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The role of collateral in supporting liquidity

Yuliya Baranova, Zijun Liu and Joseph Noss

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Abstract

Collateral plays an important role in supporting a vast range of transactions that help ensure the efficient functioning of the financial system. But collateral markets also have the potential to exacerbate risks to financial stability, not least given that during periods of market stress demand for high-quality collateral may increase, whilst collateral availability may fall. This paper offers a means to estimate how this potential imbalance between collateral supply and demand is likely to vary as a function of market stress. In doing so, it offers an estimate of the increase in market volatility sufficient to cause a dislocation in the market for collateral and a subsequent deterioration in market functioning. It suggests that — from the perspective of financial stability — the implications of an imbalance between the supply and demand of collateral are likely to be comparatively benign, but that the implications of a reduction in the willingness and/or ability of market participants to act as intermediaries in collateral markets are likely to have more serious consequences for market functioning. This work also provides a framework through which policymakers might be able to investigate how regulations might affect the proximity of these risks.

Key words: Collateral, securities financing transactions, derivatives, regulation, liquidity.

JEL classification: G13, G17, G29.

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1 Introduction

Collateral – that is, securities pledged to secure loans and other counterparty exposures – is used to support a vast range of market-based transactions that together help support the efficient functioning of the financial system. These include its role in mitigating counterparty credit risk, and in acting as a liquid store of value with which firms can manage their funding. Collateral also plays an important role in enabling leveraged financial institutions to fund purchases (and collateralise against short sales) of financial assets. This latter role is particularly important in supporting market liquidity, which in turn plays an important role in ensuring the provision of market-based finance.[1] In what follows, we refer to the role of collateral in supporting such activities as that of supporting 'liquidity'.

The behaviour of collateral markets can also play a role in exacerbating risks to financial stability. One such risk arises from how the balance between demand for collateral and market participants' ability and/or willingness to supply it may behave procyclically. During the 2007-2008 financial crisis, the quantity of high-quality securities made available for use as collateral reduced due to perceptions of increased counterparty credit risk (which caused a reduction in securities lending) and as market intermediaries sought to deleverage. At the same time, demand for high-quality collateral increased as, for example, firms began to hoard liquid assets, volatile markets caused an increase in margin held against derivatives, and lower quality securities were no longer accepted as collateral.[2] Together, these developments contributed to a pernicious spiral of rising margin requirements, lower risky asset prices, and a decline in market functioning and liquidity, including in markets that played an important role in extending funding to the real economy.

Given these developments, it is perhaps not surprising that recent regulation has sought to reduce some of the procyclicalities associated with collateral. Such regulation includes a set of numerical haircut floors for non-centrally cleared securities financing transactions, and the agreement of methodological standards around how these haircuts should be set (see Financial Stability Board (2014)). The regulatory minimum leverage ratio (see Basel Committee on Banking Supervision (2014)) also has the potential to limit the extent to which financial intermediaries can increase their capacity to act as intermediaries in markets for collateral during periods of benign market conditions. And in derivatives markets, most jurisdictions are in the process of adopting margin requirements for non-centrally cleared derivatives.[3] Together, these regulations should go some way towards dampening the procyclicalities seen during the crisis, and limit the degree to which the effective supply of collateral expands during benign market conditions only to contract sharply during stress.

There remains, however, the important question of at what level(s) the effective supply of and demand for high-quality collateral will settle following the introduction of these regulations and whether this will be sufficient to ensure the stable functioning of financial markets during periods of stress.[4] This is particularly important, not least given how some of the regulation introduced since the crisis, whilst reducing the procyclicalities described above, might also increase demand for high-quality collateral during periods of stress.[5]

To assess this question, the paper begins by providing a comprehensive framework to assemble and quantify the factors that affect the supply of and demand for high-quality collateral. Although the aggregate supply of such collateral is vast, only a small proportion of this is made available – via securities lending and repo transactions – to support market functioning. We then go on to estimate the degree to which this available supply of high-quality collateral is likely to decrease – and its demand increase – during periods of stress. This is due to a number of reasons, including the deterioration in market participants' perceptions of their counterparties' creditworthiness, and increases in the demand for collateral for use as initial margin and in liquid asset buffers. We capture this variation in supply and demand by drawing together a number of observed empirical relationships between market participants' behaviour in collateral markets and a combination of average dealer credit default swap premia (which we take as a proxy for perceptions of

[1] See Anderson et al (2015).
[2] For a more in-depth account of these developments, see Berrospide (2012) and Gorton and Metrick (2012).
[3] See Financial Stability Board (2015).
[4] In what follows, we implicitly assume this equilibrium level to be non-zero; i.e. that a cash-only system would be inefficient, either because some leverage is a requirement of an efficient financial system, or it is inefficient for institutions that are not cash rich to hold cash as an asset.
[5] See Financial Stability Board (2014).

counterparty credit risk) and the VIX volatility index (which we take as a proxy for market stress and general economic conditions).[6]

A further contribution of this work is to consider the role of intermediaries in the market for high-quality collateral. There is some evidence that, during the recent crisis, such intermediation activity by broker-dealers reduced considerably, as falls in asset prices forced such firms to deleverage. Given the lack of historical data on such dynamics, this work provides a theoretical model of this behaviour – parameterised using broker-dealer balance sheet data – and uses this to estimate the degree to which the intermediation in collateral markets might be reduced during periods of stress.

This leads to two key results. First, there is a risk that demand for high-quality collateral exceeds the supply made available during periods of stress. This analysis indicates that this risk might crystallise at levels of stress commensurate with the VIX volatility index exceeding around 44 per cent for a period of around a quarter. This has occurred on only one occasion historically, at the height of the recent crisis in late 2008. That said – even if this risk were to crystallise – we judge that it might have only moderate impact, as the cost of borrowing high-quality collateral might, in time, adjust to restore equilibrium between supply and demand.

A second risk – whose impact we judge to be potentially more severe – arises from how most end-users of collateral are not directly connected to its suppliers. Instead, a network of leveraged financial institutions (principally broker-dealers) acts as intermediaries between those that supply high-quality collateral and those that demand it. As market stress intensifies, the ability and willingness of these institutions to obtain the leverage necessary to perform this intermediation tends to decrease. This leads to the risk that in future periods of stress – although the demand for collateral might not exceed *un*leveraged end investors' ability to supply it – collateral may become 'blocked': that is, unable to reach those that wish to use it, due to a shortage of intermediation capacity.

Whilst we estimate this second risk might crystallise at similar levels of market stress, its consequences for financial stability could be far further reaching. These might include a sudden inability of market participants to obtain the collateral they need to manage the risks associated with their business, including payment of initial margin on derivatives transactions. It also might risk impairing dealers' abilities to fund other leveraged investors' (i.e. hedge funds') purchases of financial assets, which might have implications for market functioning and liquidity.

Throughout, this analysis is informed by a range of background literature, which provides partial analysis of many of the dynamics that have increased the relevance of collateral to financial stability in recent years. Krishnamurthy and Vissing-Jorgensen (2012) examine the increase in demand for high-quality collateral – in particular, US treasuries – during the recent crisis. Pozsar (2011) asks whether the supply of such securities might be insufficient to meet institutional investors' demand for safe and liquid instruments. Aguiar et al (2016) provides a map of collateral uses and flows and documented an increase demand for collateral due to regulatory reforms. Singh (2011) examines the frequency with which collateral is reused and documents a decline in both the supply of collateral by end users, and the 'velocity' with which it is passed between intermediaries following the height of the recent financial crisis. A number of papers also examine collateral re-use in a number of jurisdictions (e.g. Fuhrer, Guggenheim and Schumacher (2015), Cheung, Manning and Moore (2014) and Capel and Levels (2014)). Other recent literature has focussed on how the increased reliance on collateral (e.g. ESRB (2014)) may pose financial stability risks. In particular, Infante (2014) uses a theoretical model to show that dealers that act as intermediaries in the market for collateral can be exposed to the risk of a sharp withdrawal of funding by collateral providers.

This work extends the existing literature by providing a means by which to draw together many of these dynamics. In doing so, it provides a comprehensive framework with which to assess the drivers of the supply of and demand for collateral during periods of stress. Its applications to public policy are broadly three fold:

- First, its results provide a ready reckoner for the degree of market stress that might be expected to trigger an imbalance between the supply of and demand for, as well as the insufficient intermediation of, collateral. It may therefore serve as a quantitative risk assessment tool for any authority interested in assessing risks associated with collateral markets.

[6] This is not without precedent; see Rey (2013).

- Second, it offers a framework for considering how changes to the *structure* of the financial system – and, in particular, the network of market intermediaries who stand between the largely unleveraged institutions that act as end suppliers and users of collateral – might change the level of market stress at which these risks are likely to crystallise. One example of such a structural change (examined in Section 5) is the failure of a dealer from the network of intermediaries (or a severe deterioration in market perceptions of a dealer's credit worthiness that discourages other institutions transacting with it). This has the effect of making the above risks more proximate.

- Finally, this work offers a framework with which policy makers could consider how recently introduced regulations (including the leverage ratio, initial margin and minimum haircut requirements) might affect market participant behaviour, and hence the level of market stress at which these risks may crystallise.

Throughout, the focus of the analysis is confined to high-quality collateral.[7] This is due to how – during past periods of market stress – market participants tend to turn to higher-quality securities for use as collateral. In particular, we assume that only high-quality securities are used as initial margin, central counterparty default fund contributions, and in banks' liquid asset buffers.[8]

This paper proceeds as follows. The next section offers a framework for considering the key drivers of the supply of and demand for high-quality collateral, and offers a guide to their current levels (at least following the full implementation of recently-introduced regulation). Section 3 introduces a stylised framework for considering how these may vary with market stress, including as a result of the prudent risk management of market participants, and the risks to which these give rise. The role of leveraged intermediaries – including broker-dealers – is considered in Section 4, as well as the further risk that arise from these activities. Section 5 offers some sensitivity analysis around these results, as well as examining the effect of dealer failure (or decline in dealer credit worthiness). A final section concludes. Technical details are confined to the Annexes.

2 A stylised framework for considering the steady-state supply/demand of collateral

This section sets out a framework for considering the components of collateral supply and demand. We assume that the demand for collateral is exogenously driven by regulatory requirements and demand for safe assets, as described in more detail below. In absence of supply constraints, prices should adjust so that the steady-state supply always equals demand. In practice, however, the supply of collateral is actually bounded above by the amount of collateral made available to borrowers ('made available supply'), which is not currently binding according to our estimates, but could become so as market stress increases as described in Section 3. In the following, we estimate the made available supply of collateral in a number of steps, starting from the aggregate supply of collateral and unencumbered supply of collateral.

The analysis is predicated on benign market conditions, which we take to correspond to those in the three months ending in August 2015, when the VIX volatility index averaged around 17 per cent. The figures that follow apply to the global market for high-quality collateral, and represent estimates of the supply of and demand for collateral following the full implementation of recently introduced regulation.

2.1 Aggregate supply of collateral versus unencumbered supply of high-quality collateral

The aggregate supply of high-quality collateral (i.e. the amount of high-quality securities outstanding) is vast, and was – at end-2014 – estimated to be in the region of US$42 trillion (**Table 1**).

Only a small proportion of this is available to support market functioning, however. This is because a large proportion of the total supply of high-quality collateral is encumbered – that is, it is in some sense siloed

Table 1 – Aggregate supply of high-quality collateral

Type of security	Amount outstanding (US$ trillion)
AAA/AA-rated government bonds (ex. China)	34.6
Agency MBS	6.0
Supranationals	1.3
Total	**41.8**

Source: BIS, SIFMA, Dealogic. Data as of Sep 2014. Numbers in the table do not add up due to rounding errors.

[7] This includes AAA/AA-rated government bonds (excluding China), Agency MBS, and securities issued by supranational institutions.
[8] Note, the definition of high-quality assets applied here is more narrow than those accepted in banks' liquidity coverage ratio under recently-agreed international regulation; see Basel Committee on Banking Supervision (2013).

and used for a purpose that prevents it being used to support liquidity.[9] This occurs for a variety of reasons including use in institutions' liquid asset buffers and initial margins/default fund contributions against derivative exposures, as well as being siloed by end-investors who are prevented from lending securities to other investors.[10] These we treat as fixed claims that – for low levels of market volatility – reduce the available collateral pool (the possibility that they increase as a result of market stress is examined in Section 3).

Estimates of the total stock of high-quality securities encumbered via these means are given in **Table 2**. The remaining unencumbered supply of high-quality collateral lies at US$9.5 trillion. These figures do not, however, account for the additional encumbrance of collateral due the implementation of recently introduced OTC derivatives regulatory reforms, which include mandatory exchange of margin on a variety of derivatives transactions. According to Bank for International Settlements (2013), the full implementation of such reforms will result in roughly US$1trn of additional high-quality collateral being encumbered. This has the effect of reducing unencumbered supply to US$8.5 trillion, which consists of $7.7 trillion held by largely unleveraged institutions (who engage in securities lending (see below)) and $0.8 trillion held by dealers.

Table 2: Encumbrance of high-quality collateral (US$ trillion)

Owner type	Holdings	Amount encumbered	Source of encumbrance	Unencumbered supply
Governmental institution	8.9	8.9	Inability to engage in securities lending	0.0
Commercial Bank	5.3	4.5	Liquid asset buffer or initial margin	0.8
Insurance company or pension fund	5.7	0.0		5.7
Central banks[11]	4.4	4.2	Mostly lending against other government bonds	0.2
Non-resident[12]	11.5	11.3	Foreign exchange reserves	0.2
Other[13]	6.0	3.5	Various	2.6
Total	**41.8**	**32.3**		**9.5**
Total post derivatives reform		**33.3**		**8.5**

Source: BIS, SIFMA, ECB, IMF. Numbers may not add up due to rounding.

2.2 Unencumbered supply versus made available supply of high-quality collateral

Only a fraction of the unencumbered supply of collateral is made available for use in facilitating market transactions, however, as explained below. In what follows we refer to this as the 'made available supply' of collateral. This comes about via two main channels:

Table 3: Split of total stock of high-quality securities made available for loan, and on loan, by type of beneficial owner

Type of owner	Securities available for loan	Securities on loan
Pension fund and insurers	39%	34%
Banks	11%	15%
Sovereign Wealth Funds	24%	32%
Asset Managers	20%	12%
Others Financial	4%	6%
Non-Financial	2%	1%
Total	100%	100%

Source: Markit.

- First, securities lending, in which beneficial owners make their assets available for dealers to borrow. These institutions are typically long-term investors that use securities lending to generate additional income on their portfolios. They include insurance companies, pension funds, asset managers, sovereign wealth funds, commercial banks, and other financial and non-financial institutions. **Table 3** gives a breakdown of high-quality securities that are available for loan and those that are on loan, by type of beneficial owner.

- Second, dealer financing, whereby banks and dealers who hold high-quality securities repo them out to finance their operations. We estimate collateral involved in such activity to stand at around $773bn.[14,15]

[9] Note this definition of 'encumbrance' differs to that used in recent financial risk assessment and regulation (see Bank of England (2012) in which an asset is said to be 'encumbered' if it is under claim by another party).
[10] For example some intra-governmental holdings, government foreign exchange reserves, central bank and money market fund assets are unavailable for use in securities lending.
[11] This includes securities purchased through quantitative easing programmes.
[12] Refers to owners of high-quality collateral domiciled in jurisdictions other than jurisdictions in which high-quality collateral is originated.
[13] 'Other' includes money market funds, asset managers and other non-bank financial institutions.
[14] Collateral supply provided via dealer financing is calculated as the difference between current end-user demand for high-quality collateral (as given in Table 4) and the amount of high-quality collateral on loan.
[15] There are two other channels through which the unencumbered supply could be made available for loan. These include: (i) fund leverage, whereby investment funds with long positions in high-quality collateral may also choose to gain leverage by pledging the collateral with dealers in the repo markets and thereby securing financing for other asset purchases; and

We estimate that, at present, only 28% of high-quality assets held by owners participating in securities lending programmes (the largest constituent of total unencumbered supply) are actually available for loan. This is likely in part due to the regulatory constraints on institutional investors that prevent them from engaging in securities lending transactions on a larger scale.[16] Such securities lending is also like to vary over the economic cycle, including as a result of beneficial owners' changing perceptions of counterparty default risk (a dynamic explored further in Section 3).

2.3 Demand for high-quality collateral

Not all of the made available supply of high-quality collateral is utilised, however. We estimate that the total demand for high-quality collateral currently stands at around $1.6 trillion.[17] This stems from a number of sources. These include reverse repos – that is, transactions in which cash is lent against high-quality collateral – performed by real money investors (including money market funds); and lending of lower quality securities against high-quality collateral (both of which are assumed to remain constant over time).[18,19] Demand for high-quality collateral also stems from the reinvestment of cash collateral by securities lenders (in particular, in reverse repos against high-quality collateral). **Table 4** provides a summary.

We assume that collateral demanded at this stage is not re-used further. In particular, money market funds and corporates investing cash in reverse repo do not re-use the high-quality collateral that they receive. Also, agent lenders (largely banks) that re-invest cash in reverse repo against high-quality assets on behalf of beneficial owners do not have the legal right to re-use this collateral.

Table 4: Sources of demand for high-quality collateral

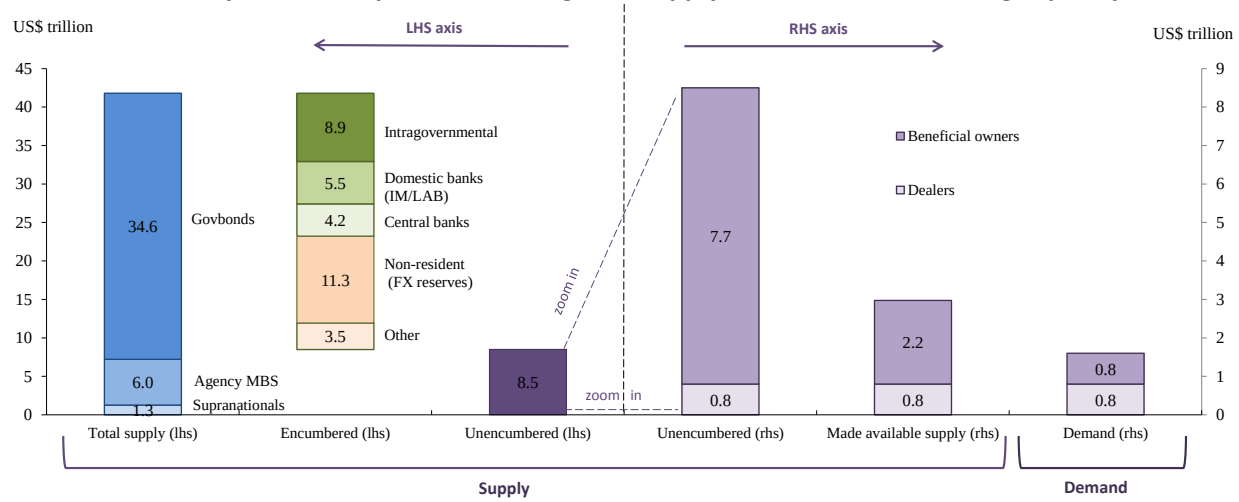
Source	Current demand (US$ bn)
(i) Reverse repos by real money investors	1261
(ii) Lending of non-HQ securities against HQ collateral	184
(iii) Reinvestment of cash collateral by securities lenders	176
Total	1621

Source: Data explorers.

2.4 Summary of analytical framework

A summary of these components of the supply of and demand for high-quality collateral is shown in **Chart 1**. Note that, of an overall $41.8 trillion supply of high-quality collateral (far-left bar), we estimate that only $1.6trn is used on a day-to-day basis to support market functioning (far right bar).

Chart 1: A summary of the components of the global supply of, and demand for, high-quality collateral



Source: BIS, SIFMA, Data Explorers, Dealogic, ECB, IMF. Numbers may not add up due to rounding.

(ii) assets placed with dealers by their clients (e.g. hedge funds) for a variety of purposes. Both activities are – in the case of high-quality collateral – relatively small in scale, and so are ignored in what follows.

[16] For example, according to Financial Stability Board (2012), in the US, registered investment companies (which include mutual funds, money market mutual funds, closed-end funds, and exchange traded funds) may not lend more than one third of their total assets under management.

[17] Note that high-quality collateral used as initial margins and banks' liquid asset buffers in benign market conditions is – under this framework – considered part of the encumbered collateral supply.

[18] Whilst the magnitude of money market funds' reverse repos might be expected to increase during market stress, we see little evidence of this empirically. And given that those institutions that receive high-quality collateral against the lending of lower-quality securities are exposed to little counterparty risk in doing so, we might expect this activity to stay constant across the cycle.

[19] Collateral siloed within payment and settlement systems is not included in our framework due to its limited size and procyclicality.

3 How the supply/demand of high-quality collateral might vary with market stress

This section provides a simple and stylised model of how changes in the supply of, and demand for, high-quality collateral vary with market stress. In doing so, it aims to assess the risk that – during periods of financial market turbulence – the demand for such collateral might exceed its supply.

The overall approach is based on a simple model of market participant behaviour, and how this varies as a function of two variables that, together are used to capture the degree of stress in financial markets; these are:

- The VIX volatility index;[20] and
- The average credit default swap (CDS) premia on the senior unsecured debt of Global Systemically Important Banks (G-SIBs),[21] which we take as a proxy for perceptions of counterparty risk associated with major dealers.

For presentational convenience, we choose to show results as a function of a single variable, the VIX index. To do so, it is necessary to estimate a mapping between this and the average CDS premia. This historical relationship between the VIX index and CDS premia varies considerably over time and may have been altered by the effect of recently introduced regulation, which has aimed to increase the resilience (and hence perceptions of counterparty risk) of dealers during stress. For this reason, rather than drawing on the past observed relationship between market volatility and financial institutions' CDS premia (which might not be representative of that likely to hold in future), we employ a structural model of credit risk and how this varies with the volatility of dealers' assets.

Throughout, we aim to capture market participant behaviour that is consistent with market participants' prudent risk management; that is, the degree to which they scale back their securities lending, demand more initial margin and increase their liquid asset buffers, as an increasing function of market stress and counterparty credit risk. Actual behaviours of investors are likely more complicated and can be more or less procyclical than those shown here. Nonetheless, we aim to exposit a simple and parsimonious framework that serves to give a simple illustration of the risks involved. Sensitivity analysis is given in **Section 5**.

3.1 A simple model of how the made available supply of collateral varies with perceptions of intermediaries' counterparty risk

The supply of collateral made available via securities lending has varied historically – particularly during the crisis – with lenders' varying perceptions of counterparty credit risk.[22] The relationship between high-quality securities available for loan and counterparty credit risk is shown in **Charts 2 and 3**. During the crisis, the amount of high-quality securities available for loan clearly fell with increased perceptions of counterparty risk. Whilst the relationship between the two series lacks statistical significance[23] (full regression results for this, and the other relationships given in the charts that follow, are given in **Annex 1**), we nonetheless include it here in order to capture the possible directionality of the relationship during periods of future stress.

We capture this co-movement between extreme changes in CDS premia and securities lending availability (expressed as a proportion of beneficial owners' holdings of high-quality collateral) by means of a simple linear regression, the slope of which is shown by the black line in **Chart 3**. This suggests that a 10 basis point increase in average dealer CDS premia is associated with a 0.2 percentage point reduction in the proportion of beneficial owners' securities available for loan.

3.2 A simple model of how collateral demand varies with market stress and perceptions of intermediaries' counterparty risk

Variation in demand for collateral stems from two sources – reinvestment of cash collateral from securities lending transactions and changes in initial margins/liquid asset buffers from their levels in benign market conditions – both of which vary with the level of market stress. These are dealt with in turn.

[20] The VIX index is a measure of market expectations of 30-day volatility as conveyed by S&P 500 stock index options prices. It is widely taken as a summary measure for market participants' perceptions of uncertainty and risk aversion; see, for example, Rey (2013).
[21] G-SIBs included are HSBC, JP Morgan, Barclays, BNP Paribas, Citigroup, Deutsche Bank, Bank of America, Credit Suisse, Goldman Sachs, Mitsubishi, Morgan Stanley and Royal Bank of Scotland. Other G-SIBs are not included due to their limited presence in collateral markets.
[22] See Dive, Hodge and Jones (2011).
[23] It is not significant at the 5 or 10 per cent significance level.

Throughout, we abstract from the possibility that, during market stress, the value of high-quality collateral in supply is likely to increase (for example, due to increased government bond issuance). This may lead to a slight under-estimation of the available collateral supply during stress.

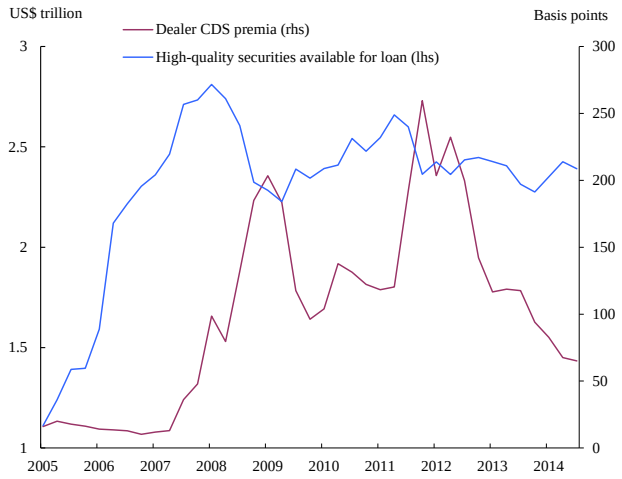
3.2.1 *Reinvestment of cash collateral in reverse repos against high-quality assets*

We assume that the size of cash collateral reinvestment via reverse repo falls during stress, as lenders become more concerned about counterparty risks. This fall could be attributed to two drivers:

- A fall in the amount of securities lent against cash (due to increased counterparty risk, proxied by dealer CDS premia, driving an overall decline in securities lending activity);
- A fall in the proportion of cash collateral reinvested in reverse repos against high-quality securities (driven by risk appetite of beneficial owners), proxied by the VIX index.

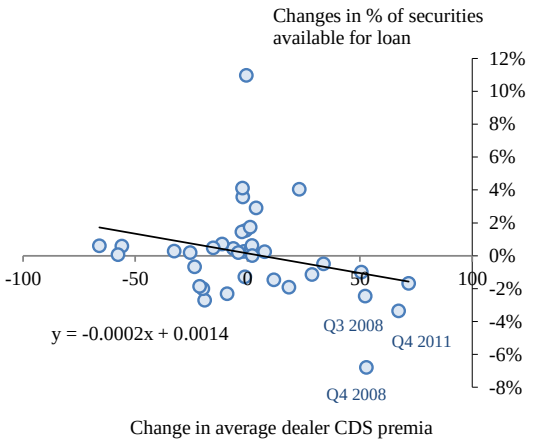
Again, both effects are captured using linear regressions. **Chart 4** shows the relationship between percentage changes in the amount of securities lent against cash versus change in dealer CDS premia, which is statistically significant (at 5% significance level) and illustrates the possible relative changes in the two variables during future periods of stress (details are given in **Annex 1**). **Chart 5** shows that between changes in the proportion of cash collateral reinvested in reverse repos against high-quality collateral versus changes in the VIX index. Although this relationship lacks statistical significance, we include it in order to capture the possible directionality of relative changes in the two variables during future periods of stress.

Chart 2: Level of high-quality securities available for loan and average dealer CDS premia



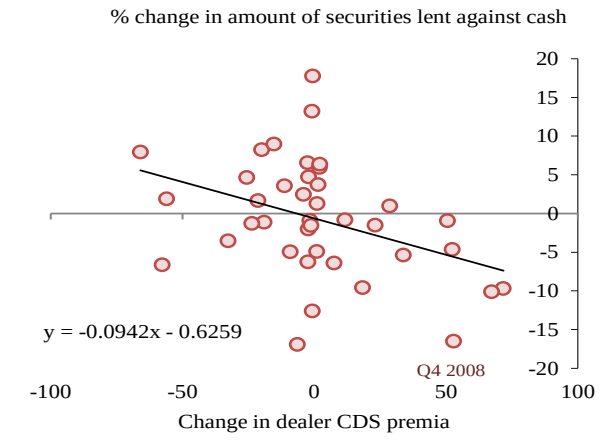
Source: Bloomberg, Data Explorers.

Chart 3: Change in average dealer CDS premia versus change in proportion of high-quality securities available for loan[(a)]



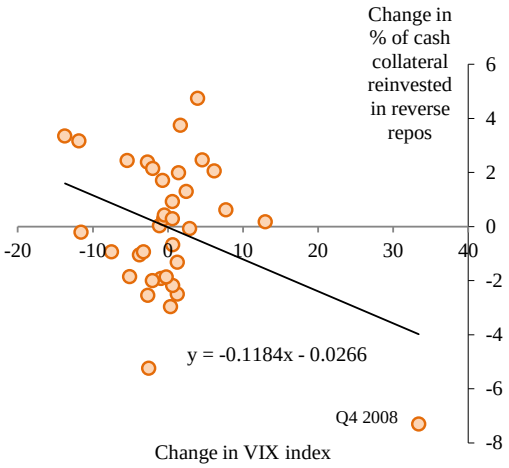
Source: BIS, SIFMA, ECB, Data Explorers.
(a) As a proportion of beneficial owners' total supply of unencumbered collateral.

Chart 4: Percentage change in amount of securities lent against cash versus change in average dealer CDS premia



Source: Bloomberg, Data Explorers.

Chart 5: Change in the percentage of cash collateral reinvested in high-quality repos versus change in the VIX index



Source: Bloomberg, RMA.

3.2.2 *Demand for use of collateral in initial margin and liquid asset buffers*

Demand for collateral for use as initial margin and as part of banks' liquid assets is assumed to increase with market stress. Note that, in what follows, we consider only increases in demand for collateral for these purposes over and above the steady-state level set out in **Section 2**.

Demand for collateral for use as initial margin (from both dealers and end-users) is assumed to increase as a linear function of financial stress (which again is proxied by the VIX index).[24] This assumption of linearity is consistent with the dynamics of the models used by major central counterparties to calibrate their calls for initial margin.[25] It might, however, overestimate the true increase in initial margin that would be called for during periods of stress, particularly if market participants were to reduce their exposures to risk.

Increases in banks' liquid asset buffers (held in the form of high-quality securities) are also modelled as a linear function of market stress, given empirical evidence on banks' liquidity hoarding behaviour during the financial crisis.[26] To calibrate changes in these liquid asset buffers we regress monthly changes in UK banks' liquid asset buffers (expressed as a proportion of their total assets), on changes in the VIX index (**Annex 1, Table D**). This suggests a positive – albeit statistically insignificant (at the 10% significance level) – relationship between the two. This may be explained by banks' propensity to increase their holdings of liquid assets for precautionary reasons during periods of stress. We further assume that the relationship calibrated for UK banks holds for the wider banking system.

3.3 Summary: the risk of demand exceeding supply (Risk 1)

A summary of these drivers of changes in collateral supply and demand – and their modelled dependence on changes in market stress and/or CDS premia – is given in **Table 5.**

Table 5: A summary of factors leading to the variation in collateral supply/demand away from their levels in benign market conditions (described in Section 2) during market stress

Factor	Current size (US$ trillion)	Assumed to vary with		Calibration methodology
		Stress (proxied by VIX index)	CDS premia	
Supply				
Made available supply	2.91	Decreases	-	Regression of changes in proportion of high-quality securities available for loan on changes in dealer CDS premia (Chart 3)
Demand				
Reinvestment of cash collateral	0.18	Decreases	Decreases	Empirical regression of: • Changes in proportion of cash reinvested in high-quality reverse repos on changes in VIX index (Chart 5); • Percentage changes in securities lent against cash on changes in dealer CDS premia (Chart 4).
Reverse repo by real money investors	1.26	Fixed		-
Non-high-quality securities lending versus high-quality collateral	0.18	Fixed		-
Additional demand for initial margin (post the implementation of derivatives reform)	0	Increases	-	Assumed to vary linearly with the VIX index (based on inference from a hypothetical CCP initial margin models; see Section 3.2.2).
Additional demand for banks' liquid asset buffers	0	Increases	-	Regression of changes in dealers' liquid assets buffers (as a proportion of their total assets) on changes in VIX.

[24] This assumption follows that in Bank for International Settlements (2013). See also Holden, Houllier and Murphy (2016).
[25] For details see Murphy, Vasios and Vause (2014).
[26] For example, see Berrospide (2012).

Drawing these components together – and combining them with the modelled relationship between the VIX index and dealers' CDS premia described above – allows us to consider the total supply of and demand for high-quality collateral as a function of the VIX index. This is shown in **Chart 6.** The black line in which shows the total demand for high-quality collateral. The shaded areas beneath it decompose this total demand into its constituent parts:

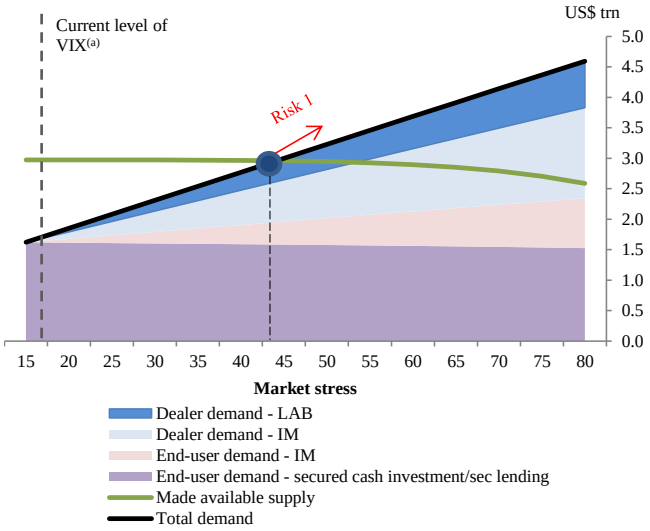
- *The purple area* illustrates demand stemming from the need for secured reinvestment of cash (i.e. cash reinvestment in reverse repos against high-quality collateral by MMFs, corporate and agent lenders). This constituent of demand for high-quality collateral is largely 'static' (with the exception of cash collateral re-investment) and varies little with the level of market stress;

- *The pink area* illustrates demand for high-quality collateral for margining purposes from non-dealers (i.e. from end-users of collateral);

- The *light and dark blue areas* illustrate demand by dealers for collateral for the use as initial margin and in banks' liquid asset buffers, respectively.

As market stress intensifies, total demand for high-quality collateral eventually exceeds its made available supply (illustrated by the green line in **Chart 1**). This is estimated to occur when the VIX index reaches a level of around 44 per cent – which is labelled 'Risk 1'. Given that the bulk of the calibration described above is based on quarterly data, it seems natural to assume that – in order for this risk to crystallise – the VIX volatility index would have to remain at (or above) this level for a similar period (i.e. around three months).

Chart 6: Modelled collateral supply/demand for different levels of market stress



(a) Average level of the VIX index between June and August 2015.

Whilst this level of the VIX index gives an (albeit rough) guide to the level of market stress required for this risk to crystallise, its impact is harder to judge. On one hand, it might be natural to expect that market prices might adjust to restore the equilibrium between supply and demand. Such an adjustment might take the form of an increase in the returns on securities lending, which would encourage beneficial owners to increase their securities lending and redress the mismatch between collateral supply and demand. That said, it is also conceivable that if the mismatch between supply and demand were to occur very rapidly, there might be insufficient time for beneficial lenders – particularly those not very active in securities lending markets – to undertake securities lending in a volume necessary to redress the imbalance.

4 The role of dealers in collateral markets and procyclicality of their behaviour

The final piece of this framework considers the role played by leveraged intermediaries in mobilising high-quality collateral: that is, acting as intermediaries between those (principally unleveraged) end-investors that supply and demand it.

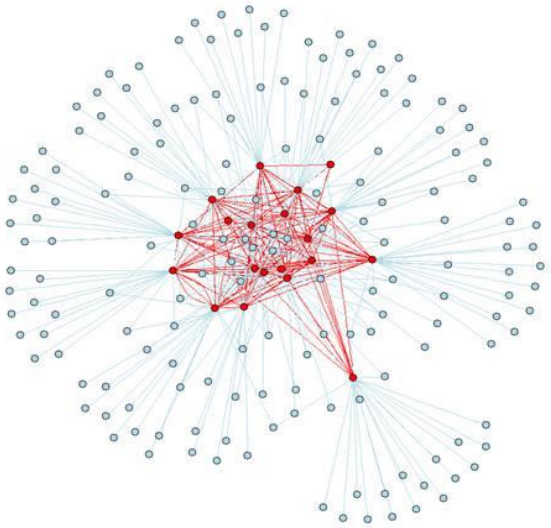
In what follows, we assume these intermediaries to take the form of broker-dealers, who – via a series of repo, reverse repo and securities lending transactions – are able to pass collateral between those that supply and demand it. [27]

[27] Prospectively, such institutions may also be disintermediated via 'all-to-all' electronic platforms that directly connect suppliers and users of collateral and/or via entities not subjection to prudential bank regulation. But – according to recent industry analysis (for example, see International Capital Market Association (2015)) – such alternative solutions do not currently exist on a substantial scale.

4.1 Required intermediation capacity

Not every such dealer transacts directly with every supplier or demander of collateral (or indeed, with every other dealer), as illustrated in the network shown on **Figure 1**. This consistent with the finding that interbank networks typically have a 'core-periphery' structure (see Langfield et al. (2014)). This could be due to the costs associated with setting up and maintaining bilateral repo relationships (e.g. costs of legal agreements and counterparty credit risk assessment), as well as due to the established interpersonal relationships between repo desks at certain financial institutions. This means that every unit of collateral that passes from those that supply collateral to those that use it has to pass through a chain of intermediaries. Using a range of global data on repo and securities lending transactions, we estimate that the average length of the 'supply chain' for high-quality collateral to be around 3.9; that is, every unit of collateral passed between those that supply to those that demand it passes across an average of 3.9 intermediaries.[28] From here on, we refer to this as the 'required intermediation capacity' associated with a given level of demand for high-quality collateral.

Figure 1: Outstanding repo transactions between banks (red) and non-banks (in blue)



Note: Covers UK-regulated banks and investment firms only. Red dots represent dealers and blue dots represent customers. Red lines represent interdealer repo transactions; blue lines those between dealers and their clients. More connected counterparties are clustered in the centre of the network. Data are as at end-2014.

4.2 Dealers' intermediation capacity

There is significant evidence to suggest that dealers scaled back on their securities financing activities during the crisis. During a downturn, leverage may rise purely in response to the falls in asset prices and the corresponding falls in the mark-to-market value of dealer equity. This places balance sheets under pressure, forcing dealers to deleverage, unwinding repo borrowing and thereby reducing dealers' intermediation (see Adrian and Shin (2010)).

But, this particular firm aside, estimating the likely degree of dealer deleveraging – and consequent reduction in intermediation capacity – that might occur in future episodes of market stress is impeded by limited historical data of the necessary granularity.

Given this, we instead incorporate the effect of dealer deleveraging by drawing on a theoretical model of dealers' choice of leverage (and hence intermediation capacity). This is based on the premise that dealers' intermediation capacity depends on two factors, both a function of the level of market stress (proxied by the VIX index): first, the equity dealers have available to carry out securities financing transactions; second, dealers' choice of optimal leverage, or balance sheet size, for a given level of equity.

The quantity of equity that dealers are willing to allocate to securities financing transactions is modelled as a decreasing function of market stress. The intuition is that as market stress intensifies dealers experience losses that reduce the value of their capital (including equity allocated to repo/reverse repo transactions). Dealer equity allocated to repos is estimated as the amount outstanding of securities financing transactions associated with the mobilisation of high-quality collateral divided by the average dealer leverage (as inferred from Federal Reserve Board (2015)). The sensitivity of dealer equity to the level of market stress is calibrated using the empirical relationship between the median return on equity for major global banks and the VIX index (**Annex 1, Table E**).

To model changes in dealers' optimal leverage we appeal to a theoretical model of dealer behaviour. Under it – for any given level of stress – dealers choose a level of leverage that maximises their shareholders' value,

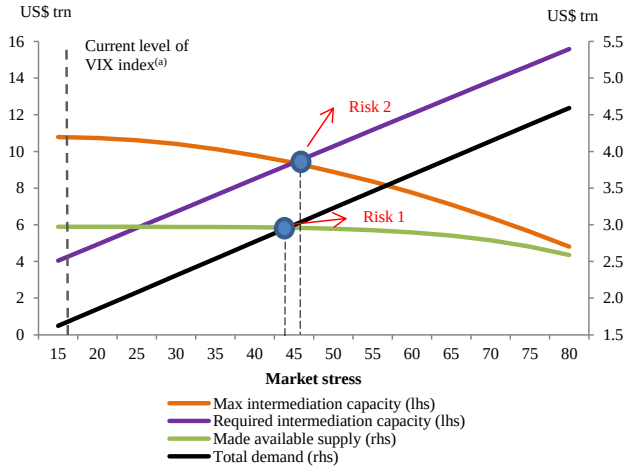
[28] This is total high-quality collateral received by dealers that is that used in interdealer repos and securities lending transactions divided by total high-quality securities on loan. This is estimated on a global basis and based on a range of sources including Financial Stability Board (2014), International Capital Market Association (2014) and International Securities Lending Association (2014). Our estimate differs from that of Singh (2011) in part because it includes only high-quality collateral (whereas Singh (2011) includes all collateral, including equities). It omits repo/reverse repos by hedge funds, because we believe that most such transactions are 'relative value arbitrage' trades that do not facilitate collateral intermediation.

subject to a regulatory constraint on their minimum leverage that – if breached – leads to their default, and the claim of equity holders being reduced to zero.[29] As market stress – and hence asset volatility – increases, the threat of insolvency causes shareholders' optimal choice of leverage to fall, reducing dealers' capacity to act as intermediaries. Technical details of this model, and its calibration, are given in **Annex 2.** Throughout, this constraint on dealers' leverage is assumed to match that imposed by the regulatory minimum leverage ratio. This is assumed to be 3% (equity as a proportion of total assets), in line with the internationally agreed Basel III standard.[30]

When multiplied together, the level of equity that dealers allocate to securities financing transactions and their optimal choice of leverage provide an estimate of the amount of balance sheet dealers, in aggregate, make available to act as intermediaries in collateral markets. We can also see how this varies as a function of market stress (proxied by the VIX index). This is shown by the orange line in **Chart 7**, alongside the required intermediation capacity (purple line) that corresponds (via a fixed scalar multiple of 3.9, described above) to a given level of demand for high-quality collateral (shown by the black line).

4.3 The risk that the required intermediation capacity necessary to meet a given level of collateral demand exceeds dealers' maximum intermediation capacity (Risk 2)

Chart 7: Estimated required intermediation capacity necessary to meet demand for collateral (RIC) versus the maximum intermediation capacity of dealers – for different levels of financial stress



(a) Average level of the VIX index between June and August 2015.

The level of market stress at which required intermediation capacity exceeds that which dealers are willing to provide is where the second risk identified in this framework crystallises. Note that this risk could crystallise even in the absence of Risk 1. That is, even if demand for collateral does not exceed its available supply – perhaps because, despite market stress, the return on securities lending adjusts and increases the proportion of assets that are made available for loan – the dealer intermediation required might exceed that which dealers are willing/able to provide, which is labelled as 'Risk 2'. Put differently, this is the risk that collateral might get 'blocked' in the network of dealer balance sheets. We estimate that this risk would materialise with levels of market stress roughly commensurate with the VIX volatility index exceeding 46 per cent over a period of a quarter.

Although Risk 2 is slightly less likely to crystallise than Risk 1 (since it is triggered by a slightly higher level of market stress), it could have a significant negative impact on financial stability. In particular, if triggered, Risk 2 will likely prevent collateral from performing its role of supporting the functioning of markets, including the facilitation of liquidity. The consequences of this might include a sudden inability of market participants to obtain the collateral they need to manage the risks associated with their business, including payment of initial margin on derivatives transactions. It also might risk impairing dealers' ability to fund other leveraged investors' (e.g. hedge funds') purchases of financial assets, which might have implications for market functioning and liquidity. Were this to be the case, it might risk an impairment of secondary market transactions in securities which are important for financing investment in the real economy and therefore have negative implications for economic growth.

5 Sensitivity analysis

The preceding sections present a simple and parsimonious framework for considering market participant behaviour in collateral markets and how this varies under stress. This is based on a number of simplifying assumptions, around which this section provides some sensitivity analysis. In particular, it aims to offer some insight into how the proximities of the two risks outlined above changes as we vary the strength of the empirical relationships – and hence the procyclicality of market participants' behaviours – estimated in **Sections 3 and 4**. To do so, it estimates two alternative scenarios, which we label as 'benign' (where the relationships – and procyclicality of market participant behaviours – are *weaker* than in the central case

[29] This is in the spirit of other literature analysing the effects of bank regulation; see Episcopos (2008).
[30] See Bank of International Settlement (2014). To the extent that off-balance sheet collateral flows are not included in the leverage ratio measure, our model may understate the 'true' leverage of the dealer.

described above); and 'severe' (where they are stronger). Details of how these are calibrated are given in **Table 6**.

Combining the 'benign' and 'severe' calibrations allows us to calculate an upper and lower bound for the levels of market stress at which **Risks 1** and **2** materialise. Recall that, in the central case given in **Sections 3 and 4**, Risk 1 is estimated to crystallise at a value of the VIX index of around 44 per cent, and Risk 2 at 46 per cent. In contrast:

- In the 'benign' scenario **Risk 1** materialises at VIX = 65 per cent, and **Risk 2** at VIX = 60 per cent.
- In the 'severe' scenario **Risk 1** materialises at VIX = 36 per cent, and **Risk 2** at VIX = 40 per cent.

Thus, the range of VIX index values at which **Risk 1** is likely to begin to crystallise is between 36 and 65 per cent, and the analogous range for **Risk 2** is 40 and 60 per cent. This is illustrated in **Charts 8 and 9**.

To put this into perspective, **Chart 10** shows historical values for VIX index along with the central, benign and severe calibrates for the levels at which **Risk 1** (maroon dotted and solid lines) and **Risk 2** (green dotted and solid lines) crystallise. As discussed above, we estimate that the VIX index would need to exceed these levels for around a quarter in order for those risks to crystallise.

Historically, there has only been one occasion on which the quarterly average value of the VIX index (shown by the orange line) was at a level sufficient to trigger both **Risks 1 and 2.** This occurred at the height of the recent crisis, in late 2008. This suggests that – to the extent that the past value of the VIX index gives a guide to its future distribution – both risks are of relatively low probability. That said, as discussed above, the crystallisation of **Risk 2** could have a significant impact on market functioning,

Table 6: Sensitivity analysis

Type of driver (in bold) and methodology for calibration of central case estimate	**Inputs into…**	
	…benign scenario calibration	**…severe scenario calibration**
Supply		
Proportion of high-quality securities that beneficial owners make available for loan: linear regression of its changes on changes in average dealer CDS premia	Estimate of regression coefficient + 1 standard error (as shown in Chart 2)	Estimate of regression coefficient - 1 standard error (as shown in Chart 2)
Demand		
Banks' liquid asset buffers (as proportion of total assets): linear regression of changes in liquid asset buffers on changes in VIX index.	Estimate of regression coefficient - 1 standard error	Estimate of regression coefficient + 1 standard error
Changes in initial margin: varies in proportion to changes in VIX index. Size of derivative positions is assumed to be fixed.	Increases proportionally with VIX index, as per central case, but the size of derivative positions declines linearly as stress increases and reaches a level observed during the 2008-09 for a commensurate level of the VIX index (of around 80 per cent).	Based on the rerun of 2008-2009 financial crisis on a hypothetical CCP initial margin model. Assumes such a model is applied to all OTC transactions.
Maximum dealer intermediation capacity		
Dealer equity allocated to securities financing transactions	Coefficient of this regression + 1 standard error	Coefficient of this regression - 1 standard error

Chart 8: Risks from collateral markets – 'benign' scenario calibration – upper bound

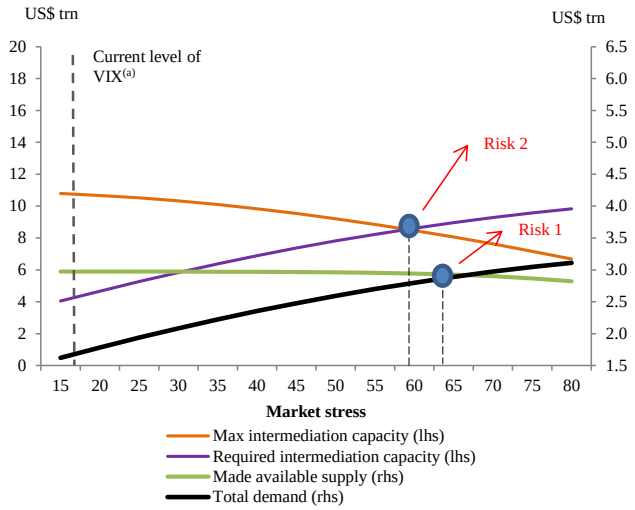
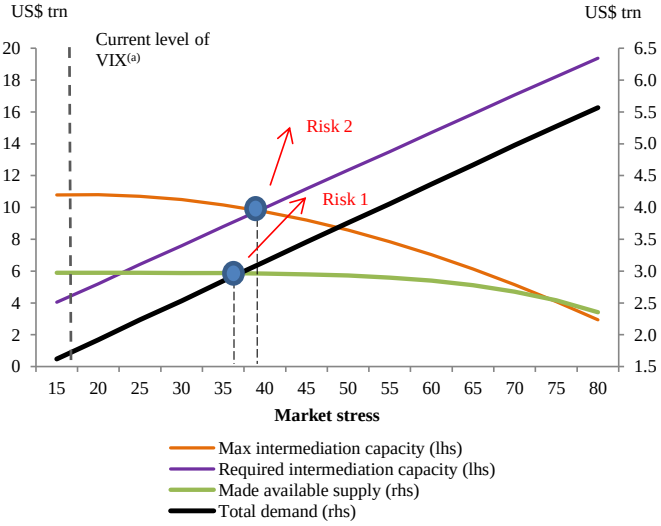


Chart 9: Risks from collateral markets – 'severe' scenario calibration – lower bound



(a) Quarterly VIX average is for Jun-Aug 2015.

The effect of dealer stress

The changes in collateral supply and demand described in **Sections 3 and 4** are designed to reflect behaviour by market participants consistent with their prudent risk management. This section explores an element of stress over and above this, by considering the effect of excluding a single dealer or multiple dealers from the network of intermediaries between collateral suppliers and end-users. This could proxy for a situation where a dealer either failed, or was perceived by its counterparties to be sufficiently close to failure that they chose not to transact with it.

This exclusion of a dealer or multiple dealers from the network of intermediaries has two effects:

- First, it causes the average length of the chain of intermediaries required to move collateral between those that supply and demand collateral to increase (due to less intermediaries operating in the network), increasing the intermediation capacity required to deliver a certain level of collateral demand by end users;

- Second, it reduces the total equity that dealers allocate to their repo books – that is, it reduces dealers' aggregate capacity to act as intermediaries.

Chart 10: Historical values of VIX index and ranges of estimates in which Risks 1 and 2 might crystallise

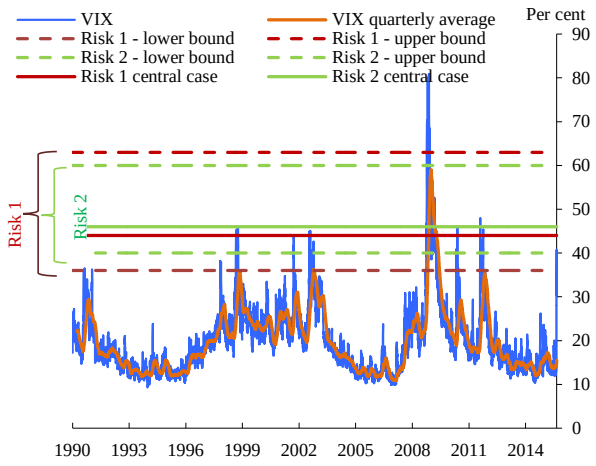


Chart 11 shows these effects – in the case of the exclusion of two most interconnected dealers – via the movements in the maroon and blue lines, respectively. The sum total of these effects is to reduce the level of market stress at which Risk 2 crystallises – proxied by the VIX index, from 46 to 35 per cent. **Chart 12** illustrates how the level of the VIX index at which **Risk 2** crystallises changes as a given number of most interconnected dealers are excluded from the repo network simultaneously.

Chart 11: The effect of two dealers' failure on the level of market stress at which Risk 2 crystallises

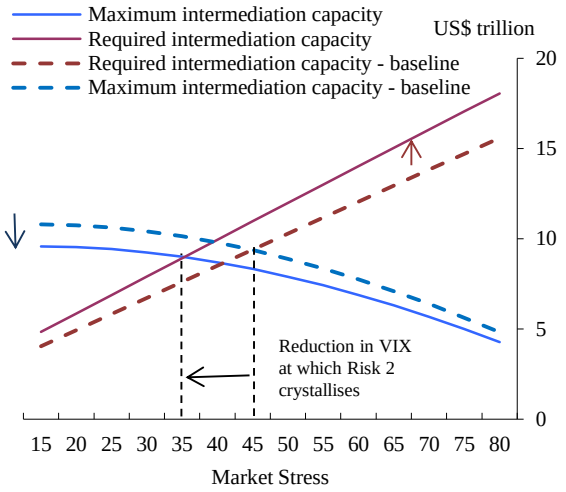
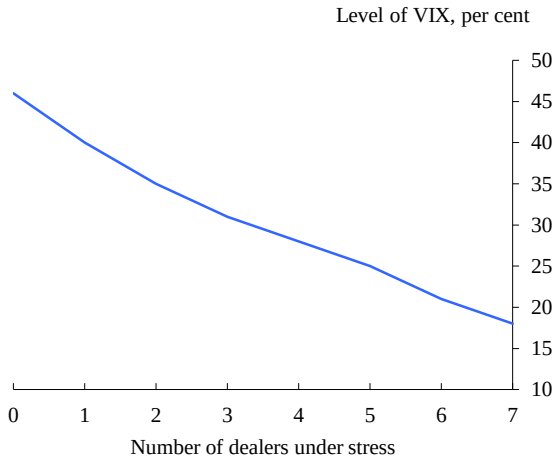


Chart 12: Level of market stress at which Risk 2 crystallises when different numbers of dealers experience stress



6 Conclusion

This paper identifies and quantifies a number of procyclical behaviours of market participants that cause their supply, of and demand for, high-quality collateral – as well as their willingness and/or ability to act as intermediaries in the market for securities financing transactions – to decrease/increase in response to market stress. These include increased perceptions of counterparty risk (which causes a reduction in securities lending) and the likelihood that key financial intermediaries may seek to deleverage. Demand for collateral may also increase as, for example, firms hoard liquid assets, and volatile markets cause an increase in initial margin held against derivatives.

These dynamics give rise to two potential risks. The first of these – demand for collateral exceeds its supply as market stress increases – is judged to crystallise for a level of market stress commensurate with the VIX volatility index remaining at a level of around 44 per cent or above for around a three month period. Were this risk to crystallise, however, we judge it would have only moderate impact on financial stability, since – at least in a matter of days – the price of accessing high-quality collateral should adjust to restore the equilibrium between collateral supply and demand.

A second risk, that is potentially more pernicious in its impact, is that as market stress increases the intermediation capacity of dealers required to move collateral from end-suppliers to end-demanders starts to exceed that which dealers are willing/able to provide**.** This analysis estimates this risk might crystallise at a similar level to that described above, but that this might have a more significant negative impact on market functioning. The withdrawal of dealers from their role as intermediaries – including due to their failure or deterioration in counterparty credit quality – is estimated to make these risks more proximate.

These conclusions are not without caveats. Most notably, this work seeks to form a simple and parsimonious framework to describe the behaviour of market participants in the market for collateral based on historical data. Given that these may differ to the richer set of behaviours that might be witnessed in future – including given the effects of recently introduced regulation – there is considerable uncertainty around their exactitude. The levels of market stress at which we estimate the above risks to crystallise should therefore be viewed as broad approximations rather than precise estimates.

There are a number of possible extensions to this work. Most notably, it offers a framework with which policy makers could – if they so choose – in future consider how the effects of recently introduced regulation (including the regulatory minimum leverage ratio, initial margin and minimum haircut requirements) might affect market participant behaviour, and hence the level of market stress at which these risks may crystallise. This is, however, left as future work.

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Technical Annexes

Annex 1: Regression results for relationships used in model calibration

Table A (Chart 3) - Change in proportion of high-quality securities available for loan (as percentage of holdings) versus change in average dealer CDS premia (in basis points), based on quarterly averages

Regression Statistics	
Multiple R	0.2684
R Square	0.0720
Adjusted R Square	0.0455
Standard Error	0.0273
Observations	37

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0.0014	0.0045	0.3195	0.7512
Change in CDS	-0.0002	0.0001	-1.6481	0.1083

Table B (Chart 4) - Percentage change in the amount of securities lent against cash versus change in average dealer CDS premia (in basis points), based on quarterly averages

Regression Statistics	
Multiple R	0.3842
R Square	0.1476
Adjusted R Square	0.1245
Standard Error	7.0251
Observations	39

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-0.6259	1.1257	-0.5560	0.5816
Change in CDS	-0.0942	0.0372	-2.5310	0.0158

Table C (Chart 5) - Change in the percentage of cash collateral reinvested in high-quality repos versus change in the VIX index (in percentage points), based on quarterly averages

Regression Statistics	
Multiple R	0.3625
R Square	0.1314
Adjusted R Square	0.1059
Standard Error	2.3774
Observations	36

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-0.0266	0.3963	-0.0671	0.9469
Change in VIX index	-0.1184	0.0522	-2.2682	0.0298

Table D – Changes in banks' liquid asset buffers held in the form high-quality collateral (as a proportion of total assets, expressed in per cent) versus changes in the VIX index (in percentage points), based on weekly data (due to a limited number of observations)

Regression Statistics				
Multiple R	0.1041			
R Square	0.0108			
Adjusted R Square	0.0066			
Standard Error	0.2905			
Observations	235			
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0.0038	0.0190	0.1987	0.8427
Change in VIX index	0.0110	0.0069	1.5973	0.1116

Table E – Median return on equity (in percentage points) for major global banks versus VIX Index (in percentage points), quadratic relationship based on quarterly data

Regression Statistics					
Multiple R	0.3608				
R Square	0.1302				
Adjusted R Square	0.1090				
Standard Error	5.8150				
Observations	85				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	414.9664	207.4832	6.1360	0.0033
Residual	82	2772.7742	33.8143		
Total	84	3187.7406			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	
Intercept	9.4924	4.8026	1.9765	0.0515	
VIX Index	0.5082	0.4102	1.2389	0.2189	
VIX Index^2	-0.0147	0.0079	-1.8671	0.0655	

Annex 2: Calibration of dealer optimal leverage

This annex describes the approach used to estimate the optimal level of dealers' aggregate leverage for a given level of market stress, as proxied by the VIX index.

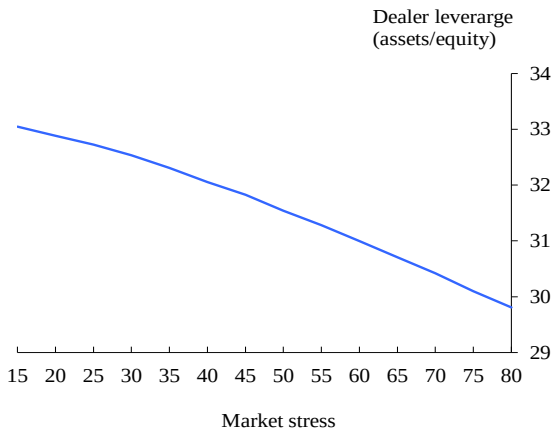
This is estimated via a variant of the 'structural' credit risk model, which was introduced by Merton (1973). Under it, the value of a firms' equity is modelled as the value of a call option, struck at the face value of the firms' debts, whose value can be determined using option-pricing techniques.

Importantly for the application described here, however, the value of dealer's equity is modelled as a 'knock out option', that expires worthless if the value of the dealer's assets fall below a 'barrier' level commensurate with its regulatory minimum leverage ratio (which is assumed to equal 3%), *at any time* prior to the maturity of the debt. This is intended to reflect the possibility that a regulator intervenes to wind up a dealer's business in the case that its assets fall below this value (or its leverage exceeds it maximum permitted level), even if it is still solvent (ie. its assets exceed the face value of its debt).

Throughout, it is assumed that the dealer's balance sheet – and, in particular, its choice of leverage – is constructed to maximise the payoff to its shareholders. It is further assumed that book value of the dealer's equity is fixed – that is, any change in its leverage (or expansion/contraction in its balance sheet) is financed/achieved via the issuance/redemption of its debt.

Crucially, under these assumptions, there exists a level of dealer's assets – or, correspondingly, a level of leverage – that maximises the value of the dealer's equity for each level of asset volatility (which we take as corresponding to different levels of market stress, as proxied by the VIX index). Intuitively, this is because too low a level of asset volatility will leave the dealer seeking to lever up – increasing its leverage in order to maximise the potential returns for its equity holders, but without significantly increasing the probability of breaching the regulatory minima. But too high a level of leverage will significantly increase the probability of the dealer breaching its regulatory minima, which will cause the equity holders' claim to expire worthless. Put differently, the dealers' optimal choice of leverage is determined by balancing potential future returns to its equity holders and the possibility of a regulatory breach, which could lead to further dealer distress.

Chart 13 Optimal dealer leverage



This optimal level of leverage – and how it varies as a function of the VIX volatility index – is shown in **Chart 13**.

To calibrate the optimal dealer leverage we use the volatility of major global banks' return on assets as a proxy for their asset volatility. We also assume that the dealer faces a regulatory minimum leverage ratio of 3% (in line with the internationally agreed Basel III standard), an average debt maturity of 2.5 years, and an expected return on assets of 0.5%.