stop-loss orders amplified moves, and automated liquidity provision was withdrawn.
South African rand (USD/ZAR) *Scant economic news exposed crowded positions*	10 Jan 2016 22:10 UK time (00:10 local time)	Ca 8% fall in the rand in 10 minutes. It recovered 75% of the fall within four hours.	Intelligence points to a reduction in Asian retail investors' exposure to the rand (which was a popular carry trade).	Initial moves are likely to have been exacerbated by **hedging of barrier options** at a time of illiquidity **and stop-losses** on sizeable Asian retail positions.	No clear stabiliser.	The lack of investors trading in early Asian market hours combined with options-related hedging and stop-loss order flows.
New Zealand dollar (NZD/JPY)	24 Aug 2015	Ca 10% fall in the New Zealand dollar over two	Sharp sell-off in the US equity market triggered risk reduction and closing of carry	Dealers became unable to hedge cross-asset exposures in real time given changing correlations and	No clear stabiliser	The event occurred during what is a relatively less liquid

Little economic news exposed crowded positions	14:10 UK time (01:10 local time)	minutes. It recovered ca 100% of the fall within 35 minutes.	trades. A number of other currencies also experienced large movements.	**withdrew from two-sided market-making.**		time of the day for the New Zealand dollar in particular.
US dollar (EUR/USD) *Little economic news exposed crowded positions*	18 Mar 2015 21:00 UK time (16:00 local time)	EUR/USD rose ca 2% in a matter of minutes before mostly retracing.	The move followed a more dovish FOMC statement than expected, but the move did not exactly align with the release of the statement or press conference.	Occurred late in the New York session (so, not peak liquidity) and is likely to have reflected an unwind of crowded positioning short the euro.	Real money investors and corporates stepped in to buy dollars.	Also featured a trading halt on the CME.