BANK OF ENGLAND

Staff Working Paper No. 665

Dealer intermediation, market liquidity and the impact of regulatory reform

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July 2017

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Abstract

We develop a model of dealer intermediation in bond markets that takes account of how changing regulatory requirements for banks since the financial crisis, in particular, the introduction of minimum leverage ratio requirements, affect the cost and ability of dealer banks to provide intermediation services. The framework considers two distinct dealer functions: that of provider of repo financing (to prospective bond market participants) and that of market-maker. The cost and ability of dealers to provide these services under different regulatory constraints determines the price impact of a given trade on the market — or the level of 'market liquidity premia'. In the model the impact on market liquidity varies for different levels of market volatility or 'stress'. We find that under normal market conditions estimates of corporate bond liquidity risk premia are higher under the new regulations, but also that corporate bond market liquidity is more resilient due to better-capitalised dealers continuing to intermediate markets under higher levels of market stress than pre-crisis. Mapping these changes in liquidity premia to GDP, via their impact on the cost of borrowing for corporates in the real economy, the results of the model suggest that under normal market conditions there may be a greater cost of regulation via corporate bond markets than incorporated in earlier studies. However, once offset against the benefits of greater dealer resilience, including the benefits to market functioning, there remain net benefits to new regulations.

Key words: Regulation, market liquidity, dealer intermediation, corporate bonds, cost-benefit analysis.

JEL classification: G12, G23, G24, G29.

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The views expressed in this paper are those of the authors, and not necessarily those of the Bank of England or its committees. We are grateful to Tobias Adrian, Niki Anderson, Graeme Douglas, Nigel Jenkinson, Joseph Noss, Jon Relleen, Vicky Saporta, Hyun Shin, Nicholas Vause and seminar participants at the Federal Reserve Board, Securities Exchange Commission, Bank for International Settlements and Bank of England. All errors are ours.

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ISSN 1749-9135 (on-line)

1. Introduction

Market-based finance, that is provision of finance to the real economy from outside the core banking sector, has become increasingly important as a source of finance for the real economy. In particular, in the aftermath of the financial crisis as banks retrenched from lending, most of the net finance raised by UK non-financial corporates came from corporate bond markets (Bank of England (2015)).

This highlights the importance of the efficient functioning and liquidity of primary capital markets. The liquidity of capital markets relies heavily on the liquidity of secondary markets, where securities already issued trade. In particular, a fall in securities prices in secondary markets caused by market illiquidity is likely to affect securities' pricing in the primary market as well (see ICMA (2013)). In addition, a fall in the prices of government bonds due to illiquidity could make them a less useful benchmark of interest rates with adverse effects on pricing and hedging in financial markets (see Fleming (2000)).

Many of the most important fixed income markets, such as those for corporate bonds and government bonds, are heavily reliant on dealer intermediation to support market liquidity and functioning. Dealers are important for supporting fixed income market liquidity in two ways. First, they directly support liquidity by continuously providing two-way quotes to market participants. In particular, roughly 90% of trading volume in the gilt market and around 95% of trading volume in the US corporate bond market is dealer-intermediated. Second, they indirectly facilitate market liquidity by providing secured (repo) funding to leveraged investors who in turn support market liquidity via their trading activity.

However, there have been recent concerns expressed by market participants about a perceived increase in the fragility of market liquidity in dealer-intermediated markets (IMF (2015)). For example, US dealers have reduced their corporate bond inventories by nearly 80% since 2013, and the price impact of large trades has increased (Committee on the Global Financial System (2016)). This has been accompanied by some evidence of a reduction in the volume, and increase in the price, of repo financing secured against UK government bonds (Bank of England (2016)). It is therefore beneficial for policy makers to be able to examine how changes in the behaviour of dealers can affect market liquidity.

Recent developments in market liquidity have occurred at the same time as regulatory reforms, including new capital and liquidity requirements for banks and dealers announced or introduced following the 2007-2008 financial crisis (Basel Committee on Banking Supervision (2015)). Although evidence is still inconclusive, the impact of new bank regulation is recognised as one of potential drivers of recent trends in market liquidity (Committee on the Global Financial System (2016)). This is alongside other developments, for example changes in the risk appetite of firms and the low yield environment, that may also have affected market participation, and hence liquidity.

A number of studies have been carried out to assess the real economy impact of post-crisis changes in regulations, e.g. the Basel Committee on Banking Supervision (2010) and Brooke et al (2015). However, these studies mainly focus on the impact of regulations on bank lending rates to households and non-financial companies, and do not take into account the impact of regulation on dealers' incentives to intermediate financial markets and market-based finance more broadly. Our paper aims to fill this gap by developing a framework for examining the role of dealers in supporting market liquidity (both via market-making and the provision of secured funding), and how that might be affected by prudential regulations faced by dealers.

We consider the impact of dealer intermediation on market liquidity by comparing liquidity risk premia (estimated as the price impact of a trade) before and after changes in prudential regulation, in both normal and stressed times. We focus on the corporate bond market in this paper, but have also applied our model to the UK government bond market (gilts). We have chosen liquidity risk premia as a gauge of market liquidity in our study for the following reasons. First, it allows us to naturally map from the costs (including regulatory costs) that a dealer is exposed to in its market-making and financing activities to the price of market liquidity. Second, liquidity risk premia are one of the components of funding costs for corporates and governments, which allows us to estimate the costs to the real economy arising from lower market liquidity.

To obtain estimates of liquidity risk premia, we have constructed a partial equilibrium model with three representative participants: a seller of an asset (e.g. a real money investor); a leveraged buyer (a hedge fund), who needs repo financing to fund its purchases; and a dealer that both clears the market and provides repo financing to the leveraged buyer. Liquidity premia estimates are based on the price discount required by the dealer to accommodate an initial sale of a given size by the real money investor. This setup is consistent with the economics of market making as described in Committee on the Global Financial System (2014).

We assume dealers cannot raise new equity in the short run, implying that the balance sheet capacity available to warehouse new inventory or for repo provision is fixed. In the model, dealers' market-making and repo desks have some initial allocated balance sheet capacity to start with; once it runs out the dealers may reallocate capital from other business lines. However, when dealers run out of balance sheet capacity at firm-level, they would not be able to accommodate asset sales (unless they sell some of their other assets), which could lead to significant disruptions to market functioning.

In order to consider the impact of regulatory reforms on bond markets, we compare model estimates over time. Specifically we use dealer balance sheet structure and regulatory requirements (including higher risk-weighted capital requirements, leverage ratio and liquidity regulations) as they stood back in 2006 and contrast this with estimates using current dealer balance sheet structure and the set of regulations expected to be implemented by end-2018 (by which time most of the agreed reforms should have been implemented).

We find that liquidity premia vary depending on the level of stress, and there are substantial differences in liquidity premia in pre- and post-crisis regulatory regimes. At low levels of stress (proxied by the VIX index), liquidity premia are estimated to be around 40bps higher than pre-crisis, suggesting a potential cost to the real economy. But at higher levels of stress, the greater resilience of dealers post-crisis limits the increase in their own funding costs, so liquidity premia rise by less than pre-crisis. Also, we estimate that the level of market stress at which dealers run out of their spare balance sheet capacity is slightly higher post-crisis, suggesting a small positive net benefit of regulation to the resilience of market liquidity.

Our framework could also be used for assessing the impact of various policies, including those aimed at improving market resilience during times of stress, such as countercyclical capital requirements. If we assume that under post-crisis regulations dealers hold a countercyclical leverage ratio buffer in normal times that can be released during stress, then dealers are expected to run out of capacity at even higher levels of market stress than if they had to still meet the buffer requirement, resulting in a substantial increase in market resilience.

Finally, we map our estimates of liquidity premia to estimate the effects on GDP and do a cost-benefit analysis of the post-crisis regulatory reform package, building on existing literature. We find that post-crisis regulations still have a substantial net benefit after considering the impact via capital market channels. Nonetheless, the costs of regulations via capital market channels are much larger (relative to the costs of regulations via bank lending channels) than implied in earlier studies, which have focused on risk-weighted capital requirements and assumed that banks respond to higher regulatory costs on both the banking book and the trading book by increasing lending spreads only. This suggests value in looking at both channels separately when assessing the potential impact of regulatory changes.

The rest of the paper is structured as follows. Section 2 provides a review of the related literature. Section 3 describes the setup of the model, Section 4 and 5 explain how we vary model parameters with market stress and regulation and how they are calibrated. We present our results and cost-benefit analysis in Section 6 and 7, and conclude in Section 8. Details on calibration of parameters and sensitivity analysis can be found in appendices.

2. Literature review

This paper relates to the academic literature on the impact of capital market frictions on asset prices. For example, Gromb and Vayanos (2002) find that arbitrageurs subject to financial constraints might fail to take a socially optimal level of risk, and He and Krishnamurthy (2013) show that intermediaries subject to equity capital constraints can lead to higher risk premia, which can be effectively reduced by equity injection. Other work in this area include Basak and Croitoru (2000), Gromb and Vayanos (2012) and Duffie and Strulovici (2012). Nonetheless, our paper is the first to structurally estimate the impact of the post-crisis regulatory reform on dealer intermediation and market liquidity with real-world calibrations.

Our model of dealer intermediation is based on the standard asset pricing literature, but is extremely simplified. For instance, our assumptions that the hedge fund maximises expected profits taking into account the effect of its trading on the price, and that the market maker sets the price to break even and trades the market-clearing quantity, are consistent with Kyle (1985). The hedge fund in our model acts as a speculator that provides market liquidity subject to funding constraints, which is similar to the setup in Brunnermeier and Pederson (2008). However, our model does not have any uncertainty regarding the fundamental value of the asset and has only one period. We judge that this simplification was sufficient to derive the key results of our model, and a more complex model would make it difficult to calibrate the model to real data.

This paper also relates to the literature on liquidity premia in financial assets. Following Amihud and Mendelson (1986), we define liquidity premia as the price discount required by investors to compensate for the expected cost of the future liquidation of the asset. It is well documented that default risk only accounts for part of the spread on corporate bonds (e.g. Longstaff, Mithal and Neis (2005)), and there have been various attempts in the literature to decompose corporate bond spreads (see Webber and Churm (2007)). In this paper, we compare model-estimated corporate bond liquidity premia to empirical estimates based on the structural model developed by Leland and Toft (1996).

There is an emerging strand of literature on the impact of regulation on financial markets. So far the evidence has been mixed. Trebbi and Xiao (2015) find that the Volcker Rule did not appear to have produced structural deteriorations in bond market liquidity. Dick-Nielsen and Rossi (2016) find that the cost of immediacy for corporate bonds increased significantly following the post-crisis regulatory reform. Duffie (2016) argues that the post-crisis regulatory reforms caused some reduction in secondary market liquidity, especially in safe assets such as government bond repo markets.

The rest of the paper is structured as follows. Section 2 describes the setup of the model, Section 3 and 4 explain how we vary model parameters with market stress and regulation and how they are calibrated. We present our results and cost-benefit analysis in Section 5 and 6, and conclude in Section 7. Details on calibration of parameters and sensitivity analysis can be found in appendices.

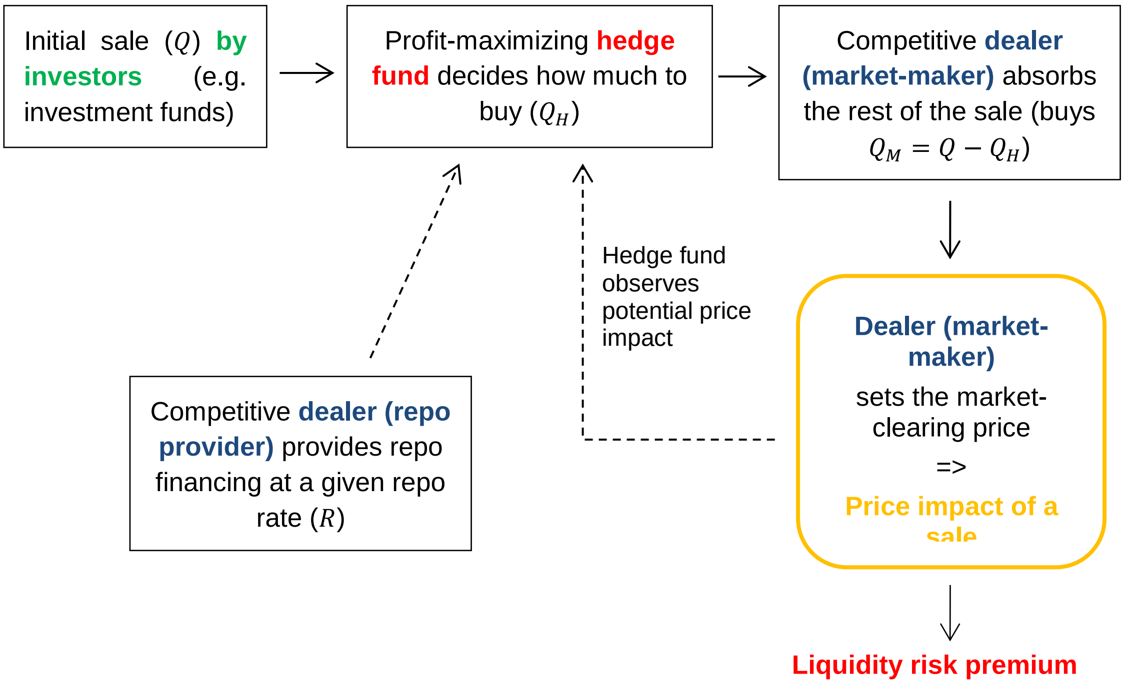
3. Model Setup

We consider the impact of dealer intermediation on market liquidity by modelling how it affects bond liquidity premia in both normal and stressed times, before and after the post-crisis changes in prudential regulation faced by dealer banks. Conceptually, we think of liquidity premia as the price discount required by investors to compensate them for the expected cost of liquidating the asset, consistent with Amihud and Mendelson (1986). In dealer-intermediated markets, the expected cost of liquidation is mostly driven by the price impact of the sale, or the price discount required by the dealer (or market-maker) to cover its cost of trading. To estimate this, we have constructed a partial equilibrium model with three representative participants: a seller of an asset (e.g. a real money investor); a leveraged buyer (a hedge fund), which needs repo financing to fund its purchases; and a dealer that both clears the market and provides repo financing to the leveraged buyer. The setup of the model is illustrated in Figure 1 and described in further detail below.

3.1 Initial sale by the investor

We assume that the investor sells a given amount of bonds (denoted by Q) to the dealer (as market-maker) at the starting point of time for reasons outside of the model. For example, this could be interpreted as a mutual fund having to liquidate its assets due to redemptions (see Braun-Munzinger, Liu and Turrell (2016) and Baranova et al (2017)). The behaviour of the investor is exogenous, i.e. the investor does not vary its size of sale in anticipation of potential price impact.

Figure 1: **Model setup**



3.2 Dealer as the market maker

We aim to estimate the potential price discount required by the dealer (as a market-maker) to accommodate a sale of bonds by the investor. (See Committee on the Global Financial System (2014) for a stylised description of dealer behaviour.) Assuming that the dealer cannot find an immediate buyer for the bonds, it needs to hold the bonds in its inventory, at least in the short-term, which gives rise to a number of costs:

- If the position is unhedged, the dealer needs to hold capital (which is costly) against the market risk exposure under the risk-weighted regulatory capital regime. The capital requirement is higher in the post-crisis regulatory regime due to revisions to the market risk framework (Basel 2.5 and the fundamental review of the trading book) and higher capital ratio requirements in Basel 3 (see Appendix I for calibration details).
- If the position is hedged via derivatives, the dealer needs to pay a hedging cost. In addition there will be a cost of capital arising from the higher leverage ratio exposure (assuming that the hedged position has zero market risk capital requirements) in the post-crisis regulatory regime only (the leverage ratio requirement was introduced after the crisis).
- The dealer also needs to pay the cost of financing the increase in its inventory in the repo market. This includes the repo funding cost, which is higher in the post-crisis regulatory regime due to the introduction of the net stable funding ratio (NSFR), and the cost of holding additional liquid assets under the liquidity coverage ratio (LCR) requirement.

We construct a representative dealer subject to regulatory and other costs as described above. We assume that the dealer is risk-neutral and requires a price discount to exactly cover the marginal costs associated with its purchase of bonds. There are plausible reasons why this estimate may over- or under-estimate the price discount dealers require in reality. On the one hand, dealers are not perfectly competitive and so may require a larger price discount than the marginal cost. On the other hand, dealers may have spare capital on their balance sheet and so may not require a price discount to cover the full marginal cost.

Specifically, we have

$$D = (1 - U) \times [HP_M \times (LR \times C + FC) + HC] + U \times HP_M \times (RWA \times C + FC)$$

where D is the required price discount (in % of fundamental value), U is the proportion of inventory that is unhedged, HP_M is the dealer's expected inventory holding period, LR is the leverage ratio requirement, C is the cost of equity, HC is the cost of hedging (via interest rate and credit derivatives), FC is the funding cost and RWA is the risk-weighted capital requirement for market risk. Both HP_M and HC are increasing functions of the size of the purchase.[1]

We assume that the dealer finances its inventory with secured funding (repos). The dealer pays the risk-free rate on the repo borrowing given that it is over-collateralised, but needs to pay the unsecured funding cost on the over-collateralisation (repo haircut, h_M), plus additional funding costs associated with liquidity regulations. Assuming that the unsecured funding cost covers the expected loss on an unsecured loan to the dealer (i.e. probability of default PD times loss given default LGD), we have:

$$FC = r_f + h_M \times (PD \times LGD) + LCR + NSFR$$

where r_f is the risk-free interest rate, h_M is the haircut on the repo borrowing, PD is the dealer's probability of default, LGD is the dealer's expected loss given default, LCR is the cost of holding liquid asset buffers against the repo borrowing and $NSFR$ is the additional cost of term funding required under the net stable funding ratio. The dealer's probability of default (PD) is calculated using a simplified version of the Merton model (Merton (1974)) where we assume that dealer equity is a call option on dealer assets that have normally-distributed returns. The dealer's funding cost as a function of its probability of default is shown in Chart 1. The required price discount for varying levels of increases in the dealer's inventory is illustrated in Chart 2.

Chart 1: Dealer funding cost as a function of probability of default

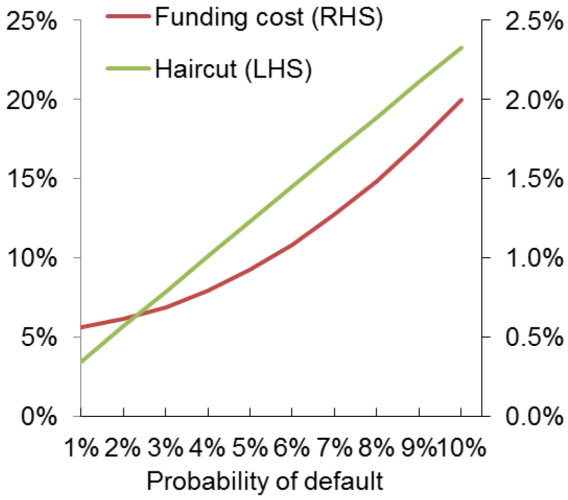
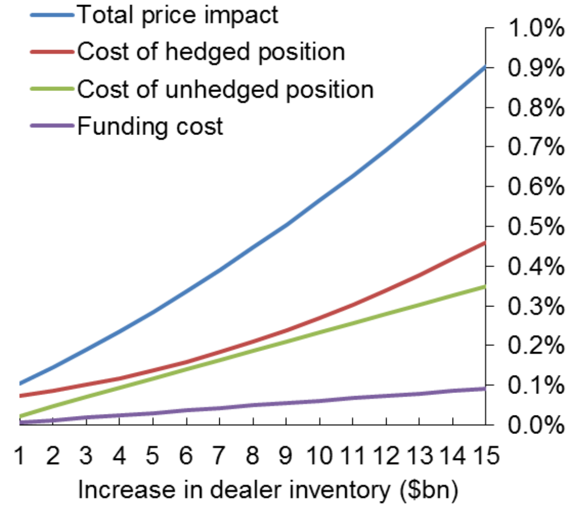


Chart 2: Price discount required for a given increase in dealer inventory



Note: See Appendix I for calibration details.

[1] We assume that the dealers expect to liquidate a certain amount of corporate bonds with zero price impact (i.e. at fundamental value) each day, and the expected inventory holding period is calculated by dividing the size of the purchase by the daily liquidation amount.

3.3 Hedge fund and dealer as the repo provider

So far we have assumed that the dealer accommodates the investor sale by taking all the bonds onto its balance sheet. In practice, dealers may try to find willing buyers in the market to offload part of the sale, and market participants, having observed some initial price decline, may actively come into the market and purchase part of the sale. Such market participants are likely to be leveraged investors (e.g. hedge funds) who are able to identify the opportunity and place trading orders within a short period of time. In particular, Ferguson and Laster (2007) argue that hedge funds add liquidity to markets and are broadly stabilising.

Our model captures the above dynamic by assuming that a risk-neutral hedge fund is able to purchase the bonds via the dealer (as a market maker). For a given dollar amount of initial sale by the investor (Q) and a given dollar amount of purchase by the hedge fund (Q_H), the residual of the sale ($Q_M = Q - Q_H$) will be bought by the dealer. Consistent with Kyle (1985), we assume that the dealer (as a market maker) sets the market clearing price, so that the hedge fund purchase (Q_H) will be at the same price as the dealer purchase (Q_M), discounted at D. The hedge fund can observe Q as well as the potential market clearing price as a function of Q_M, and chooses Q_H to maximise its expected profit. The hedge fund faces a constrained optimisation problem.

The hedge fund needs to finance its purchase of bonds via repo financing provided by the dealer. We assume that the dealer is competitive and requires a repo rate that covers the marginal cost associated with the transaction, which include its funding costs and the cost of capital (due to the leverage ratio). Specifically, we have

$$R = FC + LR \times C$$

where R is the rate of repo financing required by the dealer. In practice, the hedge fund needs to pay haircuts on the repo financing and have enough liquid assets to meet the haircut requirement on the borrowing. In order to capture this, we introduce a constraint that the haircut required on the borrowing must be less or equal to the amount of unencumbered liquid assets available to the hedge fund.

Given the price discount required by the dealer (D) and the repo rate, the hedge fund chooses Q_H to maximise its expected profit

$$\max Q_H \times (D(Q_H) - R \times HP_H - S)$$

subject to the constraint

$$Q_H \times h_H \leq HFLA$$

where HP_H is the hedge fund's expected holding period, S is the standard bid-ask spread paid on the purchase, h_H is the haircut on hedge fund repo borrowing and $HFLA$ is the amount of unencumbered liquid assets held by the hedge fund.

The expected profit of the hedge fund and its optimal amount of purchase are solved for numerically and illustrated in Chart 3. When the rate of repo borrowing (R) is higher, it is optimal for the hedge fund to purchase a smaller amount of bonds (Q_H).

To summarise, given the initial sale Q, the hedge fund determines its optimal amount of purchase Q_H (taking into account the potential price discount and repo rate set by the dealer), and the dealer purchases the residual amount of sale and sets the market-clearing price to cover its marginal costs. This determines the equilibrium price impact of the initial sale and hence the liquidity premium.

Chart 3: Hedge fund profit function and optimal amount of purchase

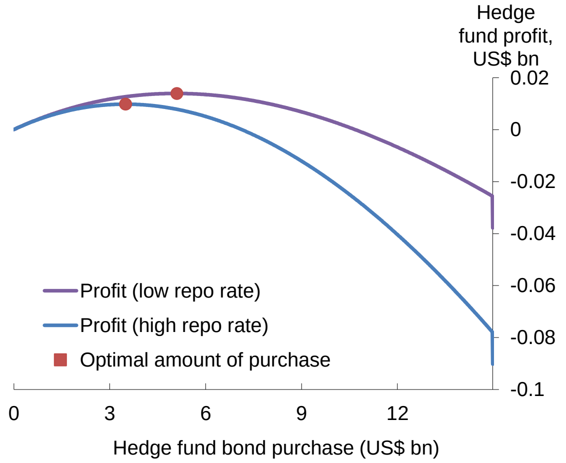
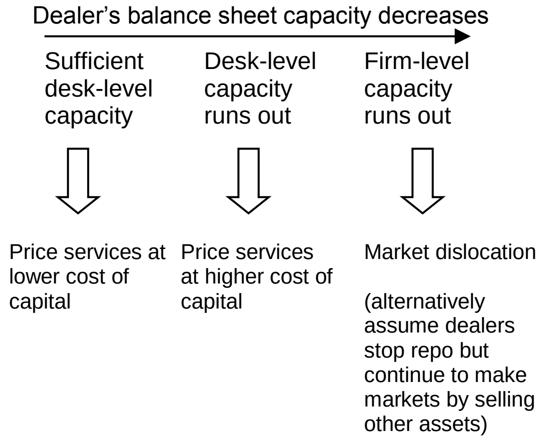


Chart 4: Dealer's spare balance sheet capacity and pricing of services



3.4 Dealer balance sheet capacity

The model so far assumes that there is no constraint on the amount of bonds the dealer is able to purchase or the amount of repo financing the dealer is able to provide. However, the dealer's ability to warehouse bonds and/or extend repo financing will depend upon constraints on the use of its balance sheet.

These constraints include regulatory requirements, including those relating to capital and leverage ratios. Assuming that the equity capital of the dealer is fixed in the short-run, then the need to meet a capital or leverage ratio requirement could limit the capacity of a dealer to expand its balance sheet.

Moreover, the dealer may become unwilling to expand its balance sheet even if the regulatory leverage ratio requirement is not binding. This is because the dealer wants to hold a capital buffer above the regulatory minima in order to avoid the risk of breaching the regulatory requirement. Following Baranova, Liu and Noss (2016), we model this in a knock-out option framework, where the dealer chooses the optimal leverage to maximise shareholder value subject to the risk of being 'knocked-out' (i.e. breaching the leverage ratio requirement), for a given level of volatility of the return on its assets. The dealer's spare balance sheet capacity is then given by

$$SC = E \times OL - BS$$

where SC is the dealer's spare balance sheet capacity, E is the dealer's current equity capital, OL is the optimal leverage and BS is the dealer's current balance sheet size.

While in most jurisdictions capital and leverage ratio requirements only need to be met at the group or legal entity level, there are a wide range of approaches that firms can take to deciding how they allocate spare balance sheet across their business. In our model, we assume that the firm-level spare balance sheet capacity (SC) is allocated to the market-making and repo desks proportionately according to their relative size (desk-level balance sheet capacity, DC_M and DC_R respectively) in the current balance sheet. When there is spare balance sheet capacity at the desk level to increase its inventory and provide repo financing, the dealer will set the price discount and repo rate to cover its marginal costs. When the desk-level balance sheet capacity is exceeded, the dealer is assumed to be able to accommodate the sale by re-allocating capital from other business lines but at a higher cost of capital (C^*). If the dealer runs out of balance sheet capacity at firm-level, the secondary market becomes dysfunctional as dealers are no longer able to make markets (referred to as 'market dislocation'). As an alternative, we can also estimate 'shadow liquidity premia' by assuming that the dealer requires a significantly higher price discount to trade (RC, to cover the potential costs associated with liquidation of assets to generate spare balance sheet capacity), but will always stop providing repo financing.[2] This is illustrated in Chart 4.

4. Varying parameters with market stress and regulation

The next step in our analysis is to vary model parameters with market stress, which is proxied by the VIX index,[3] and changes in regulation. This allows us to assess the impact of regulations on bond liquidity premia in both normal and stress times.

Changes in the level of stress have two key effects on the model. First, we assume it causes the dealer to incur losses on its assets which reduces its equity, and its return on assets becomes more volatile as the VIX increases. This means that the dealer's probability of default goes up (which leads to higher funding cost), and both its current equity and its optimal leverage go down (which leads to less spare balance sheet capacity). Second, the dealer also faces higher market risk capital charges and hedging costs as the VIX increases, which means that the cost of increasing its inventory becomes larger.

In order to capture the impact of regulation, we run the model under two scenarios: one with regulation and dealer balance sheets as they were in 2006; and the other with regulation and dealer balance sheets as they are projected to be in 2018. As mentioned previously, the key regulatory changes since 2006 include higher risk-weighted capital requirements for market risk (Basel 2.5), higher minimum risk-weighted capital requirement (Basel 3), leverage ratio, fundamental review of the trading book, and the liquidity coverage ratio and the net stable funding ratio. We use 2018 as the 'post-regulation' period because all of the regulatory changes described above would have been fully implemented by that time.

There were significant changes in dealer balance sheets between 2006 and 2018, both in terms of capital ratios and composition of assets. While regulatory change is probably a major driver, the changes in

[2] We assume the dealer will stop providing repo financing when firm-level capacity runs out, because according to our market intelligence, dealers generally consider repo as a low-margin add-on service provided to clients and hence are unlikely to liquidate other assets to generate balance sheet capacity for it.
[3] VIX is typically used as a measure of financial market stress (see, for example, Adrian and Shin (2008)).

balance sheets may also have been driven by other factors, e.g. reduced risk appetite and changes in expected returns for various asset classes (including due to accommodative conventional and unconventional monetary policy). Given it is difficult to distinguish between these drivers, we attribute all of the difference in liquidity premia between the two scenarios to regulatory change in our analysis. This is clearly a strong assumption.

5. Calibration

We calibrate our model to the global corporate bond market, including USD, EUR and GBP investment grade corporate bonds. Where applicable, the relevant parameters (e.g. volatility) are calculated as an average across the three markets weighted by size. The reason for not focusing on a particular market is because dealers typically have footprints across different markets, and it is difficult to estimate how spare balance sheet capacity is allocated across different markets. For example, UK banks only account for around 30% of the trading volume in sterling corporate bonds.

The representative dealer in our model is calibrated based on the aggregate balance sheets of sixteen global dealers[4], as presented in annual reports. For banking groups that have both commercial and investment bank subsidiaries (e.g. Barclays), we have included only the investment bank business of the group. Some granular information about individual business lines (e.g. the relative size of repo business) is not available in annual reports and is calibrated based on supervisory information on major UK banks.

Full details about the calibration of the parameters can be found in Appendix I.

6. Results

Chart 5 shows, for our central calibration, the effect of the regulatory reforms on the dealer's probability of default at varying levels of the VIX index. The changes in regulation since 2006 imply a substantial reduction in the probability of dealer default in stressed conditions, because dealers are much better capitalised in 2018. Chart 6 shows the balance sheet capacity of the dealer at different levels of the VIX index for the two regulatory regimes. The post-crisis regulatory reforms reduce balance sheet capacity for market-making and provision of financing in 'normal conditions', i.e. for levels of the VIX index below a critical value, because dealers in 2006 were subject to much lower regulatory capital requirements (leverage ratio requirements in particular) and hence had much higher optimal leverage. However, under the regulation in place by 2018, balance sheet capacity runs out at a higher level of the VIX index, implying a positive impact on market resilience at higher levels of market stress. This is intuitive because dealers in 2006 were much more leveraged, so their optimal balance sheet size falls much faster when they experience losses during market stress.

However, it may not be the case that the dealer's balance sheet capacity runs out at higher levels of the VIX index in 2018 than in 2006 for certain calibrations of the model (i.e. the purple curve in Chart 6 might lie below the green curve for all levels of the VIX index). On the one hand, higher capital requirements mean that dealers operate with lower leverage and hence run out of balance sheet capacity at a slower rate as market stress increases. On the other hand, higher capital requirements could imply

[4] These include Bank of America, Barclays, BNP Paribas, Citi, Credit Agricole, Credit Suisse, Deutsche Bank, Goldman Sachs, HSBC, JP Morgan, Morgan Stanley, Nomura, Royal Bank of Scotland, Societe Generale, Standard Chartered and UBS.

that dealers have less room to expand their balance sheets in stress times, all else equal. Which effect dominates depends on the size of 'voluntary capital buffer' that firms initially choose to hold above the regulatory minima. For instance, if firms choose to hold very small voluntary buffers above their leverage ratio requirement in 2018, they could run out of balance sheet capacity at lower levels of the VIX index than in 2006. See Appendix II for an analysis of the sensitivity of results to the calibration.

Chart 5: Dealers' probability of default

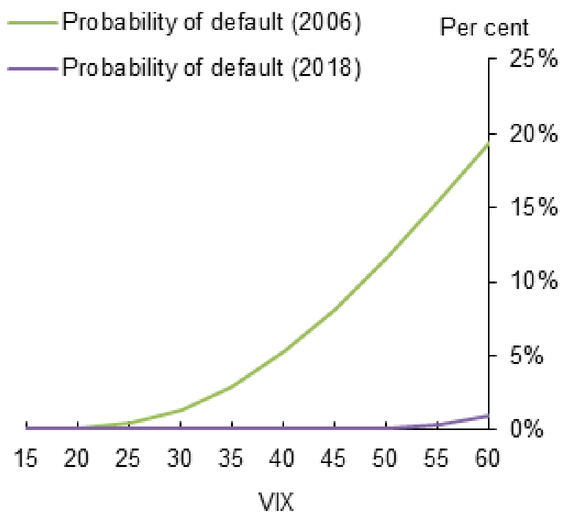
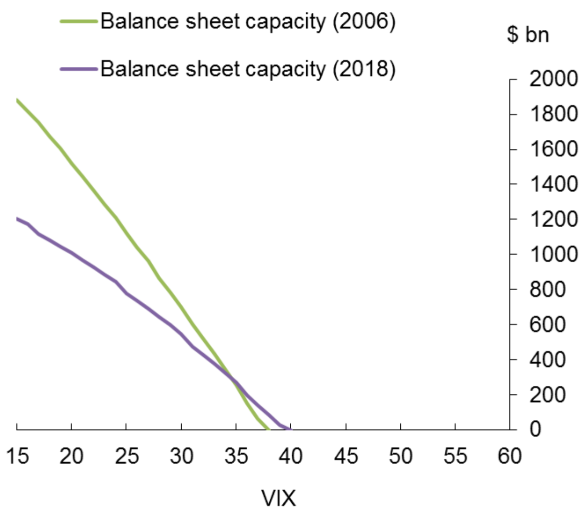


Chart 6: Dealer's spare balance sheet capacity



Note: See Appendix I for calibration details.

The impact of regulation on liquidity premia – that is, the price discount the dealer requires to absorb the residual amount of bonds the investor sells after the hedge fund has bought – varies with the level of stress. At low levels of stress, for our central calibration, liquidity premia are estimated to be higher than pre-crisis (Chart 7). Weighting the estimate of liquidity premia by the probability of different levels of stress crystallising (estimated from the empirical distribution of the VIX index[5]), the expected liquidity premia are about 40 basis points higher under the 2018 regulations (Table 1).

When the dealer's balance sheet capacity runs out, the secondary market becomes dysfunctional as dealers are no longer able to make markets, but we can still estimate the 'shadow' liquidity premia shown by dotted lines in Chart 7. (These are not taken into account when we calculate the probability-weighted liquidity premia.) We also compare our results with independent empirical estimates of liquidity premia for different levels of VIX, based on a decomposition of corporate bond spreads using the structural model in Leland and Toft (1996). While we do not expect our estimates to completely fit the empirical ones, given our model misses a lot of the real-world features of financial markets (e.g. central bank interventions), Chart 8 shows that our estimates and the observed liquidity premia are broadly comparable.

In stress times, the 'shadow' liquidity premia are much lower in 2018 compared to 2006, because dealers in 2018 hold much more capital and hence their funding costs rise less as market stress increases. In addition, market dislocation occurs at a higher level of VIX (and hence is less likely) in 2018 than in

[5] Using historical values of VIX here does not account for the fact that, if post-crisis regulations have made the financial system as a whole safer, the probability of observing extreme VIX values may be lower going forward.

2006, because dealers' balance sheet capacity runs out later in 2018, as shown in Chart 6. However, the difference between the points of market dislocation in 2006 and 2018 is small for our central calibration (Table 1), driven by the fact that dealers in 2018 are also subject to a much higher leverage ratio requirement, as mentioned previously. In our model, this requirement includes a 3% minimum requirement plus a 1% buffer (a weighted average of current UK and US requirements).

Chart 7: Estimated liquidity premia for different regulation and VIX

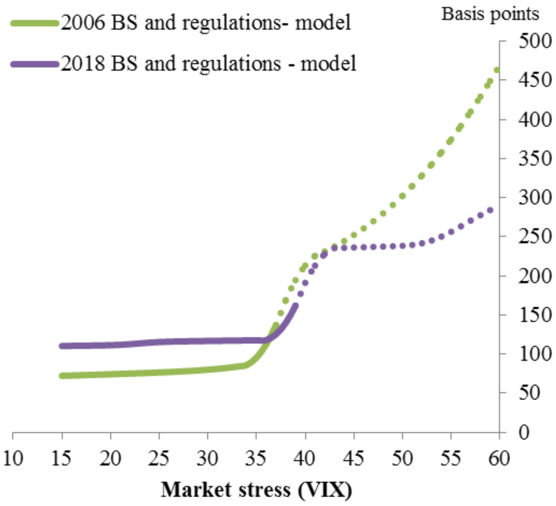


Chart 8: Estimated liquidity premia vs. observed liquidity premia

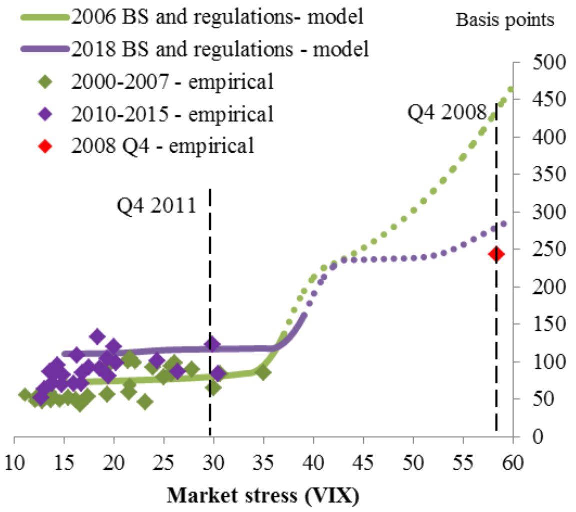


Table 1: Impact of regulatory reforms on corporate bond liquidity risk premia

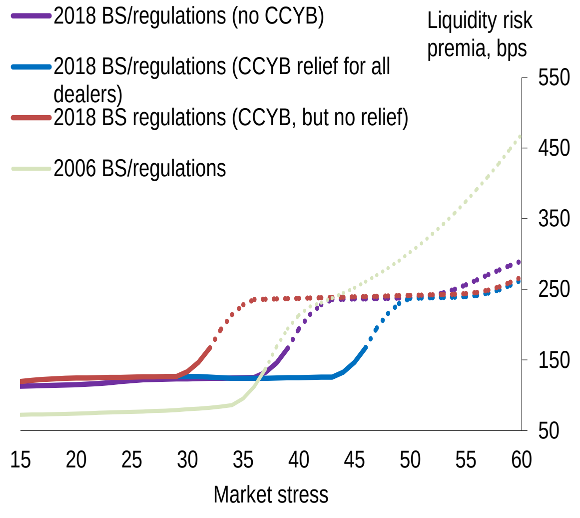
Average (weighted by probability density of VIX)	Dealer spare capacity ($bn)	Dealer funding cost	Repo spread	VIX when balance sheet capacity runs out	Liquidity premia (bps)	Change in liquidity premia relative to 2006 (bps)
2006 balance sheet and regulation	1466	0.64%	0.01%	38	75	-
2018 balance sheet and regulation	962	0.54%	0.75%	40	115	40

We have also applied our framework to the UK government bond (gilt) market (calibration details can be found in Appendix I). We find that liquidity premia on gilts are around 8 bps higher in normal times post-regulation. The impact of regulation on gilts is smaller than that on corporate bonds, because the gilt market is much more liquid and gilt holdings are subject to lower risk-weighted capital requirements and liquidity requirements. We do not estimate gilt liquidity premia under market stress, given that we expect them to be compressed due to safe haven flows from investors, which are not included in our model.

The framework presented above could be useful for assessing the impact of various policies, including those aimed at improving market resilience during the times of stress, such as countercyclical capital requirements. For example, if we assume that during normal times dealers accumulate a leverage ratio buffer of around 0.9%,[6] this would imply higher capital requirements and slightly higher (by less than 10 bps) liquidity risk premia in normal times (Chart 9).[7] If this buffer is released during stress, the market is estimated to dislocate when VIX reaches 47 (solid blue line, Chart 9), much later than the baseline scenario with no countercyclical buffers (solid purple line, Chart 9). This suggests that building countercyclical leverage ratio buffers that can be released during stress could help increase the potential balance sheet capacity of dealers and support the resilience of markets.

The ultimate success of such countercyclical policies would depend on the extent to which dealers make use of the additional capacity released by regulators. For example, dealers may choose not to run down their buffers if they were concerned about a potential increase in funding costs if they disclose a lower leverage ratio to the public. However, there are a couple of reasons one might expect dealers to use their leverage ratio buffers when released during stress, at least to some extent. First, dealers may need to continue providing market-making services due to market-making obligations or franchise value concerns. Second, higher leverage may not lead to an increase in funding costs if it arises from an increase in low-risk activities (e.g. holdings of government bonds or repos). Third, dealer transactions are generally of a short-term nature (say, as compared to long-term mortgages or other loans), so dealers could easily scale down their balance sheets in case countercyclical capital requirements go back up.

Chart 9: Estimated liquidity premia with countercyclical leverage ratio buffer



7. Cost-benefit analysis of regulation

As mentioned previously, a number of studies have been carried out to assess the real economy impact of post-crisis changes in regulations. However, these mostly focussed on estimating how changing regulatory requirements might affect the rate at which banks lend to households and non-financial companies - that is how any cost to banks of new regulations are ‘passed on’ to their borrowers. In contrast, our estimates allow us to consider how regulation affects the ability of dealer banks to provide

[6] Based on FPC guidance, a risk-weighted capital buffer of 2.5% would correspond to a countercyclical leverage ratio buffer of around 0.9% (35% of 2.5%).
[7] Here we also assume that in the presence of a countercyclical leverage buffer, dealers would choose to hold smaller voluntary management buffers on top of their regulatory requirements, knowing that the buffer requirements will likely be released in stress.

services to support market liquidity, and hence the impact of bank regulation on capital markets channels, as well as bank lending channels

In doing so, we draw on analysis and estimates from earlier studies of the benefits from regulations in reducing financial crises and the costs arising from higher bank lending spreads. To this we add our estimates of costs arising from higher corporate bond and government bond liquidity premia. Throughout what follows we focus only on the impact of regulation on 'steady-state' GDP, ignoring any temporary effects that might occur.

Benefits of regulation

To estimate the benefits of regulation in reducing the costs of financial crises, we use the approach developed in Brooke et al (2015). In particular, we define the benefits arising from the introduction of the expected set of regulatory reforms as the reduction in the expected cost of crises before and after new regulations. The pre-crisis regulatory set comprises a Tier 1 capital ratio of 8% and no total loss-absorbing capacity requirements (TLAC) and the probability of financial crisis is estimated at 1.2% and the net present value cost of a crisis is 73% of GDP. Post-regulatory reforms, assuming a Tier 1 capital ratio of 11% and implementation of TLAC, result in an estimated probability of financial crisis of 0.5% and the net present value cost of a crisis of 43% of GDP. Calculating the difference between the expected cost of crises before and after the regulatory reforms, gives us a total benefit of post-crisis regulatory reforms of around 65 bps (see Table 2).

Costs of regulation

Costs of regulation arise from two key channels:

- ***bank lending channel*** (higher bank lending spreads);
- ***capital markets channel*** (higher government and corporate bond liquidity risk premia).

As we take account of the impact of TLAC in our estimates of benefits of regulation in reducing the costs of crises, we also take account of the regulatory costs of TLAC.

To quantify regulatory costs via the ***bank lending channel***, we assume that for a 1 percentage point increase in the Tier 1 capital ratio lending spreads rise by around 5 bps (as in Brooke et al (2015)). In order to isolate the impact of regulation on lending spreads on the banking book (rather than banks' trading books), we scale the increase in spreads proportionately (we estimate the share of risk-weighted assets on trading book positions in the overall risk-weighted assets of the bank to be 12%). The result is that the increase in Tier 1 capital ratios from 8% to 11% leads to a 12.5bps increase in bank lending spreads (Table 2).

This result assumes that regulation leads banks to substitute more expensive equity for cheaper debt funding and that banks pass on those costs to the borrowers via higher bank lending spreads. This estimate also accounts for the positive impact that a higher share of equity has on reducing the cost of debt for firms (Modigliani-Miller effect).

In order to estimate the impact of higher bank lending spreads on corporate borrowing, investment and ultimately GDP we use the results of a number of semi-structural macroeconomic models, calibrated for the United Kingdom (as in Brooke et al. (2015). In particular, higher bank lending spreads could impact steady-state GDP by:

- prompting corporates to substitute more expensive capital for labour, which leads to lower long-term capital stock;
- having a negative impact on total factor productivity (TFP).

We estimate that for a permanent 10 bps increase in bank lending spreads, steady-state GDP could be 1bps lower due to the capital stock channel and up to 18 bps lower if we account for both TFP and capital stock channels. Following Brooke et al (2015), our central case uses the average of the two approaches, which implies that for a 12.5 bps increase in bank lending spreads, the costs to the steady-state GDP are around 12 bps (Table 2).

The costs of regulation via the ***capital markets channel*** arise from higher liquidity risk premia in dealer-intermediated markets (corporate and government bonds) leading to higher borrowing costs for corporates.

We estimated earlier that post-regulation corporate bond liquidity risk premia could on average (for different levels of market stress) be 40 bps higher than pre-crisis. Corporate bonds currently account for roughly 8.5% of the capital structure of UK private non-financial corporations (PNFCs). Higher corporate bond liquidity risk premia would, other things equal, lead to an increase in the corporate weighted average cost of capital and ultimately to a lower capital stock and lower steady-state GDP. Also, corporate bonds account for around 10% of banks' capital structures and such an increase in bank funding costs is likely to be passed on to borrowers via higher bank lending rates with the associated impact on steady-state GDP. In total, we estimate that a 40 bps increase in corporate bond liquidity risk premia leads to a roughly 5 bps decline in steady-state GDP (Table 2).

Calibrating the model to consider the impact of changes in dealer intermediation on liquidity premia in the gilt market (Sterling-denominated, UK government bonds), we generate an increase in gilt liquidity risk premia post-regulation of 8 bps. Given that the government bond yield curve sets the benchmark for pricing in other markets, we assume that this would result in an increase of similar magnitude in the cost of equity and bond funding for both UK PNFCs and banks. Non-bank funding accounts for around 70% in the capital structure of UK PNFCs and equity and bonds account for around 20% of the capital structure of UK banks. Thus, we estimate that GDP costs from higher gilt liquidity risk premia are likely to be around 3 bps of steady-state GDP (Table 2).

Finally, we quantify the costs of higher TLAC requirements. To do so we use the estimates from the Financial Stability Board (FSB). The FSB conducted a survey of global systemically important banks (G-SIBs) on how much eligible instruments they would need to raise to meet TLAC requirements, which once raised would increase their weighted average cost of funding. Assuming that G-SIBs recover these costs by increasing their lending spreads, this is estimated to lead to an increase in lending spreads of around 3.2bps globally (once adjusted for the share of G-SIBs in the global banking system), which in turn would translate to a steady-state output loss of around 2.8bps.

Bringing the estimates of the costs and benefits of post-crisis regulation together we can conclude, that in our central case the package of regulatory reforms results in a net benefit of about 45 bps of steady-state GDP.

Table 2: Cost-benefit analysis of post-crisis regulatory reforms (central calibration)

Type of cost/benefit	Value	Units	Comment
BENEFITS			
Probability of crises (pre-regulatory reforms)	1.2%		Brooke et al (2015)
Cost of crises (pre-regulatory reforms)	73%	of annual GDP	Brooke et al (2015)
Expected cost of crisis (pre-regulatory reforms)	***87.6***	**bps, of steady-state GDP**	
Probability of crises (post-regulatory reforms, incl. TLAC)	0.5%		Brooke et al (2015)
Cost of crises (pre-regulatory reforms, incl. TLAC)	43%	of annual GDP	Brooke et al (2015)
Expected cost of crisis (pre-regulatory reforms)	***21.5***	**bps, of steady-state GDP**	
Benefit (of regulation due to reduction in expected cost of crises)	***66.1***	*bps, of steady-state GDP*	
COSTS			
Increase in bank lending spreads	12.4	bps	Brooke et al (2015), for 3% increase in risk-weighted Tier 1 capital ratio, adjusted for trading book
GDP cost of higher bank lending spreads	***11.8***	***bps, of steady-state GDP***	Average of capital stock and full (incl. TFP) multipliers
Increase in corporate bond liquidity premia	41.0	bps	As derived from partial equilibrium model, conservative estimate
GDP cost of higher corporate bond liquidity premia	***4.8***	**bps, of steady-state GDP**	Impact of higher bond borrowing costs on capital stock and pass-through to bank lending rates
Increase in government bond liquidity premia	8.0	bps	As derived from partial equilibrium model, conservative estimate
GDP cost of higher government bond liquidity premia	**2.9**	**bps, of steady-state GDP**	Impact of higher government bond yields on cost of market-based finance for corporates/banks
Increase in bank lending spreads due to TLAC	3.2	bps	FSB (2015)
GDP cost of TLAC	***2.8***	**bps, of steady-state GDP**	FSB (2015) multipliers
Total costs of regulatory reforms	***22.3***	***bps, of steady-state GDP***	
NET BENEFIT	**43.8**	***bps, of steady-state GDP***	

The estimates of both costs and benefits of regulation are sensitive to the assumptions made, as is the overall estimate of net benefits. In particular, to quantify benefits we use Brooke et al (2015) estimates of the probability of crisis and the costs of crisis. For comparison, the Basel Committee on Banking Supervision (2010) estimated a much larger decrease in the probability of crisis due to regulatory reforms (from 6.3% to 2.9%), which would imply a significantly larger net benefit.

We also judge there to be two keys areas of uncertainty that might bias our estimates of the costs of regulatory reforms:

(i) our model-based estimates of corporate and government bond liquidity risk premia could be 'conservative'. In our central case we assume that dealers fully price in all the regulatory costs at the transaction level, both for their repo and market-making businesses. However, this approach does not account for the possible innovations and other actions that dealers might undertake to lower the regulatory costs of such activities (e.g. more efficient netting or capital management). See Appendix II for an analysis of the sensitivity of our results to assumptions about pricing of regulatory costs.

(ii) the estimates of higher bank lending spreads on steady-state GDP might overestimate the extent to which total factor productivity declines. Our central case estimates use the average of two approaches, one with the capital stock effect only and the other with additional TFP effects. However, if we believe that the rise in bank lending spreads due to regulatory changes is not sufficient to cause a decline in TFP (e.g. due to potential non-linear relationship between the two), then our total costs of regulation could be much lower. In particular, the total cost of regulatory reforms would fall from 23 bps to 5 bps.

8. Conclusion

We develop a model of dealer intermediation in bond markets that takes account of how changing regulatory requirements since the financial crisis, in particular, the introduction of minimum leverage ratio requirements affects the cost and ability of dealer banks to provide intermediation services. We estimate the impact of changes to the provision of dealer services on liquidity premia in bond markets, for both normal and stressed times, both before and after changes in regulation. We find that at low levels of stress, liquidity premia are estimated to be around 40bps higher than pre-crisis, suggesting a potential cost to the real economy of the post-crisis regulatory changes. But as stress increases, the enhanced resilience of dealer banks following regulatory changes keeps their funding costs lower. So the degree to which liquidity premia spike higher in stress is smaller than pre-crisis. We also estimate that the level of market stress at which dealers run out of balance sheet capacity with which to provide liquidity is slightly higher post-crisis, suggesting a small positive benefit of regulation on the resilience of market liquidity. In turn this suggests the provision of market-based finance to real economy borrowers (such as corporates) is more resilient.

We also map the estimated changes in liquidity premia to GDP, via their impact on the cost of borrowing for corporates in the real economy. The results of this mapping suggest that under normal market conditions there may be a greater cost of regulation via corporate bond markets than incorporated in earlier studies. However, once offset against the benefits of greater dealer resilience, including the benefits to market functioning, there remain net benefits to new regulations.

There are some limitations to the model to be considered when interpreting the results. First, the model assumes that dealers pass through the full regulatory costs of transactions as if all regulatory constraints are binding. Second, the model does not account for the potential market innovations, such as a move towards agency-based (rather than principal-based) models of market intermediation that could reduce reliance of fixed income markets on dealer balance sheets. Given this, the estimates of liquidity risk premia from the model could be seen as ‘conservative’ or ‘upper-bound’ estimate.

The model also misses some important features of the real world. For example, it does not take into account that other investor might behave counter-cyclically during stress. It also does not consider how higher intermediation costs in normal times might act to limit excessive risk taking in upswings, reducing the probability of stress.

Nonetheless, we believe this model provides a framework to assess the impact of regulations on capital markets (market-based finance) that provides an important complement to earlier studies considering the impact of regulation on bank-lending channels.

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Appendix I: Calibration of Model Parameters

Corporate bonds

Parameters	Description	Value	Calibration approach
Q	size of sale in $bn	15	We calculated the expected monthly net outflow from US corporate bond mutual funds (source: ICI) and then scaled to the global market.
VaR	market risk VaR (10 day 99%)	$0.001 \times \text{VIX} - 0.0021$	For a given bond index, the VaR is calculated as $\frac{D}{100} \times \sigma \times 2.33$, where D is the modified duration of the bond proxied by average maturity and σ is the standard derivation of 10-day changes in bond yield. The global VaR is calculated as the average VaR across USD, EUR and GBP bond indices, weighted by their market size. The VaR is assumed to be a linear function of VIX, estimated based on historical data (Datastream).
S	market maker bid-ask spread	12bps	MarketAxess
DC_M	market maker desk-level balance sheet (% of total)	2006: 11.1% 2018: 3.1%	Based on major UK banks' balance sheets
DC_R	repo dealer desk-level balance sheet (% of total)	2006: 0.37% 2018: 0.15%	Based on major UK banks' balance sheets
marketRiskCharge	market risk capital charge	2006: VaR $\times$ 3 Basel 2.5: $(\text{VaR} + 0.0129 \times 2) \times 3 + 0.0129 \times 3$ FRTB: $(0.0129 \times 3) \times 3 \times 0.64 + 0.0129 \times 3 \times 1.55$	The market risk capital charge for an unhedged position of bonds, given its VaR, is $3 \times VaR$ in Basel II (2006). The capital charge in Basel 2.5 is $3 \times (VaR + Stressed\ VaR) + IRC$, where stressed VaR is assumed to be 2 times the VaR, and the IRC (incremental risk charge) is assumed to be the same as stressed VaR, based on average data from UK banks. The stressed VaR does not vary with VIX. The capital charge in FRTB is $ES + DRC$ where ES is assumed to be 64% of $3 \times (VaR + Stressed\ VaR)$ and DRC is assumed to be 155% of IRC, according to Basel QIS. ES does not vary with VIX.
capitalRatio	tier 1 capital ratio requirement	2006: 4% 2018: 11%	
RWA	risk-weighted capital requirement	marketRiskCharge$\times$12.5$\times$ capitalRatio	
LR	leverage ratio requirement	2006: 1.5% (internal) 2018: 4%	We assume that 2006 dealers have an internal minimum leverage ratio of 1.5%. The leverage ratio requirement in 2018 is a weighted average of requirements in corresponding jurisdictions of global dealers.
LCRcap	LCR inflow cap	2006: 1 2018: 0.75	Basel Committee on Banking Supervision. We assume that the LCR inflow cap binds on the dealers.
LABcost	cost of borrowing LAB	17bps	Based on the cost of borrowing government bonds in the securities lending market
NSFRrevr	NSFR RSF factor for reverse repo	2006: 0% 2018: 14%	Weighted average of Basel requirements
NSFRmm	NSFR RSF factor for corporate bonds	2006: 0% 2018: 43%	Weighted average of Basel requirements
termPremium	term premium for repo >1Y	25bps	Based on yield curves
LCR	cost of LCR	$(1 - \text{LCRcap}) \times \text{LABcost}$	LCR is equal to $(1 - \text{LCRcap}) \times \text{LABcost}$, assuming that the inflow cap binds.

$NSFR$	cost of NSFR	For market-making: $Q_M \times max(0, \text{NSFRmm} - E/BS) \times \text{termPremium}$ For repo provision: $Q_M \times max(0, \text{NSFRrevr} - E/BS) \times \text{termPremium}$	The cost of NSFR is different for market making versus repo provision. Equity capital also qualifies as stable funding and therefore needs to be deducted in the calculation.
OL	optimal leverage		This is based on a bank maximising its value in a barrier option model. The barrier is the minimum leverage ratio requirement and the stock return (similar to bank return on assets) follows a normal distribution with mean roaMean and standard derivation roaVol.
BS	current leverage exposure	2006: 12717 2018: 11306	SNL
E	current tier 1 capital	2006: 283 2018: 621 Changes with VIX: ((ΔVIX×0.0223-ΔVIX^2×0.0115) /100	According to SNL and our estimates, dealer leverage is around 45 in 2006 and 18.2 in 2018. We assume a non-linear relationship between return on equity and market stress, estimated based on historical data. As a result, dealer capital will decrease with VIX when VIX is high.
PD	probability of dealer default		PD is estimated based on a simple Merton model of a bank with equity equal to E, total assets equal to BS, and return on assets following a normal distribution with mean roaMean and standard derivation roaVol.
U	proportion of position to hedge	2006: 0.5 2018: 0.4	We assume dealers hedge half of their inventory in 2006 based on Naik and Yadav (2003). In 2018, the hedging ratio is lower give less liquid CDS markets.
hedgingImpact	price impact of hedging	0.005 per \$1bn	We assume that the price impact of hedging in the CDS market is around 50bps per \$1bn notional, based on Gehde-Trapp et al (2015).
hedgingSpread	spread cost of hedging (IRS+CDS)	$6.5 \times 5/2$	We assume the bid-ask spreads in the interest rate derivatives market and the CDS market are 0.5bps and 6bps respectively, according to ISDA (2011) and Arakelyan and Serrano (2012). The actual cost the dealer needs to pay is equal to $S \times M/2$, where S is the bid-ask spread, M is the maturity of the hedging contract (assumed to be five years) and the product is divided by 2 to get the distance between the ask-price and the mid-price.
hedgingPremium	CDS premium	$(65.195 + 1.4272 \times \text{VIX})/10000$	The cost of paying the CDS premium is assumed to be a linear function of market stress based on regression estimates between the average of CDX.NA.IG and iTraxx Europe indices and the VIX index.
HC	hedging cost	$HP_M \times$(hedgingPremium+ hedgingImpact $\times Q_M \times U$)+ hedgingSpread	Hedging costs include bid-ask spreads on derivatives, as well as CDS protection premium paid (increasing with the size of hedged position).
Q_M/HP_M	daily liquidation amount by market maker	\$260m	Based on Begalle et al (2013) and estimates based on TRACE data
C	cost of capital (pre-tax)	$0.1/(1-0.3)$	When spare capital is available, 10% (based on King (2009)) divided by (1-tax rate) where tax rate is 30%
C^*	cost of capital after desk-level capacity runs out	16.7%	Historical average RoE of Morgan Stanley and Goldman Sachs (SNL).

RC	cost of capital reallocation	$\text{roaMean}/0.0427$	The average return on assets of dealers discounted by their historical weighted average cost of capital (SNL)
freqSale	frequency of outflows in a given year	3	US corporate bond mutual funds have net monthly outflows roughly 3 times a year (source: ICI).
roaMean	mean of dealer RoA		Based on historical RoA from Morgan Staley and Goldman Sachs (SNL).
roaVol	volatility of dealer RoA	$(\text{VIX} \times 0.0114 + 0.08)/100$	The volatility of dealer return on assets is assumed to be a linear function of market stress and calibrated based on a regression between VIX and historical RoA from Morgan Staley and Goldman Sachs (SNL).
$HFLA$	spare liquid assets of fixed income hedge funds	40	FCA Hedge Fund Survey and SEC Private Fund Statistics
h_H	haircut on hedge fund repo borrowing	$VAR + 0.094$	Estimated based on Committee on the Global Financial System (2010)
$1 - LGD$	recovery rate of dealer debt	0.3756	Moody's
h_M	haircut on dealer repo borrowing	$VAR + 2.2 \times PD$	Estimated based on Committee on the Global Financial System (2010)
r_f	Risk-free interest rate	0.5%	

UK government bonds

Parameters	**Description**	**Value**	**Calibration approach**
Q	size of sale in \$bn	2.7	We calculated the expected monthly net outflow from US government bond mutual funds (source: ICI) and then scaled to the gilt market.
VaR	market risk VaR (10 day 99%)	$0.0007 \times \text{VIX} + 0.0127$	For a given bond index, the VaR is calculated as $\frac{D}{100} \times \sigma \times 2.33$, where D is the modified duration of the bond proxied by average maturity and σ is the standard derivation of 10-day changes in bond yield. The VaR is assumed to be a linear function of VIX, estimated based on historical data (Datastream).
S	market maker bid-ask spread	0.11bps	Bloomberg
DC_M	market maker desk-level balance sheet (% of total)	2006: 6.7% 2018: 5.5%	Based on major UK banks' balance sheets
DC_R	repo dealer desk-level balance sheet (% of total)	2006: 16% 2018: 10%	Based on major UK banks' balance sheets
marketRiskCharge	market risk capital charge	2006: VaR × 3 FRTB: $0.0232 \times 3 \times 0.64$	The market risk capital charge for an unhedged position of bonds, given its VaR, is $3 \times VaR$ in Basel II (2006). The capital charge in FRTB is $ES + DRC$ where ES is assumed to be 64% of $3 \times (VaR + Stressed\ VaR)$. ES does not vary with VIX.
capitalRatio	tier 1 capital ratio requirement	Same as corporate bonds	
RWA	risk-weighted capital requirement	Same as corporate bonds	
LR	leverage ratio requirement	Same as corporate bonds	
NSFRrevr	NSFR RSF factor for reverse repo	2006: 0% 2018: 10%	Weighted average of Basel requirements

NSFRmm	NSFR RSF factor for government bonds	2006: 0% 2018: 5%	Weighted average of Basel requirements
termPremium	term premium for repo >1Y	Same as corporate bonds	
LCR	cost of LCR	0	The cost of LCR is zero for government bonds.
$NSFR$	cost of NSFR	Same as corporate bonds	
OL	optimal leverage	Same as corporate bonds	
BS	current leverage exposure	Same as corporate bonds	
E	current tier 1 capital	Same as corporate bonds	
PD	probability of dealer default	Same as corporate bonds	
U	proportion of position to hedge	0.5	We assume dealers hedge half of their inventory in 2006 based on Naik and Yadav (2003).
hedgingImpact	price impact of hedging	0.001 per \$1bn	Based on Amihud measures calculated on transaction data of interest rate derivatives.
hedgingSpread	spread cost of hedging (IRS+CDS)	$0.5 \times 5/2$	We assume the bid-ask spread in the interest rate derivatives market is 0.5bps, according to ISDA (2011). The actual cost the dealer needs to pay is equal to $S \times M/2$, where S is the bid-ask spread, M is the maturity of the hedging contract (assumed to be five years) and the product is divided by 2 to get the distance between the ask-price and the mid-price.
HC	hedging cost	$HP_M \times$ hedgingImpact $\times Q_M \times U +$ hedgingSpread	
Q_M/HP_M	daily liquidation amount by market maker	\$1bn	Based on Begalle et al (2013) and scaled to the gilt market
C	cost of capital (pre-tax)	Same as corporate bonds	
C^*	cost of capital after desk-level capacity runs out	Same as corporate bonds	
freqSale	frequency of outflows in a given year	6	US government bond mutual funds have net monthly outflows roughly 3 times a year (source: ICI).
roaMean	mean of dealer RoA	Same as corporate bonds	
roaVol	volatility of dealer RoA	Same as corporate bonds	
$HFLA$	spare liquid assets of fixed income hedge funds	24	
h_H	haircut on hedge fund repo borrowing	$VAR + 0.02$	
$1 - LGD$	recovery rate of dealer debt	Same as corporate bonds	
h_M	haircut on dealer repo borrowing	$VAR + 0.5 \times PD$	
r_f	Risk-free interest rate	Same as corporate bonds	

Appendix II: Sensitivity Analysis

We explore the sensitivity of model results to the following:

1) The assumption that all regulatory costs are priced in at the transaction level;
2) The calibration of the voluntary buffer that dealers choose to hold on top of their regulatory minima requirements.

Pricing of regulatory costs

In our model we assume that the leverage ratio is the binding constraint for the representative dealer, and that the associated regulatory (capital) costs of conducting new business are priced in at the transaction level. This holds for both repo and market-making. For example, if a dealer sought to maintain a target post-tax return on equity for gilt repo activity of 10% and assuming a leverage ratio requirement of 4%, an increase in the gilt repo bid-offer spread of around 55 basis points could be warranted relative to a counterfactual without a leverage ratio. However, firms that are unconstrained by the leverage ratio at the consolidated level (which is likely to be the case for universal banks) would not need to assume that the capital deployed to repo business is 4% of exposures, and therefore the actual increase in the gilt repo bid-offer spread could be lower than 55 basis points.

Given this, we test the sensitivity of our estimates of liquidity risk premia for global corporate bonds and gilts to varying assumptions regarding the maximum level of bid-offer spreads that a repo dealer can charge, which we take as a proxy for the extent to which the regulatory costs are priced in. For example, if we assume that regulatory costs are priced in to such an extent that repo bid-offer spreads are capped at 20 bps, then liquidity risk premia in corporate bond and gilt markets would be 10 bps and 2 bps lower respectively, as compared to the case without a cap on repo spreads (**Chart A**).

Chart A: Repo spread and liquidity risk premia

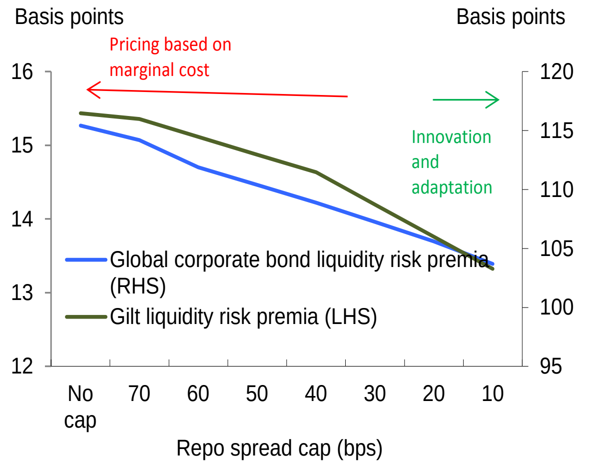
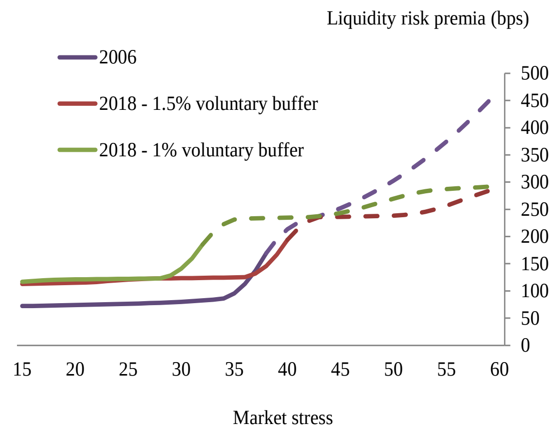


Chart B: Voluntary capital buffer and market dislocation



Voluntary capital buffers and the point of corporate bond market dislocation

As mentioned briefly in Section 5, the point at which corporate bond market is expected to dislocate is sensitive to calibration. In particular, it is most sensitive to the size of voluntary capital buffer which dealers choose to hold on top of their minimum leverage ratio requirement.

In our central calibration, we assume that once all planned regulatory reforms are fully implemented global dealers on average will be required to have a minimum 4% leverage ratio (which includes buffers) and that they choose to hold a 1.5% voluntary buffer on top of that,[8] which brings their total leverage ratio to 5.5%. In this case, the market is expected to dislocate at a slightly higher level of market stress in the post-crisis regulatory environment (at VIX = 40% vs. 38% pre-crisis) (**Chart B** red and purple lines). If we assume that banks instead choose to hold only 1% buffer on top of the regulatory minima (which is close to global dealers' current position), then the corporate bond market is expected to dislocate earlier than pre-crisis (at VIX less than 35%) (**Chart B**, green line). That said, as outlined in earlier in the paper, the level of market stress at which corporate bond market is expected to dislocate can be increased materially if leverage ratio buffers are implemented and become usable during the periods of stress.

[8] This is around a third of the voluntary buffers held by UK banks historically in the risk-weighted capital regime.