BANK OF ENGLAND

Financial Stability Paper No. 42 – July 2017

Simulating stress across the financial system: the resilience of corporate bond markets and the role of investment funds

Yuliya Baranova, Jamie Coen, Pippa Lowe, Joseph Noss and Laura Silvestri

BANK OF ENGLAND

Financial Stability Paper No. 42 – July 2017

Simulating stress across the financial system: the resilience of corporate bond markets and the role of investment funds

Yuliya Baranova, Jamie Coen, Pippa Lowe, Joseph Noss and Laura Silvestri

The authors would like to provide special thanks for major contributions to: Niki Anderson, Neha Arora, David Baumslag, Matthieu Chavaz, Nicola Gregory, Ahsan Rathore (Bank of England). Thanks also to David Aikman, Pavel Chichkanov, Rohan Churm, Jon Relleen, David Mallaburn, Conor Sewell (Bank of England) and participants of the FSB AGV Workshop for useful comments and discussions.

yuliya.baranova@bankofengland.co.uk
FS Strategy and Risk Directorate, Bank of England, Threadneedle Street, London EC2R 8AH
jamie.coen@bankofengland.co.uk
FS Strategy and Risk Directorate, Bank of England, Threadneedle Street, London EC2R 8AH
pippa.lowe@bankofengland.co.uk
FS Strategy and Risk Directorate, Bank of England, Threadneedle Street, London EC2R 8AH
joseph.noss@bankofengland.co.uk
FS Strategy and Risk Directorate, Bank of England, Threadneedle Street, London EC2R 8AH
laura.silvestri@bankofengland.co.uk
FS Strategy and Risk Directorate, Bank of England, Threadneedle Street, London EC2R 8AH

The views expressed in this paper are those of the authors, and are not necessarily those of the Bank of England. This paper was finalised on 12 July 2017.

© Bank of England 2017
ISSN 1754–4262

Contents

Foreword

Alex Brazier, Executive Director and member of the Financial Policy Committee

Almost a decade ago, the global financial crisis saw $300 billion losses related to subprime mortgages amplified to well over $2.5 trillion of write-downs in the global banking system as a whole. Weakened banks were unable to supply credit to economies; prices of financial and property assets fell; and some financial markets effectively shut. Even the functioning of corporate bond and foreign exchange markets was disrupted. The system was structured in a way that did not absorb economic shocks; it amplified them.

With the financial system disrupted and unable to supply credit, transfer risks and, in some cases, almost unable to facilitate payments, economic activity fell sharply. The financial system turned an economic downturn into a disaster. In the United Kingdom, output fell by more than 7% — the largest recession in the post-war period.(1) Ultimately, the banking system had to be supported with public funds. Total taxpayer support for UK banks peaked at £1.2 trillion between 2007 and 2010.

An ambitious programme of regulatory reforms has made the financial system safer, simpler and fairer.(2) Macroprudential policy frameworks have been introduced, including in the United Kingdom, with the aim of ensuring that the financial system continues to be able to support the real economy in bad times as well as good, by absorbing economic shocks rather than amplifying them.

Stress testing aims to ensure the banking system can absorb, rather than amplify, economic shocks

The Financial Policy Committee of the Bank of England is the macroprudential authority in the United Kingdom.(3) A core element of its approach has been the introduction of transparent stress tests of major banks. Those tests, in place since 2014, ask what would happen to banks in the event of a severe, synchronised economic and market shock. These test the ability of banks to keep lending through even a severe shock.

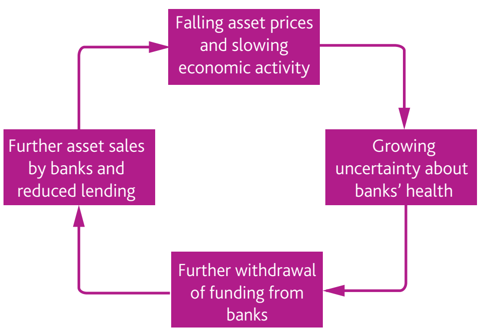
Those stress tests demonstrate that the UK banking system can now absorb within its capital buffers shocks of such severity that would have wiped out the entire capital base of the system in 2008.

The system is not the sum of its parts

The crisis demonstrated very clearly how a full assessment of the strength of the banking system needs to take account of how problems can spread between banks and the wider financial system.

Before the crisis, banks' tripled their lending to each other.(4) When the crisis hit, uncertainty about the creditworthiness of banks caused this inter-bank lending to collapse.(5) Banks that had received funding from others saw it withdrawn, or the conditions on it tighten. They were forced to protect their balance sheets through selling assets and cutting lending to the economy. That caused a self-reinforcing feedback-loop to develop, with falling asset prices and slowing economic activity resulting in more uncertainty about banks' health (**Figure 1**).

Figure 1 Illustration of the feedback loop between asset prices, economic activity and bank health



Feedback loops like this one explain why the initial losses on lending to the economy were so magnified by the financial system. Actions taken by each bank in their own interest turned the system as a whole into an amplifier of the initial shock. The system was not the sum of its parts.(6)

The Bank of England's stress tests now include the feedback loop created by interbank loans. The 2016 test results reflected the spillover effects from losses at each bank to other banks from which they had borrowed. The test showed that the potential for solvency problems to spread between UK banks through this channel has fallen dramatically since the crisis. Interbank lending has been cut back and is more

(1) See Chowla, Quaglietti and Rachel (2014).
(2) See Carney (2017).
(3) See Tucker, Hall and Pattani (2013).
(4) This refers to total intra-financial lending by the major UK banks between 2000–07. Total intra-financial lending includes lending between banks and between banks and other financial corporations.
(5) See Figure 3 of Bardoscia *et al* (2017).
(6) See Brazier (2017).

often secured against collateral.[1] And banks' improved capital positions mean that, even in severe economic stress scenarios, uncertainty about their solvency is substantially reduced.[2]

Although this feedback loop has become much less important, there is work to do to assess whether other such loops are emerging elsewhere in the system. Banks account for only half of the United Kingdom's financial system. The core principle behind bank stress testing — the need to assess whether the system could respond to severe economic shocks in ways that make them worse — needs to be applied to the wider financial system.

This is a priority for the Bank of England's Financial Policy Committee, working alongside other central banks and regulators.[3] The objective is to assess how the non-bank part of the financial system — 'market-based finance' — responds to economic shocks. Is this structured in such a way that its elements could combine to amplify these shocks?

Fire sales could create feedback loops in market-based finance

The system of market-based finance includes, among other parts, investment funds, dealers, insurance companies, pension funds and sovereign wealth funds. It supports the extension of credit and transfer of risks through markets rather than banks. It has expanded rapidly since the crisis. At the global level, assets held by non-bank financial intermediaries increased by more than a third since the financial crisis.

That growth has been beneficial. It helped to mitigate the cutbacks in bank credit as the core banking system repaired balance sheet. It was the 'spare tyre' for many businesses faced with a punctured banking system.[4] For example, all of the net increase in lending to the United Kingdom's non-financial businesses since the crisis is accounted for by corporate bond issuance.

But this growth of non-banks brings potential risks as well as opportunities. The new structure of the system has yet to be tested by severe shocks and, because it has changed so much, the system's past behaviour may not be a good guide to the future. There is therefore a case for modelling this part of the system to simulate how it could respond.

The potential spillover effects in market-based finance centre on 'fire sales' of assets, which affect prices of financial assets and functioning of markets. Participants in this part of the system can face incentives, or be forced into, sudden asset sales. These fire sales can be prompted by funding shortages and/or by falls in an institution's net worth (the difference between the value of its assets and the value of its liabilities). Because they require a buyer to be found at short notice, these fire sales can cause asset prices to fall quickly, and to levels below those implied by the cash flows the assets are expected to generate.

A feedback loop can develop in which falling asset prices drive declines in net worth and withdrawal of funding, prompting further asset sales and falls in prices. As with the earlier example of banks, institutions acting rationally in their own interest collectively turn the system into an amplifier. This has been dubbed by Marcus Brunnermeier of Princeton University as 'the Paradox of Prudence'.[5]

None of this is to say that falls in asset prices are bad; they are part and parcel of a well-functioning financial system. It is through the change in prices that financial markets help to ensure that investment is distributed across the economy in the most efficient way. But where prices overshoot and, in extreme, sufficient buyers cannot be found for what is being sold, the real economy can be affected. The disruption of important markets can have direct effects on the supply of finance for companies and, by creating a more challenging situation for banks at the core of the financial system, affect banks' ability to lend too.

The effects of fire sales were present in many markets during the financial crisis. Even in the United States corporate bond market, interest rates (which move inversely to prices) spiked up. In the United Kingdom, interest rates on investment-grade corporate bonds reached nearly 9%. These problems in markets quickly became problems for companies trying to raise finance. Corporate bond markets for riskier UK businesses closed to new issuance for a whole year.

Not stress testing firms but simulating sectors

The primary channel by which banks can amplify economic shocks is through their inability, or concerns about their ability, to repay their debt liabilities at face value. This can force them to cut the supply of essential services, such as credit supply and payment services, and undertake fire sales of assets. The focus of bank stress tests has therefore been on whether individual banks that are judged to be systemically important have the capital base to absorb losses.

The business models of companies involved in market-based finance can be very different to those of banks. Asset management is a prime example. It has been an important part of the growth of market-based finance since the crisis and could be a driver of the way the system responds to shocks in the future. Global assets under management have increased

(1) See Figure 3 of Bardoscia *et al* (2017) and Box 3 of Bank of England (2016a).
(2) See Box 3 of Bank of England (2016a).
(3) See Bank of England (2017).
(4) See Gruic, Hattori and Shin (2014).
(5) Brunnermeier and Sannikov (2016).

by two thirds since 2008. The open-ended investment fund sector has grown by 80% in the same period.(1)

Unlike banks, investment funds by and large make no guarantee that their customers' investment will be returned at face value. Moreover, fund managers do not hold assets on their balance sheets directly; they instead manage assets on behalf of clients. The risks and rewards rest with the investor rather than the fund. Asking asset managers and funds the same question asked of banks — 'do they, as corporate institutions, have the strength to withstand severe stress?' — tends to have a simple answer. They do.

Moreover, in contrast to systemically important banks, the investment fund industry is diverse, comprising a variety of investment strategies and investments. Funds play an important role in channelling savings across diverse investors and institutions into an equally diverse range of investments. The behaviour of individual funds or their investors is unlikely to shape the way the system as a whole responds to stress.

So the focus of assessments of how funds behave under stress demands a very different approach to the stress testing of banks. The focus should not be on testing the resilience, or even assessing the behaviour, of individual managers or funds. It should instead be on modelling the sector overall to assess whether, in aggregate, the activity they undertake can contribute to feedback loops.

The empirical evidence suggests their investors can collectively behave procyclically — redeeming their investments when the prices of assets fall.(2) For funds holding assets that are traded in deep and continuously liquid markets, such as advanced economy equity markets, this may be of little economic consequence. However, funds investing in less liquid assets have become more prevalent. For example, open-ended funds now hold almost a fifth of sterling-denominated corporate bonds. Access to less liquid assets has broadened and the label of short-notice redemption may be encouraging investors into these areas.

In relatively illiquid markets — where forced sales have larger impacts on prices — procyclical behaviour by fund investors could create a feedback loop, between price falls, redemptions and asset sales. A system of safe corporate entities can still present risks.

Funds do, of course, have tools at their disposal to limit redemptions under stress, but the use of such tools might create other risks. The expectation that others might respond to falling prices by redeeming their investment could encourage each investor to redeem their own. Why? As others redeem, market prices can be expected to fall, prompting further redemptions and, if that process continues, funds can be forced to suspend. Any investor expecting this has an incentive to redeem before it happens.

These dynamics were illustrated clearly in 2016 in funds investing in UK commercial property. With the property market in hiatus following the United Kingdom's referendum on membership of the European Union, these open-ended funds faced redemption requests from investors concerned about the prospect of future price falls and fearing that other redemptions would force the funds to suspend. The process was self-fulfilling and many funds were forced to suspend redemptions.(3)

Individually safe but collectively risky

The market impact of fire sales by any one part of the system depends crucially on the behaviour of other parts. Are other parts of the system stepping in to buy the assets being sold, or are they reinforcing the sales? No part of the system of market-based finance can be assessed fully in isolation. It is the spillover effects between different parts of the system that are of most interest. This calls for any simulation of market-based finance to model how the difference parts interact.

Although it may be tempting to assume there is always an investor willing to step in and buy whatever is being sold at the asset's long-term economic value, reality could be very different. Important parts of the system may be constrained, by their funding position and their net worth, including through regulations that exist to promote their individual safety.

For example, many important markets — especially fixed income markets — rely on broker-dealers to intermediate between buyers and sellers. The difficulty of matching buyers and sellers instantaneously creates a role for these 'market makers' to buy from sellers while they wait for a buyer. Ordinarily this aids market liquidity and allows markets to function more efficiently.

This relies on dealers being willing to 'warehouse' assets that are waiting for a buyer. So if fire sales of assets begin to drive down market prices, these market makers can incur losses.

Post-crisis reforms have made dealers much stronger, reducing the probability that this could lead to their distress or failure. Nevertheless, trading losses still make their funding more expensive and reduce their headroom over regulatory capital requirements, reducing incentives to take risks. That can mean shedding their inventory and stepping back from absorbing

(1) See Bank of England (2017).
(2) Goldstein, Jiang and Ng (2015).
(3) A public discussion of the challenges associated with funds that invest in illiquid assets and offer short notice redemption launched by the Financial Conduct Authority early this year is an important step towards a better understanding of risks from the open-ended fund sector. See Financial Conduct Authority (2017).

asset sales by others. Despite having the strength to withstand market shocks themselves, market-making dealers could step back just when they are needed most, reinforcing the effect of fire sales by others.

This could have additional spillovers to other parts of the system of market-based finance. Investors, such as hedge funds, that rely on broker-dealers for their funding could see that funding become less readily available. Even though they may ideally like to buy in markets where others are forced sellers, these investors could find themselves constrained from doing so and, in the limit, become forced sellers themselves.

These examples illustrate how the combination of constraints and incentives facing the different parts of the system could, in principle, add up to be an amplifier, even when each individual part of the system may be safe. It is another example of how the system may not be the sum of its parts.

This paper by Bank of England staff is an important step towards putting these principles into practice

The paper that follows seeks to model how the aggregate behaviour of several sectors within the system of market-based finance, including investment funds and dealers, could interact to spread and amplify stress in corporate bond markets. That focus stems from the growing importance of bond markets to the financing of the economy, alongside the rapid growth in holdings of such bonds in fund structures. It does not focus on individual companies; the analysis is conducted at a sector level. It is not concerned with the capacity of the sectors to absorb losses.

It is a first — pilot — step and so is an incomplete exercise, focussing on one type of stress scenario, one market and simple models of the behaviour of important parts of the system. Nevertheless, it has allowed a scenario to be explored in which large scale redemptions from open-ended investment funds trigger sales by those funds, with resulting spillover effects to dealers and hedge funds.

The exercise finds that weekly levels of redemptions from funds equivalent to 1% of their total assets — levels experienced in the financial crisis — could increase corporate bond interest rates for companies with high credit ratings by around 40 basis points. It also addresses questions about the scale of redemptions that would be needed to overwhelm the capacity of dealers to absorb those sales, resulting in market dysfunction. Investor redemptions one third higher than those observed during the crisis could be sufficient for this to happen — an unlikely, but not impossible, event.

The framework used for these exercises is a useful tool to begin to assess any tendency for market-based finance to amplify shocks. Those shocks — and the financial system — are international in scope and reach. Measuring such risks requires international cooperation and the framework used in this exercise was drawn on in the recent international pilot systemic stress simulation exercise carried out by the Financial Stability Board, which assessed the consequences of market stresses and examined the resilience of liquidity across a range of fixed-income markets.(1)

It is too soon to use simulations like this to draw policy conclusions. But the insights they could yield, after development in future, could be used alongside other analysis to inform:

- macroprudential policies regarding market-based finance activities;
- the appropriate level of bank resilience; a more amplifying system of market-based finance warrants a stronger core banking system; and
- the precise design of regulations placed on banks and others to ensure that their individual safety is achieved as far as possible in a way that also promotes the stability of market-based finance.

Overall, this work contributes to our ambition of a financial system in which not just the component parts are individually safe but, at the same time, the system as a whole is stable too. The economy deserves a financial system that serves it well in both good times and bad; a system that absorbs problems and doesn't amplify them. There is much further to go, so feedback on these steps is welcome from those inside and outside the financial system.

Alex Brazier
12 July 2017

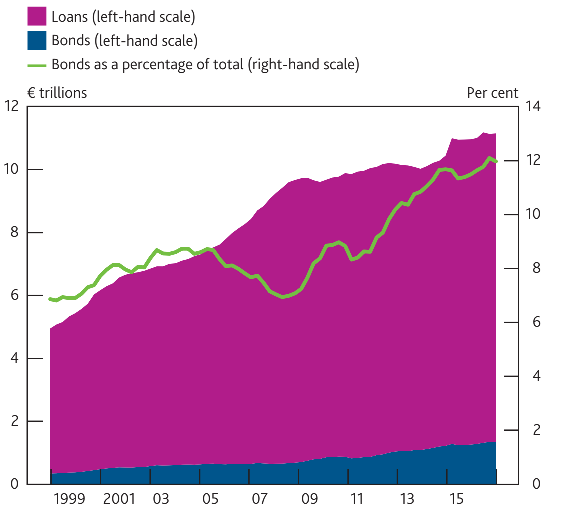
(1) See Financial Stability Board (2017).

1 Introduction

This paper provides a first step in developing a system-wide stress simulation. The model incorporates several important features of the financial system. These include several types of institution (including banks and non-banks) and how their actions may propagate and amplify stress. Rather than attempting to predict outcomes of a given stress scenario for financial sector balance sheets, it seeks to explore those conditions under which systemic stress may crystallise.

The simulation focuses on assessing the resilience of market-based finance — in particular, the provision of bond financing to real economy borrowers by the non-bank sector. Market-based finance has become increasingly important over recent years. For example, since the global financial crisis, nearly all net credit raised by non-financial companies in the United Kingdom has been through the issuance of tradable securities, and most of this through corporate bond issuance. In the euro area, corporate bonds have increased as a proportion of total bond and loan finance outstanding from around 7% during the crisis to around 12% in 2016 (**Chart 1**).

Chart 1 Outstanding amounts of bonds and bank loans for euro-area non-financial companies[(a)]



Source: European Central Bank.

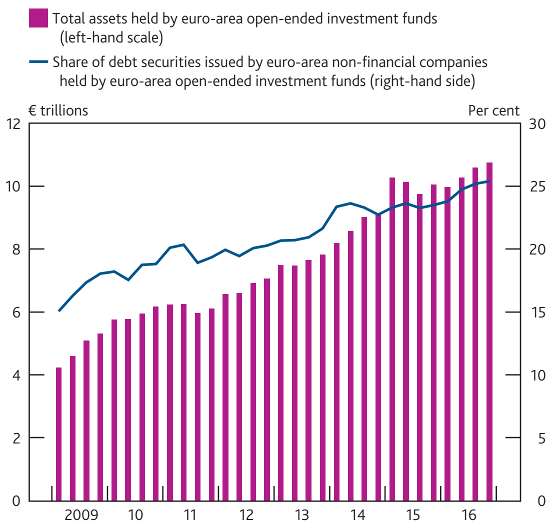
(a) Bank loans represent loans from euro-area domestic depository institutions. Loans from other financial institutions such as insurance corporations, pension funds, financial auxiliaries as well as loans from government, households, other non-financial firms and from foreign banks are excluded.

The provision of market-based finance will be more resilient when markets important for extending funding to the real economy, including corporate and government bond markets, are liquid and function smoothly. When market liquidity is resilient and reliable it encourages participation in financial markets, by providing confidence for both investors and issuers. It supports price discovery and competitive pricing for financial assets, which aids efficient allocation of risks and capital across the economy. In contrast, market liquidity that is prone to evaporate can lead to disorderly price moves in markets. Such price falls, especially if sustained, could impair the ability of some companies to refinance debt at serviceable levels (Bank of England (2015a)),[(1)] as well as prompt the cancellation of investments requiring external funding. Furthermore, sustained falls in price could impact the balance sheets of banks and other financial institutions, impairing the resilience of the core of the financial system and affecting economic growth.

This paper examines the resilience of liquidity in European corporate bond markets by exploring the interaction between dealers and open-ended investment funds that participate in those markets. In particular, it illustrates how one type of shock — that is, fund redemptions — might interact with both constraints on financial institutions and the behavioural response of investors to affect market prices and functioning.

The focus on investment funds is motivated by how, in recent years, as the provision of market-based finance has grown, open-ended investment funds have also increased in size. **Chart 2** shows that the share of debt securities issued by euro-area non-financial companies held by euro-area open-ended funds has risen from around 15% to over 25% since 2009. In this context, a number of authorities have expressed concern that large-scale redemptions from open-ended investment funds could result in sales of assets (that is, funds' demand for market liquidity) that overwhelm

Chart 2 Total assets of euro-area open-ended investment funds and their holdings of debt securities issued by euro-area non-financial companies[(a)]



Sources: European Central Bank and Bank calculations.

(a) In the calculation of the share of debt securities issued by euro-area non-financial companies held by open-ended investment funds, funds' holdings are approximated by securities other than shares.

(1) Survey evidence suggests that the proportion of UK medium-sized companies that are likely to be vulnerable to default could rise sharply were borrowing costs to rise by more than 200 basis points, as seen in 2007–09 (Bank of England (2015a)).

markets' ability to absorb them (that is, the market liquidity that dealers and other investors are able or willing to supply).

Open-ended funds offer short-term redemptions to investors while in some cases investing in potentially illiquid assets — that is, they give rise to a 'liquidity mismatch'. They also enable investors to hold diversified portfolios of illiquid assets even with a small amount of investable assets, something that would not be possible if investing directly. This may have encouraged some investors to invest more in less liquid assets than they would otherwise — for example, if investing directly and not via a fund manager.(1) Such investors could potentially behave more procyclically than others, for example, if falls in asset prices resulting from initial redemptions (including those due to a change in economic fundamentals) cause investors to reassess the liquidity of funds' holdings, and lead them to place further redemptions. The resulting asset sales could exacerbate the initial stress, leading to further price falls.(2)

Some of the potential risks associated with funds' liquidity mismatch were demonstrated during the summer of 2016, when a number of UK open-ended funds invested in property experienced significant outflows and had to suspend any further redemptions.(3) These suspensions resulted from the inability of affected funds to liquidate property assets at reasonable prices to meet large redemptions.(4)

Corporate bond markets rely on core intermediaries, or dealers, for the provision of market liquidity. Over the past few years, there has been evidence of reduced dealer intermediation and liquidity in those markets.(5) Average trade sizes and indicators of market depth have fallen. These developments have coincided with both a low interest rate environment and the implementation of post-crisis changes to regulation, which — while increasing the resilience of dealers — might constrain their ability to act as intermediaries, particularly during periods of stress.

Hence, the framework for studying the resilience of corporate bond markets set out in this paper comprises two key methodological components:

- first, that aimed at quantifying the possible *demand* for liquidity by funds and their investors;
- second, that aimed at quantifying the possible *supply* of liquidity by dealers and other market participants — that is, their willingness to act as counterparties to funds' sales.

Both components draw considerably on related literature on investor behaviour and the impact of asset sales on market prices and liquidity, and the framework itself draws on work that assesses the impact of fund redemptions on asset prices and/or market liquidity. A full literature review is provided in Box 1. The second component — the supply of liquidity — also draws on a partial equilibrium model of dealer behaviour set out in a *Bank of England Staff Working Paper*, Baranova, Liu and Shakir (forthcoming).

The exercise is structured as follows:

- It begins by assuming a range of different levels of initial investor redemptions from funds.
- To meet these redemptions, investment funds make a 'first round' of asset sales.
- The response of dealers means that a fall in price is needed to compensate them for absorbing these sales.
- Finally, the reactions of investors to these price falls in the form of a 'second round' of redemptions act as an amplifying factor, causing further asset sales and falls in price.

Results suggest that, under a severe but plausible set of assumptions regarding market participant behaviours, redemptions from open-ended investment funds can result in material increases in spreads in the European corporate bond market. In the extreme, this could lead to dislocations in corporate bond markets. Further, while such market dislocation is a low-probability event, the likelihood of it crystallising could increase if the potential demand for liquidity, including that from the investment fund sector, continues to grow relative to the supply of liquidity by dealers and other investors.

This exercise highlights only some examples of the type of stress, and channels of contagion, that a stress simulation could, in principle, involve. Its focus is, in places, quite partial. The shock on which it is based — ie that motivated by investment fund redemptions — is only one of a constellation of possible scenarios that could materialise during periods of stress. And the channels of contagion captured — namely, the procyclical behaviour of fund investors and market intermediaries are limited in scope. Nonetheless, it provides useful insights for systemic risk assessment and is intended to serve as an illustration of what such an exercise could entail and motivate further work in this area.

The paper proceeds as follows. Section 2 describes the data used in the simulation. Section 3 explains the model set-up

(1) See Cunliffe (2015).
(2) The Bank of England's Financial Policy Committee set out an assessment of this, and other risks, from investment funds in its December 2015 *Financial Stability Report* (see Bank of England (2015a)).
(3) Bank of England (2016b).
(4) In July 2016, a number of UK open-ended retail property funds announced suspension of redemptions.
(5) See Anderson *et al* (2015).

Box 1
Related background literature

This box begins with an assessment of the literature on investor behaviour and the impact of asset sales on market prices and liquidity, which we draw upon to develop the demand and supply components of our simulation framework. It then considers two key pieces of work that similarly employ a framework to model stress estimates of the impact of fund redemptions on asset prices and/or market liquidity.

Regarding *the demand for liquidity from investment funds and their investors*, evidence of pressure on asset prices arising from investment fund portfolio rebalancing and asset sales is well documented in the existing academic literature. For instance, Coval and Stafford (2007), Ben-Rephael, Kandel and Wohl (2011) and Lou (2012) find evidence of fire sales by open-ended investment funds in equity markets. Such portfolio rebalancing — particularly when it occurs at discounted prices — has also been found to lead to contagion across markets. For example, Jotikasthira, Lundblad and Ramadorai (2012) identify contagion resulting from investment funds domiciled in advanced economies liquidating their holdings of emerging markets equities. And Manconi, Massa and Yasuda (2012) study the contagion from the securitised bond market to the corporate bond market in August 2007 resulting from portfolio rebalancing of mutual funds following investor redemptions.

There is also evidence of potential procyclical behaviours on behalf of fund investors, which can magnify the demand for liquidity by funds, either to buy or sell securities.(1) For example, Sirri and Tufano (1998) find an asymmetric relationship between flows and performances in equity funds, with investors moving into well-performing funds at a higher rate than that at which they redeem from poorly performing funds. Similarly, Chevalier and Ellison (1997) estimate a convex relationship between flow and performance for equity investment funds, meaning that inflows in equity funds are more sensitive to good performance than outflows to poor performance. In contrast, Goldstein, Jiang and Ng (2015) find a concave relationship between flows and performance in corporate bond mutual funds.

There is also evidence of various fund manager behaviours that may either amplify or dampen the demand for liquidity by funds as they seek to meet investor redemptions. In particular, Chernenko and Sunderam (2016) find that investment fund managers tend to partially use cash to meet investor redemptions, which may reduce the demand for liquidity in less liquid markets. In contrast, Morris, Shim and Shin (2017) find evidence of bond fund managers increasing their cash holdings and selling more assets than is required by investor redemptions.

In the context of the *liquidity supply* component of our framework, there is academic evidence documenting various behaviours of market participants. In particular, Ferguson and Laster (2007) argue that *hedge funds* add liquidity to markets and are broadly stabilising. In contrast, Choi and Shachar (2013) find that, during the 2007–09 financial crisis, hedge funds demanded liquidity in the corporate bond market.

Dealers play a major role in intermediating certain markets, such as those for corporate bonds (Anderson *et al* (2015)). There is evidence of dealers providing liquidity in this market, including during times of stress. There is evidence that dealers continue to increase their inventories in response to a decline in demand for corporate bonds from asset managers, although to a lesser degree than pre-crisis (Bank of England (2016c)). Choi and Shachar (2013) also find that during the peak of the financial crisis dealers provided liquidity in corporate bond markets and significantly increased their inventory holdings in response to large-scale selling by clients.

Evidence on investment behaviours of institutional investors is mixed. Bikker, Broeders and Dreu (2010) find that Dutch pension funds do not continuously rebalance their asset allocations in the short term (ie they are slower-moving investors), while in the medium term there is an asymmetric reaction to shocks: stronger buying behaviour in response to equity outperformance, as compared to selling behaviour following equity underperformance. Timmer (2016) provides evidence that German insurance companies and pension funds may act countercyclically in response to changes in asset prices by buying debt securities that trade at a discount, and selling securities that trade at a premium, to levels commensurate to economic fundamentals. Alternatively, Bank of England (2016b) discusses how regulatory constraints might lead to European insurers shifting from risky to low-risk assets in response to certain financial market shocks (eg a fall in risk-free interest rates).

There are also different approaches to estimating *the impact on market prices* resulting from asset sales by market participants. A practical and common way to do so is to assume that prices vary linearly in the quantity of assets sold.(2) For example, Greenwood, Landier and Thesmar (2015) and Cetorelli, Duarte and Eisenbach (2016) calibrate such a linear price impact function using empirical estimates from the study of fire sales of downgraded corporate bonds by insurance companies (Ellul, Jotikasthira and Lundblad (2011)) and using the difference between prices of small and large trades as a measure of selling pressure on corporate bond

(1) There are also studies of the relationship between flows of capital in investment funds and the components of equity and bond asset prices. For instance, Cenedese and Mallucci (2016) find that negative discount rate shocks predict equity outflows, and that bond flows in emerging markets are sensitive to US interest rate shocks.

(2) The use of linear price impact is customary when modelling fire sale contagion via cross-holdings in the banking system (see Greenwood, Landier and Thesmar (2015) and Duarte and Eisenbach (2015)).

prices (Feldhütter (2012)). An alternative methodology is based on a measure of illiquidity defined by Amihud (2002). Cifuentes, Ferrucci and Shin (2005), meanwhile, find the solution to the fixed point problem of the price adjustment process between the demand and supply of illiquid assets in the system.

Another strand of literature uses agent-based models to capture market dynamics during stress. For instance, Braun-Munzinger, Liu and Turrell (2016) study how corporate bond prices change when funds experience losses, using an agent-based model with a market maker and active and passive funds that are subject to redemptions from a pool of investors. Bookstaber and Paddrik (2015) develop an agent-based model to describe liquidity dynamics following market shocks in a limit-order-book framework.

In addition to the literature on the liquidity demand and supply components of our simulation framework, there are also two key pieces of work that explore similar channels of systemic risk and employ a framework to estimate the impact of redemptions on asset prices and/or market liquidity.

The first of these is that undertaken by the IMF as part of its Financial Sector Assessment Program (FSAP) assessment of the US mutual fund sector in 2015.[1] In a spirit similar to our framework in this paper, the FSAP assesses the ability of markets — including those that are dealer-intermediated — to absorb sales resulting from large-scale redemptions. The IMF does so by comparing such sales to the size of dealers' inventories.

The second key piece of work in this context is Cetorelli, Duarte and Eisenbach (2016), which assesses the losses resulting from large-scale redemptions from US open-ended investment funds. Using linear price impact measures, their model assesses the impact of redemptions on asset prices. It also consists of two rounds of changes in asset prices — the first resulting from an exogenous increase in market interest rates, and a second that results from investor redemptions in response to the initial fall in fund asset prices.

(1) See International Monetary Fund (IMF) (2015).

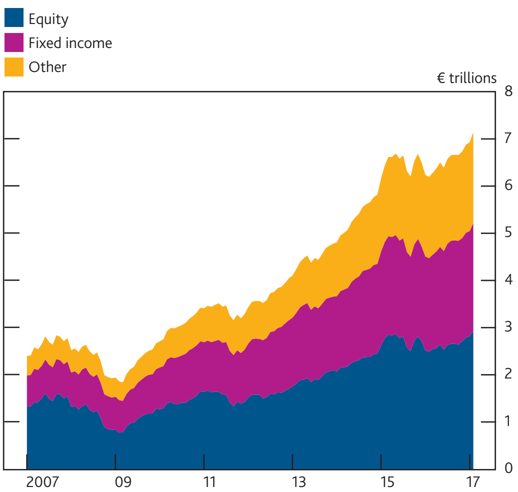
and how different model parameters are calibrated. Results and their sensitivity to key modelling assumptions are given in Sections 4 and 5 respectively. Section 6 highlights the relevance of this work for systemic risk assessment. Section 7 concludes.

2 Data

The data used in our simulation cover European-domiciled open-ended investment funds. To capture the impact of fund redemptions on European corporate bond markets, we also include selected categories of non-European funds that have material holdings of European corporate bonds.[1] Only open-ended funds are included on the basis that these are associated with the potential for procyclicality driven by liquidity mismatch between their offer of short-term redemptions and the liquidity of their assets. Exchange-traded and money market funds are excluded, given the differing nature of their assets, redemption processes and potential risks posed.[2]

Our primary source of data on funds is Morningstar, which reports Europe-domiciled funds to have combined total net assets (TNA) of around €6.5 trillion in December 2015.[3] **Chart 3** shows a broad split of these funds by type of investment, as inferred from historical TNA. These include funds regulated under both the Undertakings for Collective Investment Schemes (UCITS) and the Alternative Investment Fund Managers Directive (AIFMD).[4]

Chart 3 Total net assets for European open-ended investment funds[(a)]



Sources: Morningstar and Bank calculations.

(a) Data refer only to funds existing at the end of February 2017.

Due to specifics of their business models, we exclude from our simulation the categories of funds that pursue strategies typically adopted by hedge funds.[5]

(1) Fund categories with holdings of European corporate bonds that exceed 5% of their total net assets are included (for example, 'US OE Corporate Bond', 'Canada Global Fixed Income' and 'Japan OE Europe Bond').
(2) Funds of funds are also excluded.
(3) Total net assets are assets less liabilities such as borrowings, short positions and derivative liabilities and are calculated as the number of shares in the fund multiplied by its Net Asset Value (NAV).
(4) We understand that the majority of — but not all — such funds offer daily redemptions. Those less likely to offer daily redemptions are typically funds such as property funds, where holdings of corporate bonds (the focus of our results) are likely to be small.
(5) Categories of fund pursuing event-driven, global macro and long-short-equity strategies are excluded.

The sample used contains 281 non-overlapping categories ('fund categories') representative of their investment strategy: 266 European fund categories and 15 non-European fund categories. These are typically defined by the type of securities in which the funds invest, and the geography or currency of those investments.

Finally, the TNA of European fund categories are scaled using sector-level data from the European Fund and Asset Management Association (EFAMA), which reports total net assets of European open-ended funds of around €10.2 trillion.

The first task is to extract from these data three key items of information:

- Historical fund redemptions; redemptions are the driver of asset sales by investment funds;
- Fund asset allocations, which determine which assets are sold by funds to meet redemptions;
- Fund performance, which is used to estimate redemptions that occur in response to a fall in price (the 'second round').

For the purposes of our simulation, we define a core group of 30 European fund categories that we estimate to have significant holdings of European investment-grade corporate bonds — that is, where holdings of European investment-grade corporate bonds by funds within a particular fund category make up more than 20% of total net assets of the funds within that category.(1) These we refer to, for simplicity, as 'investment-grade corporate bond funds'.(2) These funds are used to calibrate key inputs to the simulation, such as the range of redemptions considered in the initial redemption scenario, and the relationship between redemptions and market stress.

2.1 Fund redemption data

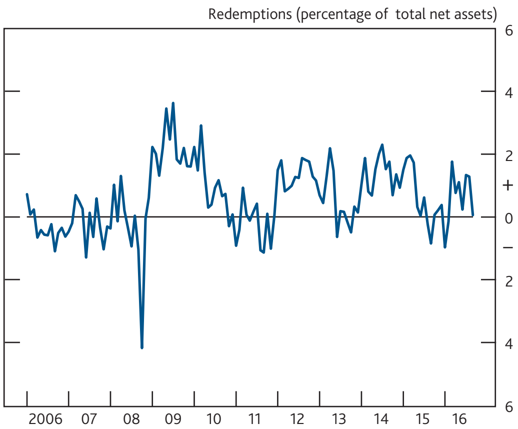
To estimate historical redemptions for each fund category, we use fund-level monthly data on TNA and Estimated Net Flows ('flows') from January 2005 to September 2016. Net assets and flows for each fund category are calculated by aggregating fund-level flows and TNA for individual funds within that category; in doing so, we include funds that closed over the period 2005 to 2015 and thereby avoid any survivorship bias. Monthly percentage flows are then estimated by dividing the flows for the fund category during a month by the total net assets of that fund category at the beginning of that month.(3)(4) When flows are negative, they are assumed to proxy net redemptions; when positive, net subscriptions.(5)

We refer to 'flows' from this point on as 'redemptions'; this does not preclude the possibility that, for some funds analysed in our simulation, first and second round redemption scenarios include subscriptions (ie inflows).

Our simulation assesses the ability of markets to absorb sales by funds in response to redemptions made over a period of a week. In the absence of suitable weekly redemptions data, we use monthly redemptions data from Morningstar to derive an *estimate* of weekly redemptions. To do so, we make the simplifying assumption that redemptions each month are evenly distributed over that month.(6)

Chart 4 shows historical redemptions since 2006 for our core group of investment grade corporate bond funds. The most severe level of redemptions from all investment grade corporate bond funds was seen in October 2008, when monthly outflows reached 4.2% of assets under management.

Chart 4 Redemptions (over a month) for investment-grade corporate bond funds



Sources: Morningstar and Bank calculations.

2.2 Fund asset allocation data

Using Morningstar data, we require — for each fund category — the absolute amount of assets held in different asset classes. These asset classes include: investment-grade and high-yield corporate bonds; government bonds; municipal bonds; equities; covered bonds; securitisations; bank loans; convertible bonds; preferred stock; cash and other assets. We differentiate between the domicile (region) of the issuer for corporate bonds, government bonds and equity. A list of the different asset classes for which we estimate holdings is set out in **Table A1.1** in the annex.

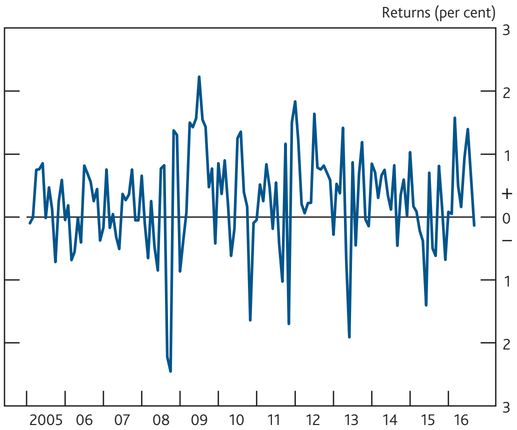
(1) Note that this definition does not match those used by Morningstar and other commentators.
(2) This definition of 'investment grade corporate bond funds' captures around 56% of estimated European investment grade corporate bond holdings of all funds included in the simulation. We exclude 'ultra short-term' bond funds from our definition.
(3) Any reported monthly flows that were greater than total net assets were removed from the data.
(4) See for instance Coval and Stafford (2007).
(5) Such flows as defined by Morningstar may not — in all cases — be a perfect proxy for redemptions. This is because in some cases flows to/from each fund are calculated from the monthly change in total net assets under an assumption that funds' dividend payments are fully reinvested in the fund (rather than paid out to investors). Where dividends are not fully reinvested, this assumption would overstate outflows and understate inflows. Reporting coverage may also vary over time.
(6) In practice, any given level of redemptions over a month may be distributed unevenly across that month. This means our estimates of the severest weekly redemptions may understate the severest weekly redemptions that have occurred historically.

Data on the proportion of fund assets allocated in each of these asset classes is taken from Morningstar, as of December 2015.[1]

2.3 Fund performance data

For each category of funds, monthly returns are calculated as the percentage change in net asset value each month. **Chart 5** shows monthly returns for European investment-grade corporate bond funds.

Chart 5 Investment-grade corporate bond fund monthly returns



Sources: Morningstar and Bank calculations.

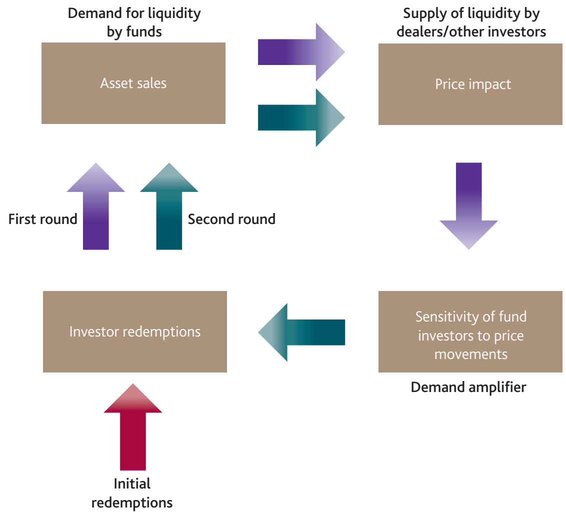
3 Model set-up and calibration

The key building blocks of the simulation are summarised in **Figure 2**. The framework allows us to simulate the impact of redemptions from open-ended investment funds on the liquidity and functioning of corporate bond markets, and comprises two key methodological components:

- First, that aimed at quantifying the possible *demand for liquidity arising from asset sales by investment funds* in response to investor redemptions;
- Second, that aimed at quantifying *the possible supply of liquidity by dealers and other market participants* that act as counterparties to funds' sales.

At a high level, the simulation begins with an assumption about initial investor redemptions (bottom left-hand corner of **Figure 2**). To meet these redemptions, investment funds make a 'first round' of asset sales, demanding liquidity in the market (top left-hand corner of **Figure 2**). The supply of liquidity by dealers and some other investors (as estimated by the partial equilibrium model described in Section 3.3) implies that a fall in price — expressed as an increase in spreads — is needed for the market to absorb the asset sales (top right-hand corner of **Figure 2**). The procyclical reactions of fund investors to these price falls trigger a 'second round' of redemptions (second-round demand for liquidity by funds), asset sales and changes in price (shown by green arrows moving clockwise around **Figure 2** from bottom right to top right). In the remainder of this section, we describe these steps in turn.

Figure 2 High-level structure of top-down simulation



Source: Bank of England.

3.1 First-round demand for liquidity by funds

Initial redemptions

The simulation assumes a range of initial redemptions from European open-ended investment funds and selected other fund categories included in scope (see Section 2). These redemptions are exogenous, in that they are not modelled as a function of anticipated price falls nor a specific stress scenario. Rather, we consider a range of redemption assumptions, which — for simplicity — are assumed to apply equally across our core group of investment grade corporate bond funds.

All other fund types (including government bond funds, high-yield bond funds, equity funds and some mixed categories of funds) are assumed to experience redemptions that differ to those from investment-grade corporate bond funds, in line with the pattern of redemptions across funds seen during the crisis.[2] For example, equity funds are assumed to experience redemptions that, on average, are half the size of those witnessed by investment grade corporate bond funds. These redemptions from other types of fund matter in the simulation that follows, because they determine the total quantity of assets sold and hence absorbed by dealers.

Throughout this exercise, we do not assess the availability and use of liquidity management tools, such as suspension of

(1) When these data are not available from Morningstar, we use a number of different estimates, including assumptions based on the fund category description provided by Morningstar. Where necessary, we adjust these data so that assets held within each broad fund category (equity, bond, mixed funds, etc) correspond to that given by the EFAMA.

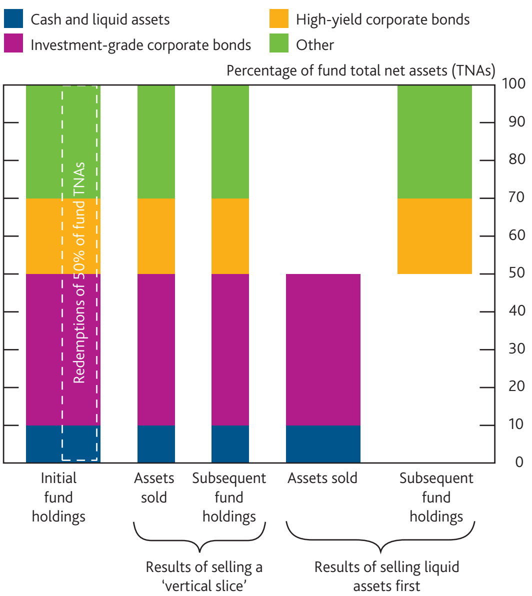
(2) Redemptions as a percentage of total net assets are capped at 100%. Where October 2008 redemption data is not available we proxy redemptions by using the fund category with the closest investment profile. This is necessary in only a small number of cases.

redemptions, by funds. This is an area for further work. Suspensions — particularly those occurring during market stress — are very rare historically, and their impact on overall fund redemptions is ambiguous. On the one hand, suspensions — by definition — limit redemptions and asset sales from those funds that suspend. On the other, suspensions might cause investors to reappraise the liquidity of other (unsuspended) funds' holdings and increase redemptions from those funds.

Asset sales

Given the assumed range of initial redemptions, the amount of each type of asset sold by funds depends on the way in which fund managers respond to those redemptions. Our baseline assumption is that funds meet redemptions by selling assets of varying liquidity in proportion to that in which they hold them (ie funds are assume to illiquid a vertical slice of their assets).(1) This is illustrated in **Figure 3** and is consistent with a recent survey of asset management firms by the Bank of England and Financial Conduct Authority, which concluded that funds would meet large redemptions by selling assets of varying liquidity (see Bank of England (2015a)). A similar assumption is made in Cetorelli, Duarte and Eisenbach (2016).

Figure 3 An illustration of the effect of funds meeting redemptions by selling assets of varying liquidity (a 'vertical slice') and of selling liquid assets first



Source: Bank of England.

Against that, some empirical evidence suggests that fund managers use cash to meet investor redemptions to a greater degree than that justified by the proportion of cash in their portfolios. This would suggest that funds respond to redemptions by selling less liquid assets in a proportion *lower* than that in which they hold them.(2) Such behaviour might reduce the impact on market prices that results from smaller levels of redemptions. However, particularly during stress, such behaviour could also lead to a 'first mover advantage' being perceived by investors, where investors are incentivised to redeem ahead of their peers in order to avoid being invested in less liquid assets (right-hand side of **Figure 3**). This might — in the longer run — lead to larger redemptions, eroding any potential benefit for market liquidity.

Fund managers may also engage in discretionary sales over and above those necessitated by redemptions alone. For example, funds might reallocate into less risky or more liquid assets in stresses to dis-incentivise redemptions and/or to increase the amount of liquid assets they might have to sell to meet future redemptions. Morris, Shim and Shin (2017), for example, find evidence of such 'cash hoarding' by the managers of both developed and emerging market bond funds.

The effect of such alternative assumptions for the responses of fund managers to investor redemptions is explored in Section 5.

3.2 Supply of liquidity by dealers and other investors and impact on corporate bond prices

Price impact

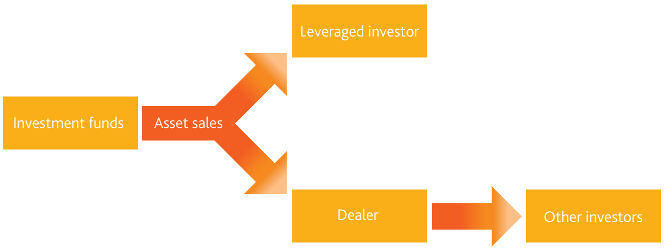
To estimate the impact of large-scale asset sales on corporate bond prices, our simulation draws on a partial equilibrium model set out in Baranova, Liu and Shakir (forthcoming). Use of this model — rather than relying upon historical empirical evidence of dealer behaviour — is necessary for three reasons. First, it allows us to estimate the impact on asset prices of redemptions that exceed those seen historically. Second, it allows us to separate the impact of the shock (ie redemptions from investment funds) from other factors that may influence market prices, which is difficult to do without using a model. Third, the model allows us to incorporate the impact of prudential regulation that has yet to come fully into force (eg the Basel III leverage and net stable funding requirements).

The model assumes that investment funds sell a given amount of assets over a period of a week. Two types of market participants provide liquidity to accommodate funds' sales of corporate bonds: dealers and hedge funds. The role of these agents and their interaction is summarised in **Figure 4**.

The hedge fund chooses the proportion of corporate bonds being sold by the investment fund sector that it wishes to buy. In doing so, it seeks to maximise its profit by balancing (i) the costs of financing its purchase via repo borrowing provided by the dealer against (ii) the profits it stands to make by 'arbitraging' any deviation of the price of the assets from their value commensurate with economic fundamentals, which

(1) Formally, a given fund category i experiencing redemptions r_i sells $s_{i,j} = r_i h_{i,j}$ where $h_{i,j}$ are holdings of asset j by fund category i. The total amount of asset j sold is $s_j = \sum_i s_{i,j} = \sum_i r_i h_{i,j}$. This includes an assumption that funds do not meet redemptions first out of maturing cash flows before liquidating other assets.
(2) See, for example, Chernenko and Sunderam (2016), who find this result in the case of both bond and equity funds.

Figure 4 A summary of the agents incorporated in the model of the impact of asset sales on price



Source: Bank of England.

results from the investment fund's sale. The dealer, meanwhile, clears the market (ie buys the remainder of the assets sold by the investment fund that are not purchased by the hedge fund).

The market-clearing price reflects the discount to prevailing prices (or increase in corporate bond spreads) at which the dealer buys those assets not purchased by the hedge fund. This discount can be attributed to the provision of market liquidity — that is, the compensation required by the dealer in return for warehousing the assets. Essentially, this price discount could be viewed as an increase in corporate bond spreads that could be attributed to market liquidity conditions (as opposed to the aggregate credit risk of the issuers). For an asset sale of a given size, the dealer costs and the associated price discount depend on a number of factors:

(i) First, the quantity of corporate bonds a dealer has to buy:

- The less willing hedge funds are to purchase corporate bonds, the greater the amount the dealer will have to absorb. Hedge funds' willingness to buy is, in itself, a function of the quantity and price at which a dealer is willing to extend repo financing to hedge funds as leveraged investors.

- Other things equal, the more assets the dealer will have to absorb onto its balance sheet, the more capital and funding it requires in order to do so.

(ii) Second, the amount of time that a dealer expects to hold assets in its inventory:

- The dealer is assumed to be able to sell a given quantity of bonds to other long-term investors (eg insurance companies and pension funds) in each period at prevailing prices (ie absent applying any price discount). The larger this quantity, the shorter the period of time the dealer expects to hold bonds in its inventory, lessening the costs it experiences in doing so.

(iii) Third, the funding, hedging and regulatory costs of holding a unit of corporate bonds in its inventory. Capital costs are assumed to increase non-linearly with the size of the purchase and depend on the amount of 'spare' capital — over and above its minimum regulatory requirements — that a dealer has to accommodate its purchase.[(1)] In particular, we assume:

- If the additional capital the dealer requires to absorb asset sales lies within the regulatory capital the dealer has allocated to its market-making function, the dealer sets the price discount to cover the marginal cost of capital, assumed to be 10% on an after-tax basis.[(2)]

- If the additional capital required exceeds the regulatory capital the dealer has allocated to its market-making function, but lies within that allocated at firm level, the dealer is assumed to reallocate some capital from another business line, but charges the market-making function a higher cost of capital to compensate for the potential loss of profit from the higher-return business lines. This we set equal to the observed historical average return on equity of major broker-dealers, at around 17%.[(3)]

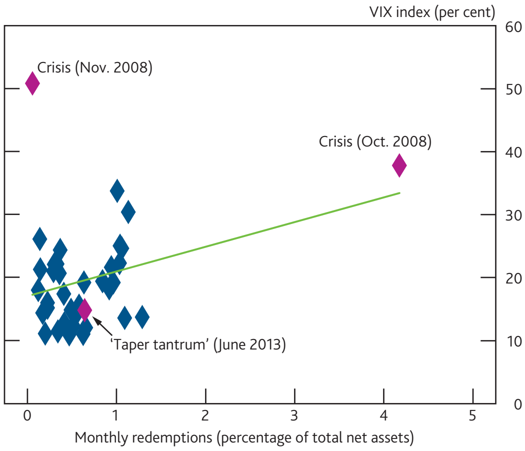
- If the extra capital required exceeds the regulatory capital dealer has allocated at firm level, the dealer is assumed to no longer be able to act as a market maker. At this point, the dealer's capacity to absorb asset sales is deemed to be overwhelmed.

The price impact of asset sales further depends on the level of market stress, to the extent that it influences each of these factors. In particular, the dealer's funding and hedging costs — affecting (i) and (iii) — are assumed to increase as a function of market stress, as proxied by the VIX index.[(4)] Increasing market stress also causes the dealer to reduce the balance sheet it allocates to market intermediation,[(5)] meaning that the higher capital costs described in (iii) apply for smaller levels of asset purchases. Throughout, we assume a fixed linear relationship between the VIX index and redemptions from corporate bond funds. This is calibrated based on historical data (**Chart 6**).[(6)]

The model in Baranova, Liu and Shakir (forthcoming) is calibrated for a dealer transacting in global markets and can be used to estimate the price impact of asset sales of generic investment grade corporate bonds in those markets.[(7)]

(1) We assume this to be equal to the difference between the size of the balance sheet that a dealer deems optimal for a given level of capital (subject to regulatory constraints) and actual balance sheet size.
(2) Estimated cost of regulatory capital allocated by dealers to their market making functions (see King (2009)).
(3) Estimated average overall return on equity of two major dealers.
(4) The VIX index is a measure of market expectations of 30-day volatility as conveyed by S&P 500 stock index options prices, which we take as a proxy for general market stress. This is not without precedent; see, for example, Rey (2013).
(5) When market stress increases, dealers incur losses which reduce their capital and their risk appetite also decreases, which results in lower balance sheet capacity allocated to market-making.
(6) We model the relationship between the VIX index and aggregate redemptions from our core group of corporate bond funds (see Section 2.2).
(7) For full details of the global calibration, see Baranova, Liu and Shakir (forthcoming).

Chart 6 Historical relationship between the three-month average level of VIX index and fund redemptions



Sources: Bloomberg, Morningstar and Bank calculations.

However, in this analysis, we seek to estimate the effect of sales of securities issued by firms in specific jurisdictions, including those whose corporate bond markets differ in their liquidity. We therefore adjust the impact of sales of bonds of issuers in different jurisdictions to reflect the size of that jurisdictions' corporate bond market. This is designed to reflect how a larger change in price is likely to result from sales of bonds issued by firms in jurisdictions with smaller corporate bond markets.

Separately, we also account for the fact that some corporate bond markets (eg those of emerging economies) are likely to be riskier and more volatile than those of advanced economies and, hence, holding such corporate bond inventory will be associated with higher dealer costs. In particular, we calibrate the costs of hedging and risk-weighted capital charges separately for each regional corporate bond market. We use a similar approach to estimate the price impacts in high yield bond markets as we do for investment grade bond markets.

While the analysis of the impact of corporate bond sales on prices described above distinguishes between bonds of different domicile and credit quality (ie investment grade versus high yield), it does not distinguish between bonds of different issuers or maturity.(1) This is akin to assuming that the composition of European investment funds' holdings of corporate bonds mirrors the entire market. This simplifying assumption may cause some bias in the results if the characteristics of corporate bonds within a category held by funds differ to those in the market at large. An extension of this work could consider greater differentiation between bond types.

Details of how we assess the impact of sales on prices for assets other than corporate bonds are set out in Annex 1.

3.3 Second-round demand for liquidity by funds

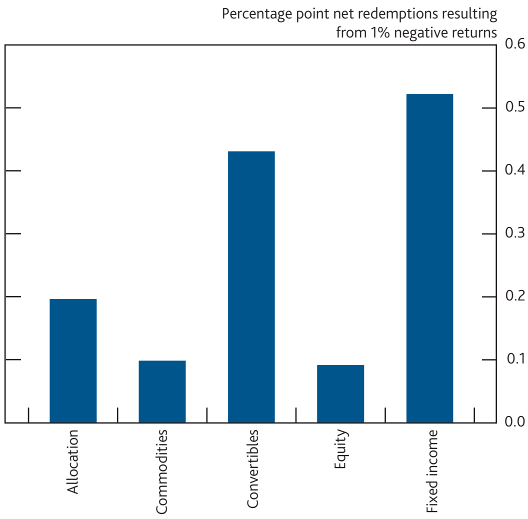
Sensitivity of fund investors to price movements

The impact on asset prices of initial fund redemptions and asset sales is assumed to lead to reductions in fund performance and further redemptions from funds. This follows from evidence that suggests that fund investors tend to behave procyclically — that is, there is a positive relationship between investment funds' performance and redemptions in the period that follows (see Box 1).

To capture this effect, we follow the approach of Morris, Shim, Shin (2017) and estimate the sensitivity of fund redemptions to returns for each category of funds by running a panel regression, which allows for fund-specific fixed effects. This involves regressing individual fund flows in each period on fund returns in both the current and previous months, along with the level of the VIX index. This specification aims to account for any correlation between current returns and redemptions, allowing us to isolate the sensitivity of redemptions to returns in the previous period.(2) Including fund-specific fixed effects, meanwhile, accounts for the possibility that individual funds' flows may differ in their long-run trends, which — if not accounted for — might risk biasing the sensitivity estimates.

Full results of these regressions are not given here (they involved almost 250 panel regressions), but a summary of the results across different categories of funds is given in **Chart 7**.(3) We estimate that redemptions that follow a 1%

Chart 7 Summary of sensitivity of fund redemptions to a 1% negative fund return



Sources: Morningstar and Bank calculations.

(1) We make the same assumption that securities are homogenous for other asset classes.
(2) Note that we estimate the sensitivity of investor redemptions to fund returns in the previous month and use this sensitivity to calibrate the second round of redemptions that — in this framework — occur over a shorter time horizon.
(3) Where missing data meant a sensitivity estimate could not be produced, an estimate for a comparable fund category was used as a proxy.

loss for fund investors range (on average) from less than 0.1% of TNA for equity funds to more than 0.5% of TNA for fixed income funds. More than 75% of the estimated relationships between past fund losses and redemptions across fund categories are significant at a 5% significance level and almost 80% at the 10% significance level.(1)

3.4 Repeat steps 3.1 to 3.3

We then repeat steps 3.1 to 3.3, such that the second round of investor redemptions derived via step 3.3 leads to further asset sales and subsequent price impacts.

Second-round sales of assets by funds are also assumed to occur over a one-week period and are accommodated by dealers and hedge funds, just as in the first round. In doing so, dealers take into account the balance sheet that has already been used in absorbing first-round fund sales. Hence, our framework models the short-term (ie within two-week time horizon) dynamics in corporate bond markets.

In principle, this process could be repeated ad infinitum, but we refrain from doing so here. This is because, with each such successive round of redemptions, the nature of the dynamic between redemptions and market prices becomes more uncertain. This is for two reasons:

- *First, the behaviour of other (non-leveraged) investors may vary over time*. As described in Section 3.3, it is assumed that dealers can sell a constant quantity of bonds to other investors, such as insurance companies and pension funds, each week without this being associated with a fall in (equilibrium) market prices. Such an assumption may be plausible over a short period time, as non-leveraged investors tend to be slower-moving and may not react quickly to changing market conditions (see Box 1). But if deviations of price from a level commensurate with economic fundamentals were to persist, institutional investors might choose to increase their investment in the less liquid asset. This would increase the supply of liquidity by other investors and ease any downward pressure on market prices.

- *Second, the redemptions that result from a given fall in prices may change with further rounds*. As described in Section 3.4, the second round of redemptions by fund investors that follows a fall in asset prices is predicated on the observed relationship between fund performance in a given month and redemptions in the month following it. But this relationship may weaken for subsequent falls in price, for example if fund investors that are most sensitive to price falls have already redeemed their investment. Modelling these longer-term dynamics is beyond the scope of the model.

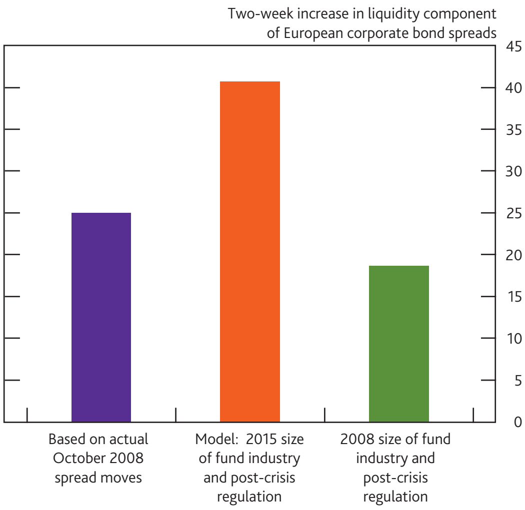
4 Simulation results

4.1 Back-testing simulation outputs

In order to gauge the plausibility of modelled outcomes, we back-test our framework by taking the fund redemptions experienced in October 2008, and comparing the model's predictions of changes in corporate bond spreads that could be attributed to market liquidity conditions to those observed over the same period.

During October 2008 European investment-grade corporate bond spreads increased by around 100 basis points, with half of this increase (ie 50 basis points) occurring in the space of two weeks. However, this increase in spread reflects both a deterioration in firm credit quality, as well as an increase in the compensation demanded for a deterioration in liquidity. We isolate the proportion of this increase in corporate bond spreads that is attributable to illiquidity (and thereby comparable to the results of this framework) by using the model described in Churm and Webber (2007). Applying this model to corporate bond spreads between 2005 and 2016 suggests that, on average, around 50% of the level of European investment-grade corporate bond spreads can be attributed to the compensation for liquidity conditions in this market, with the remainder accounted for by expectations of credit losses and uncertainty around these expectations.(2) This implies that the increase in corporate bond spreads that could be attributed to market liquidity conditions is roughly half of the 50 basis points overall increase observed over the two-week period in October 2008, which is around 25 basis points (**Chart 8**, purple bar).

Chart 8 Results of framework back-testing (October 2008 episode)



Source: Bank of England.

(1) Some of the estimated regression coefficients were not statistically significant. In these cases, we still used the insignificant results as our estimates rather than setting them to zero.
(2) Of course, it remains plausible that this illiquidity and economic fundamentals affect each other, and are therefore impossible to separate (since increasing illiquidity premia have the potential to raise firms' cost of funding and thereby weaken their solvency); but we abstract from that possibility here.

In comparison, the simulation framework described above predicts that, were the level of redemptions seen in October 2008 to reoccur, the liquidity component of corporate bond liquidity spreads would increase by around 40 basis points (**Chart 8**, orange bar).

However, this baseline estimate from the simulation is not directly comparable to the historical outcome. This is because it is predicated on a much larger investment fund sector than existed in 2008. If we adjust parameters to reflect this, the simulation predicts a smaller increase in spreads as a result of fund redemptions at October 2008 levels than that observed in reality (**Chart 8**, green bar).

There are three plausible explanations for the shortfall in price impact implied by our model relative to that observed in corporate bond markets in October 2008: (i) hedge funds might have not been providing liquidity during this episode to the extent assumed in the model (see Box 1); (ii) other market participants, not explicitly captured in the framework (eg pension funds/insurers), might have also been selling corporate bonds; and (iii) not all dealers — particularly those on the brink of failure — might have been net buyers of assets.

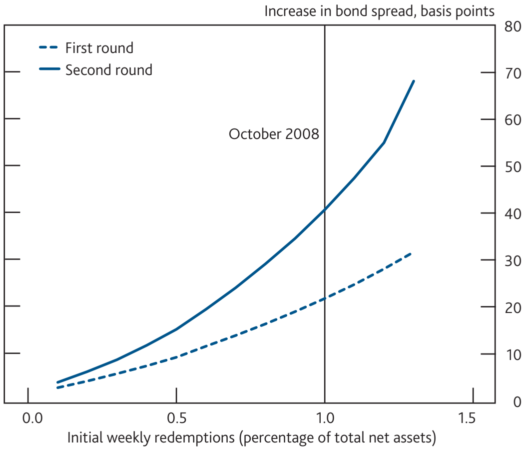
4.2 Simulation outputs and key takeaways

The simulation framework facilitates a better understanding of the potential impact of fund redemptions on the liquidity of corporate bond markets. In particular, its outputs allow policymakers to assess the extent to which:

- Corporate bond spreads may rise following initial fund redemptions of a given magnitude (*first-round price impact*), given the share of the overall corporate bond market held by funds and the corporate bond market microstructure;
- Fund investors respond to first-round reductions in performance, and the degree to which this may amplify initial price falls (*second-round price impact*); and
- Sales of assets by funds may begin to exceed market intermediaries' capacity to absorb them. This we assume to be associated with severe '*market dislocation*' and prices that are substantially removed from those commensurate with economic fundamentals. By comparing the size of the redemption shock that could potentially test market liquidity, as inferred from simulation outputs, to the historical distribution of flows to/from corporate bond funds, it is also possible to judge the likelihood of such a risk crystallising.

Chart 9 shows the outputs of the simulation for the European investment grade-corporate bond market. Results are based on the set of assumptions regarding market participant behaviour described in Section 3. The falls in price (expressed as an increase in corporate bond spreads) following the first and second round of investor redemptions are shown by the dotted and solid blue lines respectively. The difference between the two lines shows the increase in liquidity premia brought about by the procyclical behaviour of fund investors. This is shown as a function of the level of initial redemptions (as a percentage of funds' total net assets) experienced by funds that are material holders of investment-grade corporate bonds. Results correspond to funds' holdings and total net assets as of December 2015 and to the post-crisis regulatory regime for dealers and dealer balance sheets as of December 2015.

Chart 9 Estimated fall in prices (expressed as an increase in liquidity component of corporate bond spread)[(a)] for different levels of initial redemptions



Source: Bank of England.

(a) Changes in prices are shown in these charts as increases in liquidity components of corporate bond spread for illustrative purposes. In converting the estimates of change in price to increase in spreads we assume an average bond duration of five years.

The results indicate that a level of weekly redemptions from investment-grade corporate bond funds equal to 1% of total net assets (similar to those seen in October 2008 at the peak of the global financial crisis) would result in an increase in European investment-grade corporate bond spreads of around 40 basis points (**Chart 9**, solid blue line). Such an increase is material and corresponds to roughly a third of 2000–16 average investment-grade corporate bond spreads for Europe-domiciled companies. Redemptions of 1.3% of total net assets could increase spreads by around 70 basis points, which is equivalent to 50% of their historical average value.[(1)]

Moreover, second-round investor redemptions that occur in response to first-round reductions in performance are found to amplify initial market moves materially, accounting for around half of the overall change in spreads.

The steepness of the schedule of second-round price discounts increases at the point at which the dealer cannot absorb further asset sales using the capital it has assigned to its

(1) Average corporate bond spreads for Europe-domiciled investment-grade corporates are calculated over 2000–16.

market-making and repo functions. When sales exceed this point (ie equivalent to around 1.2% initial redemptions), the dealer will still be able to accommodate further sales by re-allocating capital from other business lines but at a higher cost of capital.

The level of redemptions at which the second-round price impact line ends is where dealers reach the limit of their capacity to absorb those asset sales by funds not purchased by hedge funds. We assume that market liquidity is tested at this point and refer to it as the market-breaking point. Transactions could still occur beyond this point — for example, if a dealer can immediately match a buyer and seller or if it sells other assets to purchase corporate bonds — but are assumed to take place at highly dislocated prices. For the European investment-grade corporate bond market this point arises for initial redemptions of around 1.3% of total net assets. This is around 1.3 times the level of redemptions observed in October 2008. Redemptions of this magnitude, although severe, therefore seem plausible.

5 Evaluating the effect of alternative assumptions regarding market participant behaviours on simulation outputs

The simulation results presented in Section 4 were based on certain assumptions regarding market participant behaviour, which may or may not hold in practice. This section explores the extent to which the simulation outputs are sensitive to these assumptions. It does so along three dimensions, the results of which are summarised in **Table A**.

(i) The assumed behaviours of fund investors and managers

Our first sensitivity is to assume that fund managers rely disproportionately on cash in order to meet investor redemptions, instead of selling assets of varying liquidity in proportion to their holdings (ie liquidating a 'vertical' slice). Such an alternative assumption is consistent with Chernenko and Sunderam (2016), who — for the US investment fund industry — estimate that for each dollar of outflows, equity funds decrease their cash holdings by 23 cents and bond funds by 33 cents (Scenario 1.a). We also use estimates from Morris, Shim and Shin (2017) and produce outputs under a scenario where fund managers engage in a form of 'cash hoarding' and increase their cash holdings in anticipation of future redemptions (Scenario 1.b).(1)

We further experiment with the settings for the assumed correlation between the net flows into/from funds pursuing different investment strategies. Instead of assuming that redemptions from corporate bond and other types of funds are correlated in line with the pattern observed during October 2008 (which we might expect to bear resemblance to future 'risk off' episodes), we obtain results based on the correlations observed during June 2013, when there was a sharp increase in market interest rates often referred to as the 'taper tantrum' (Scenario 1.c).

Finally, we obtain results based on assumptions that the sensitivity of second-round investor redemptions to initial falls in prices and the associated fund losses are double (Scenario 1.d) and half of those (Scenario 1.e) estimated using the panel regression analysis described in Section 3.

(ii) Ability and willingness of dealers to intermediate corporate bond markets

In the framework, dealers' assumed ability to intermediate markets and accommodate sales of corporate bonds is a function of the difference between their actual capital positions and minimum regulatory requirements. As a sensitivity, we assume that capital positions, in excess of the regulatory leverage ratio requirement, are increased by a third (Scenario 2.a).(2)

As outlined in Section 3.2, dealer ability and willingness to intermediate markets also declines as the overall level of market stress goes up. Hence, we try different assumptions as to the assumed strength of the relationship between redemptions and market stress (as proxied by the VIX index) by decreasing/increasing the regression estimate given in Section 3.2 by one standard deviation (Scenario 2 b/c).

(iii) Behaviour of other investors

The framework assumes that hedge funds act as speculators that provide liquidity subject to funding constraints. But there is empirical evidence that this assumption may not hold during times of stress (Choi and Shachar (2013)). We therefore make the alternative assumption that hedge funds act neutrally and neither buy nor sell in response to fund asset sales (Scenario 3.a).

Finally, there is a possibility that longer-term investors do not behave, as assumed in Section 3, by buying corporate bonds from the dealer at a constant rate. Instead they could behave procyclically, selling assets as prices fall (see November 2016 *Financial Stability Report*). We capture this possibility by inserting the alternative assumption that the longer-tem investor reduces the pace at which it buys assets from the dealer as market stress intensifies (Scenario 3.b).(3)

(1) As in Morris, Shim, Shin (2017): $3 of discretionary sales (increase in cash) for developed market bond funds and $10 of discretionary sales for emerging market bond funds are assumed for each $100 of investor-driven sales.
(2) In particular, we assume that instead of having a hard 4% leverage ratio requirement (which accounts for leverage ratio buffers) and 5.5% actual leverage ratio, the requirement is 3.5%, which implies that some of the buffers are useable and can be drawn on if needed to expand business activities.
(3) In particular we assume that as the market stress goes up to the levels observed in 2008 Q4, institutional investors linearly decrease the amount of assets that they buy daily from the dealer by up to a half of normal times purchase.

Table A presents the results of this sensitivity analysis. For each scenario we estimate the market-breaking point as well as the price impact, expressed in terms of the resulting increase in European corporate bond spreads, that would result from a 1.0% initial redemption from corporate bond funds.

Table A Results of scenario analysis

Scenario	Market-breaking point (initial redemption shock, as a percentage of TNA)	Final price impact as a result of 1.0% shock (basis points)[a]
Base scenario (Section 4)	**1.3**	**41**
1 Behaviours of fund investors and fund managers		
a: Fund managers partially use cash to meet redemptions	1.3	27
b: Fund managers 'hoard cash'	1.3	49
c: 'Taper tantrum' correlations of fund flows	1.3	38
d: Fund investors more procyclical	1.3	63
e: Fund investors less procyclical	1.3	31
2 Ability and willingness of dealers to intermediate corporate bond markets		
a: Higher dealer ability to intermediate markets (higher level of initial spare capital)	1.7	39
b: Impact of lower market stress on dealer ability and willingness to intermediate markets	2.4	39
c: Impact of higher market stress on dealer ability and willingness to intermediate markets	0.9	Not defined, as market dislocates before that point
3 Behaviour of other investors		
a: Hedge funds don't supply liquidity	1.3	42
b: Institutional investors act procyclically	1.3	44

Source: Bank of England.

(a) 1% is a level of redemptions similar to that experienced by corporate bond funds in October 2008.

As can be seen from **Table A** (second column), the level of redemptions at which corporate bond market dislocation occurs (ie the market-breaking point) is determined by the ability and willingness of dealers to intermediate markets, which is assumed to vary with market stress. Intuitively, if large-scale redemptions occur in normal market conditions, when the dealer is not exposed to significant overall market stress, the dealer will likely be able to accommodate the sale of assets by funds without any major disruption to market functioning (Scenario 2.b). On the other hand, if the dealer is exposed to significant market volatility when redemptions occur and incurs and/or expects to incur losses, the dealer is more likely to reduce its risk appetite and its provision of market intermediation services to the extent that even moderate levels of redemptions and asset sales could overwhelm the market capacity to absorb them (Scenario 2.c).

The price impact of fund redemptions (**Table A**, third column) is determined by a range of factors driving the demand and supply of liquidity. In particular, on the demand side, the partial use of cash to meet investor redemptions (Scenario 1.a), results in a price impact 30% lower than that when fund managers liquidate a 'vertical slice' of assets, as is the case under the baseline scenario. These results do, of course, abstract from how changes in fund managers' response to redemptions may themselves influence investor behaviour. For example, as discussed in Section 3, were fund managers' use of cash in meeting redemptions to create a perception of 'first-mover advantage' on the part of investors, this might exacerbate consequences for market liquidity during stress.[1] On the supply side, if, for example, hedge funds do not provide liquidity (Scenario 3.a) and institutional investors behave procyclically (Scenario 3.b) during the periods of stress, the impact on market prices could be higher.

6 Relevance of this work for systemic risk assessment

The stress simulation described in this paper is partial in both its nature and scope. Nevertheless, it provides a number of useful conclusions.

First, it explores how stress can be propagated by different parts of the financial system, both banks (ie dealers) and non-banks (ie investment funds and hedge funds). The simulation demonstrates how, during stress, the collective behaviour of various market participants, despite being individually rational, might result in undesirable outcomes from the perspective of financial stability. This includes both the liquidation of assets in order to meet investment funds' redemptions, as well as the defensive actions of dealers both to deleverage (and reduce lending to other investors) and reduce their market-making activity. But when both these behaviours are combined, they have the potential to result in market dislocation and increases in the cost of funding faced by firms in the real economy.

Second, it highlights certain behaviours that may amplify the initial impacts of shocks. For example, investor procyclicality — in particular, the tendency of fund investors to make further redemptions when faced with initial falls in prices — has the potential to amplify asset price falls. Other investors, eg insurance companies, may exhibit similar or offsetting behaviours, but those have not been captured explicitly by the framework as it currently stands.

Third, it illustrates the importance of exploring the impact of multiple scenarios in conducting systemic stress simulations. Sensitivity analysis presented in the paper shows that the degree to which stress is amplified depends on the scope and severity of contagion channels. Thus, exploring multiple outcomes could highlight where the most important

(1) When funds use their most liquid assets first to meet redemptions, this disadvantages investors remaining in the fund, as they are left holding assets that are on average less liquid. This might create incentives for investors to redeem ahead of others (ie the 'first-mover advantage').

vulnerabilities lie and inform where additional risk monitoring efforts are required. This justifies structuring stress simulations as flexible frameworks that could nest a variety of modelling assumptions.

Finally, the framework's outputs can be used to analyse the impact of shocks on the ability of the financial system, including that of banks and market-based finance, to support the real economy. For example, the fall in corporate bond prices and the associated increase in bond yields could directly impair the ability of companies to raise funding via capital markets. Moreover, even the short-term falls in corporate bond prices, such as those estimated in the simulation, could cause mark-to-market losses for banks, thus indirectly impairing the resilience of the core of the financial system and its ability to serve the real economy.

Even though the simulation framework has provided a range of useful insights it is not without limitations.

First, it does not explicitly model the behaviour of institutional investors. In particular, it assumes that such investors do not act fast enough to directly accommodate asset sales by funds, and instead gradually buy assets from the dealer. While this might be a reasonable assumption in the short run (ie within the two-week time horizon as assumed in the simulation), this may not hold in the longer term. Modelling such longer-term dynamics might, however, be important in order to be able to assess the likely persistence of any increases in corporate bond spreads as a result of fund redemptions and the impact that this might have on the ability of corporates to fund themselves via capital markets.

Second, the model is appropriate for capturing the dynamics of dealer-intermediated markets, such as corporate bonds or asset-backed securities, but cannot be extended easily to other types of market, the microstructure of which varies significantly from that of corporate bonds (eg government bonds or equities). For example, in equity markets less than 20% of trading volume is dealer intermediated (versus 95% in corporate bond markets), with most of the trading taking place on exchanges where the orders of multiple buyers and sellers of securities are matched.(1) In such markets, the level of activity and the price formation process are unlikely to be largely driven by dealers' willingness and ability to provide intermediation services.

Addressing such limitations will be essential in future work that aims to build a holistic analysis of the impact of stress on the financial system and, ultimately, of its impact on the real economy.

7 Conclusion

The simulation presented in this paper is a first step towards building a holistic system-wide stress simulation framework.

Even though it is partial in nature, and does not capture all financial sectors, markets and amplification mechanisms, it is a valuable contribution from two perspectives.

First, it illustrates the rationale behind developing and running systemic stress simulations and how they could be useful for analysing the impact of stress on the financial system as a whole. It also highlights some of the key elements that such simulations should seek to include (eg capturing multiple sectors of the financial system and amplification effects).

Second, it is a useful risk assessment tool in its own right. It is a flexible framework that can be used to assess the near-term impact on the pricing and functioning of European corporate bond markets of different levels of redemptions from open-ended investment funds.

The stress simulation indicates that, under a severe but plausible set of assumptions regarding market participant behaviours, investor redemptions can result in material increases in spreads in the corporate bond market and, in the extreme, in corporate bond market dislocation, threatening the stability of financial markets and institutions. While such market dislocation is a 'tail risk', the probability of it crystallising could increase, especially if the potential demand for liquidity, including that arising from the investment fund sector, continues to grow relative to the supply of liquidity by dealers and other investors. These are relevant takeaways for the assessment of risk from the systemic perspective, as they not only highlight potential risks, but also help identify areas and vulnerabilities that warrant monitoring going forward.

(1) Anderson *et al* (2015).

Annex 1
More details on the estimation of the impact of asset sales on asset prices

This annex contains a detailed explanation of how we estimate the impact of asset sales by investment funds on prices of different assets. This is necessary not just for corporate bond markets — which are the main focus of our work — but also for other markets (including equities and government bonds). This is because funds hold securities in these broader markets and their sale — and subsequent change in price — plays a role in driving further redemptions.

Estimate of the impact of sales of corporate bonds

We begin by describing how we estimate the impact of asset sales on corporate bond prices. This is based on the model of Baranova, Liu and Shakir (forthcoming) (a summary of which is contained in Section 3.3). This model estimates the impact of asset sales on the price of a generic investment grade (IG) corporate bond at a global level[(1)] without taking into account the differences between bonds issued by companies domiciled in various regions. Specifically, the model yields a function $I^{IG}_{glob}(s)$ that increases non-linearly as a function of the quantity of bonds being sold globally, denoted by s.

In order to apply this model to obtain impacts on price specific to different regional segments of IG and high-yield (HY) corporate bond markets, it is necessary to make several adjustments. First we expand the definition of the global market to cover both IG and HY corporate bond markets. Second, we adjust the quantity of sales inputted into the price impact function by the size of the different regional segments of IG and HY corporate bond markets relative to the size of the overall global market. This is designed to reflect how the change in price that results from a sale of bonds of a given size is likely to be larger, the smaller (and hence less liquid) the market for bonds issued in that region.

We estimate the impact of asset sales in different regional segments of the IG corporate bond market, which we denote $I^{IG}_{region}(s)$ for *region = {Europe, US, other developed markets, emerging markets}*, as:

$$I^{IG}_{region}(s) = I^{IG}_{glob}\left(s\frac{size_{glob}}{size^{IG}_{region}}\right), \qquad (1)$$

where $size_{glob}$ and $size^{IG}_{region}$ are the size of the global market (comprising both IG and HY corporate bonds) and the size of the regional segment of the IG corporate bond markets, respectively.[(2)]

As compared to the original approach, we also adjust for the fact some corporate bond markets (eg those of emerging economies) are likely to be riskier and more volatile than those of the developed economies, and, hence, holding such corporate bond inventory will be associated with higher dealer costs (eg we adjust the cost of hedging via CDS markets and risk-weighted capital charges based on market fundamentals).

Similarly the impact of asset sales in the HY corporate bond market is denoted by $I^{HY}(s)$ and is estimated as

$$I^{HY}(s) = I^{IG}_{glob}\left(s\frac{size_{glob}}{size^{HY}}\right),$$

A summary of the assumptions made for IG and HY corporate bonds belonging to different regions of issuance is provided in **Table A1.1**.

Estimates of the impact of sales of other assets

As summarised in **Table A1.1**, we also estimate the impact on market prices of sales of securities other than corporate bonds:

- For **government bond markets**, we follow Greenwood, Landier and Thesmar (2015) and Cetorelli, Duarte and Eisenbach (2016) and assume that the impact on market prices increases linearly with the quantity sold. We estimate these price impacts using the illiquidity measure defined by Amihud (2002), and calibrate this to data on transactions of GBP government bonds taken from the FCA ZEN database (for details see Annex 2). We adjust the estimate for GBP government bonds by the relative turnover for relevant markets in order to estimate the impact on prices for high-rated, other developed country and emerging country government bond markets.[(3)(4)] This is designed to reflect how a market for governments bonds in a region with lower turnover is — all else being equal — likely to be less liquid.

- For **equity markets**, we again assume that the price impact varies as a linear function of the quantity of securities sold, and base an estimate of this impact on the methodology of Amihud (2002). This is calibrated using data on prices and turnover of the constituents of the S&P 500 index from 2011 to 2015 from Bloomberg. We estimate that €1 billion of sales leads to a 0.07% reduction in price for US equities.

(1) Global investment-grade corporate bond market refers here to dollar, euro, and sterling-denominated corporate bond markets.
(2) This approach assumes that the impact on market prices of an investment fund sale of a given size is independent across different regional segments of the corporate bond market.
(3) Data on GBP government bonds are obtained from UK Debt Management Office (DMO); those on USD government bond from Securities Industry and Financial Markets Association (SIFMA); EUR government bonds are proxied by German government bonds whose data are obtained from Deutsche Finanzagentur.
(4) In particular, the estimate of the price impact of sales for emerging market and other developed market government bonds is obtained by multiplying the price impact for GBP government bonds by the turnover in the GBP market divided by the turnover in the EUR market. For high-rated government bonds (AAA/AA-rated) the estimate for GBP government bonds is adjusted by the weighted-average of the turnovers for relevant markets (US, UK and selected euro-area domiciles), where the weights represent the size of those government bond markets.

Given data limitations, we assume this estimate holds for all developed equity markets. For emerging markets we scale our Amihud estimate by the ratio of liquid asset requirement per unit of security taken from the Basel III Liquidity Coverage Ratio (LCR) (following Cetorelli, Duarte and Eisenbach (2016)).

- Due to lack of data, simplifying assumptions are made to model the effect of asset sales on the prices of covered bonds, securitisations, bank loans, convertible bonds, municipal bonds and preferred stock. The impact of asset sales on the price of preferred stocks is assumed to be linear and equal to that for developed markets equity. A linear price impact function is also assumed for municipal bonds. For all other asset classes mentioned above we adapt the model developed by Baranova, Liu and Shakir (forthcoming). For details see **Table A1.1**.
- Finally, no impact on market prices is assumed to follow from the sale of other assets held by funds in our sample, which we understand to consist mainly of property and cash/cash equivalents. In the case of property, we assume no impact on market prices since funds holding these assets generally have limited holdings of corporate bonds and equities. They therefore are assumed to have only a negligible effect on the returns of equity and bond funds, used when assessing the second round effects. We also assume that cash and cash equivalents[1] have no liquidation costs.

A summary of these approaches is provided in **Table A1.1**.

(1) Cash and cash equivalents include cash (including foreign currency), repos, holdings of money market funds and certificates of deposit.

Table A1.1 Summary of the methodologies used to estimate the impact of asset sales on asset prices

		Region			
		Europe	United States	Other developed markets	Emerging markets
Asset class	Investment-grade corporate bonds	Baranova, Liu and Shakir (forthcoming).			
	High-yield corporate bonds				
	Government bonds	Linear price impact estimated empirically using Amihud (2002) for GBP government bond market adjusted by relative turnover.			
	Equities	Linear price impact estimated empirically using Amihud (2002) for S&P 500 constituents.			Assumed equal to empirically estimated equity price impact for S&P 500 adjusted by relative Liquidity Coverage Ratio (LCR) coefficients for developed and emerging markets.[a]
	Preferred stocks	Assumed equal to developed market equity price impact.			
	Covered bonds	Baranova, Liu and Shakir (forthcoming) adapted for each market.			
	Bank loans				
	Convertible bonds				
	Securitisations	Non-Agency securitisations: Baranova, Liu and Shakir (forthcoming) adapted to this market; US Agencies: price impact equal to that for US government bonds.			
	Municipal bonds	Equal to other developed markets government bond price impact.			
	Other (including property)	Assumed no change in price in response to asset sales.			

(a) As in Cetorelli, Duarte and Eisenbach (2016).

Annex 2
Details on the application of Amihud (2002) in estimating price impacts

Annex 1 contains a detailed explanation of how we estimate the impact of asset sales by investment funds on prices of different assets ('price impact'). A key input to estimating price impacts for some asset classes, such as equity and government bonds, is a measure developed by Amihud (2002). Amihud (2002) defines a measure of illiquidity as the ratio between the absolute value of returns and traded volume. Multiplying this ratio by the size (volume traded) of any given transaction in an asset gives an estimate of the price impact, i.e. the change in price resulting from that transaction.

The remainder of this Annex explains how we estimate the price impacts for two markets: GBP government bonds and US equities. This is summarised in **Table A2.1**. In order to estimate price impacts for these asset classes we aggregate estimates of the Amihud price impact measure across individual securities obtained using transaction-level data.(1)

Because we lack data on fund holdings of each individual security, we assume that a fund's holdings in each market are equally split across all available securities within that market; that is, we assume that the amount of each individual security held by a fund is equal to that obtained by multiplying the amount of assets the fund holds in that market by $\frac{1}{N_j}$, where N_j is the number of securities in market $j = \{GBP\ govt, US\ eq\}$. We also assume that the total price impact of funds' sales of securities is equal to the arithmetic average of the price impacts that follow the sale of any individual security, so that the total change in price in market j is:

$$p^j = \frac{1}{N_j} \sum_{k=1}^{N_j} A^{j,k} q_{j,k}, \tag{1}$$

where:

- $A^{j,k}$ is the price impact per unit sold (or bought), estimated using the methodology of Amihud (2002), for each security k in the dataset for market j; and
- $q_{j,k}$ is the amount sold (or bought) of security k in market j;

…so that $A^{j,k} q_{j,k}$ gives the price impact for the total amount sold (or bought) of security k in market j.

Having estimated the Amihud measure, $A^{j,k}$, for each security k in the dataset for market j, we need to estimate $q_{j,k}$ — the amount sold (or bought) of each security k in the dataset for market j.

To do this we multiply holdings of each security by the proportion of net assets that are redeemed from funds. As above, we assume that funds' holdings mirror those of the market as a whole.

We assume that in response to redemptions, within one asset class funds sell securities in proportion to that in which they hold them. This assumption yields the following expression for the absolute amount of security k in market j sold (or bought), $q_{j,k}$:

$$q_{j,k} = \sum_{i=1}^{N} r_i h_{i,j,k}, \tag{2}$$

where

- r_i is the redemption value as a proportion of total net assets (TNA) for fund category i;

(1) Security-by-security estimates of price impact are preferable to those made using index-level data, since they allow identification of a more precise relationship between trading volumes and price impacts (in an index, volumes and impacts are aggregated).

Table A2.1 Details on data used to estimate price impact for different markets using Amihud (2002)

Market	Notation	Estimate	Data
GBP government bonds	A^{govt}	A^{govt} = 0.14% per €1 billion sale	Daily transaction-level data from August 2011 to March 2015 from the FCA ZEN database.
US equities	$A^{US\ eq}$	$A^{US\ eq}$ = 0.07% per €1 billion sale	Daily data on prices, volume and turnover from August 2011 to March 2015 for the constituents of S&P 500 index from Bloomberg.

- $h_{i,j,k}$ is the holdings by fund category *i* in security *k* in market *j* (where the fund category is that as used to group funds by investment style, as discussed in Section 2); and

- *N* is the total number of fund categories.

As discussed above, we assume that the proportion of market *j* comprised of each security is $\frac{1}{N_j}$. Fund holdings $h_{i,j,k}$ are assumed to reflect these market weights. This yields that the holdings by fund category *i* in security *k* in market *j* are given by:

$$h_{i,j,k} = \frac{h_{i,j}}{N_j}. \quad \textbf{(3)}$$

Substituting **(3)** into **(2)** gives:

$$q_{j,k} = \frac{1}{N_j} \sum_{i=1}^{N} r_i h_{i,j}. \quad \textbf{(4)}$$

And substituting **(4)** into **(1)** gives:

$$P^j = \frac{1}{N_j} \left(\sum_{k=1}^{N_j} A^{j,k} \right) \cdot \frac{1}{N_j} \left(\sum_{i=1}^{N} r_i h_{i,j} \right), \quad \textbf{(5)}$$

and

$$P^j = \frac{1}{N_j^2} \left(\sum_{k=1}^{N_j} A^{j,k} \right) \cdot \left(\sum_{i=1}^{N} r_i h_{i,j} \right). \quad \textbf{(6)}$$

That is, the price impact P^j for market *j*, is equal to the product of two terms:

- $\frac{1}{N_j^2} \left(\sum_{K=1}^{N_j} A^{j,k} \right)$, which is an aggregate measure of market impact that can be estimated from the data, and whose median values are those reported in **Table A2.1**; and

- $\sum_{i=1}^{N} r_i h_{i,j}$, which is the total amount sold by funds in market *j* as set out in Section 3.2.

Hence, the result in equation **(6)** (obtained under a few assumptions described above) allows us to abstract from security-level fund holdings and apply Amihud measures of price impact at the asset class level.

References

Amihud, Y (2002), 'Illiquidity and stock returns: cross-section and time-series effects', *Journal of Financial Markets*, Vol. 5, No. 1, pages 31–56.

Anderson, N, Webber, L, Noss, J, Beale, D and Crowley-Reidy, L (2015), 'The resilience of financial market liquidity', *Bank of England Financial Stability Paper No. 34*, available at www.bankofengland.co.uk/financialstability/Documents/fpc/fspapers/fs_paper34.pdf.

Bank of England (2015a), *Financial Stability Report*, December, available at www.bankofengland.co.uk/publications/Documents/fsr/2015/dec.pdf.

Bank of England (2015b), *Open Forum: building real markets for the good of the people*, available at www.bankofengland.co.uk/markets/Documents/openforum.pdf.

Bank of England (2015c), 'The Bank of England's approach to stress testing the UK banking system', available at www.bankofengland.co.uk/financialstability/Documents/stresstesting/2015/approach.pdf.

Bank of England (2016a), 'Stress testing the UK banking system: 2016 results', available at www.bankofengland.co.uk/publications/Pages/news/2016/stresstesting.aspx.

Bank of England (2016b), *Financial Stability Report*, November, available at www.bankofengland.co.uk/publications/Pages/fsr/2016/nov.aspx.

Bank of England (2016c), *Financial Stability Report*, July, available at www.bankofengland.co.uk/publications/Documents/fsr/2016/fsrjul16.pdf.

Bank of England (2017), *Financial Stability Report*, June, available at www.bankofengland.co.uk/publications/Documents/fsr/2017/fsrjun17.pdf.

Baranova, Y, Liu, Z and Shakir, T (forthcoming), 'Dealer intermediation, market liquidity and the impact of regulatory reform', *Bank of England Staff Working Paper No. 665*.

Bardoscia, M, Barucca, P Brinley Codd, A and Hill, J (2017), 'The decline of solvency contagion risk', *Bank of England Staff Working Paper No. 662*.

Ben-Rephael, A, Kandel, S and Wohl, A (2011), 'The price pressure of aggregate mutual fund flows', *Journal of Financial and Quantitative Analysis*, Vol. 46, No. 2, pages 585–603.

Bikker, J, Broeders, D and Dreu, J (2010), 'Stock market performance and pension fund investment policy: rebalancing, free float, or market timing?', *International Journal of Central Banking*, Vol. 6, No. 2, pages 53–79.

Bookstaber, R and Paddrik, M (2015), 'An agent-based model for crisis liquidity dynamics', *Office of Financial Research Working Paper No. 15–18*.

Braun-Munzinger, K, Liu, Z and Turrell, A (2016), 'An agent-based model of dynamics in corporate bond trading', *Bank of England Staff Working Paper No. 592*, available at www.bankofengland.co.uk/research/Documents/workingpapers/2016/swp592.pdf.

Brazier, A (2017), 'How to Macropru. 5 Principles for macroprudential policy', available at www.bankofengland.co.uk/publications/Pages/speeches/2017/960.aspx.

Brunnermeier, M K and Sannikov, Y (2016), *The I Theory of Money*.

Carney, M (2017), 'FSB Chair's letter to G20 Leaders – building a safer, simpler and fairer financial system', available at: http://www.fsb.org/2017/07/fsb-chairs-letter-to-g20-leaders-building-a-safer-simpler-and-fairer-financial-system/.

Cenedese, G and Mallucci, E (2016), 'What moves international stock and bond markets?', *Journal of International Money and Finance*, Vol. 60, pages 94–113.

Cetorelli, N, Duarte, F and Eisenbach, T (2016), 'Are asset managers vulnerable to fire sales?', *Federal Reserve Bank of New York*, Liberty Street Economics.

Chernenko, S and Sunderam, A (2016), 'Liquidity transformation in asset management: evidence from cash holdings of mutual funds', *Harvard Business School Project on Behavioral Finance and Financial Stability Working Paper No. 2016–01*.

Chevalier, J and Ellison, G (1997), 'Risk taking by mutual funds as a response to incentives', *Journal of Political Economy*, Vol. 105, No. 6, pages 1,167–200.

Choi, J and Shachar, O (2013), 'Did liquidity providers become liquidity seekers?', *Federal Reserve Bank of New York Staff Report No. 650*.

Chowla, S, Quaglietti, L and Rachel, L (2014), 'How have world shocks affected the UK economy?', Bank of England Quarterly Bulletin, Vol. 54, No.2, pages 167–79, available at www.bankofengland.co.uk/publications/Documents/quarterlybulletin/2014/qb14q206.pdf.

Churm, R and Webber, L (2007), 'Decomposing corporate bond spreads', *Bank of England Quarterly Bulletin*, Vol. 47, No. 4, pages 533–41, available at www.bankofengland.co.uk/publications/Documents/quarterlybulletin/qb070403.pdf.

Cifuentes, R, Ferrucci, G and Shin, H (2005), 'Liquidity risk and contagion', *Journal of the European Economic Association*, Vol. 3(2–3), pages 556–66.

Coval, J and Stafford, E (2007), 'Asset fire sales (and purchases) in equity markets', *Journal of Financial Economics*, Vol. 86, No. 2, pages 479–512.

Cunliffe, J (2015), 'Market liquidity and market-based financing', available at www.bankofengland.co.uk/publications/Documents/speeches/2015/speech853.pdf.

Duarte, F and Eisenbach, T (2015), 'Fire-sale spillovers and systemic risk', *Federal Reserve Bank of New York Staff Report No. 645*.

Ellul, A, Jotikasthira, C and Lundblad, C (2011), 'Regulatory pressure and fire sales in the corporate bond market', *Journal of Financial Economics*, Vol. 101, No. 3, pages 596–620.

Feldhütter, P (2012), 'The same bond at different prices: identifying search frictions and selling pressures', *Review of Financial Studies*, Vol. 25, No. 4, pages 1,155–206.

Ferguson, R and Laster, D (2007), 'Hedge funds and systemic risk', *Banque de France Financial Stability Review*, No. 10, pages 45–54.

Financial Conduct Authority (2017), 'Illiquid assets and open-ended investment funds', *Financial Conduct Authority Discussion Paper*, available https://www.fca.org.uk/publications/discussion-papers/illiquid-assets-open-ended-investment-funds.

Financial Stability Board (2017), 'Implementation and Effects of the G20 Financial Regulatory Reforms: Third Annual Report', available at: http://www.fsb.org/2017/07/implementation-and-effects-of-the-g20-financial-regulatory-reforms-third-annual-report/.

Goldstein, I, Jiang, H and Ng, D (2015), 'Investor flows and fragility in corporate bond funds', available at https://ssrn.com/abstract=2596948 or http://dx.doi.org/10.2139/ssrn.2596948.

Greenwood, R, Landier, A and Thesmar, D (2015), 'Vulnerable banks', *Journal of Financial Economics*, Vol. 115, No. 3, pages 471–85.

Gruic, B, Hattori, M and Shin H S (2014), 'Recent changes in global credit intermediation and potential risks', *BIS Quarterly Review*, September.

International Monetary Fund (IMF) (2015), 'US financial sector assessment program, stress testing — technical note'.

Jotikasthira, C, Lundblad, C and Ramadorai, T (2012), 'Asset fire sales and purchases and the international transmission of funding shocks', *The Journal of Finance*, Vol. 67, No. 6, pages 2,015–50.

King, M (2009), 'The cost of equity for global banks: a CAPM perspective from 1990 to 2009', *BIS Quarterly Review*, September.

Lou, D (2012), 'A flow-based explanation for return predictability', *Review of Financial Studies*, Vol. 25, No. 12, pages 3,457–89.

Manconi, A, Massa, M and Yasuda, A (2012), 'The role of institutional investors in propagating the crisis of 2007–2008', *Journal of Financial Economics*, Vol. 104, No. 3, pages 491–518.

Morris, S, Shim, I and Shin, H S (2017), 'Redemption risk and cash hoarding by asset managers', *Bank for International Settlements Working Paper No. 608*.

Rey, H (2013), 'Dilemma not trilemma: the global financial cycle and monetary policy independence', Jackson Hole Economic Symposium.

Sirri, E and Tufano, P (1998), 'Costly search and mutual fund flows', *The Journal of Finance*, Vol. 53, No. 5, pages 1,589–622.

Timmer, Y (2016), 'Cyclical investment behavior across financial institutions', *Deutsche Bundesbank Discussion Paper No. 08/2016*.

Tucker, P, Hall, S, Pattani, A (2013), 'Macroprudential Policy at the Bank of England', *Bank of England Quarterly Bulletin*, Vol. 53, No. 3, pages 192–200, avaiable at www.bankofengland.co.uk/publications/Documents/quarterlybulletin/2013/qb130301.pdf.