LIQUIDITY RISK ARISING FROM MARGIN REQUIREMENTS

by

Jessy Shanshan Hu (CID: 01231581)

Department of Mathematics

Imperial College London

London SW7 2AZ

United Kingdom

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Declaration

The work contained in this thesis is my own work unless otherwise stated.

Signature and date:

Abstract

The financial crisis has led regulators to make central clearing for standardized over-the-counter derivatives mandatory in order to minimize counterparty risk as well as increase transparency in the OTC market. More recently, margin requirements have been introduced for bilateral OTC derivatives. We examine in this report the impact of these new regulatory requirements on banks' liquidity risk and present a framework for analyzing the impact of daily margin calls on the liquidity risk of banks. We have used data on the composition of the derivative portfolios of four major US banks to construct proxy portfolios and calculate the margin payment cash flows arising from these portfolios.

Our analysis reveals that although assets subject to margin payments only make up around 20 - 30% of the banks' balance sheet, the proportion of the banks' liquid assets needed to settle margin payments can put a significant strain on banks' liquid assets.

Acknowledgements

I would first like to thank my supervisor Professor Rama Cont not only for his invaluable insights and suggestions, but also for inspiring me to accept nothing less than excellence and to question and push myself. His grasp of the current financial and regulatory environment have truly impressed me and helped me gain understanding of matters far exceeding the subject of this thesis.

I would also like to thank my friends for their helpful comments and my parents, who have always supported me and without whom I would not be where I am today.

Contents

1 Introduction

1.1 Events leading to the introduction of margin payments to more and more products

In the aftermath of the financial crisis of 2007/8 which included the (almost) default of large financial institutions such as Lehman Brothers, Bear Stearns and AIG, regulators were determined to prevent a similar event of occurring again in the future. The new regulatory framework, therefore, does not only require banks to hold a certain amount of Tier 1 capital relative to their risk weighted assets, but also introduced measures to make the over-the-counter (OTC) derivatives market more resilient to future slumps.

Since OTC derivative contracts are private and thus non-standardized, the OTC market is much less transparent than exchanges. Collateralized debt obligations (CDOs) for example, which have played a major role during the financial crisis, were one of the products solely traded in the OTC market. In this case, the lack of transparency resulted in pricing uncertainties and ended up in a vicious circle of buyers withdrawing and prices falling. The lack of transparency also contributed to the domino effect that followed the default of Lehman Brothers: Since nobody knew how much of the contaminated mortgage-backed securities was owned by each financial institution, banks refused to lend each other money and liquidity dried up.

As a result, the G20 leaders agreed that "All standardized OTC derivative contracts should be traded on exchanges or electronic trading platforms [...] and cleared through central counterparties [...]" ([29]). In the United States, the Dodd-Frank Wall Street Reform and Consumer Protection Act of 2010 has made central clearing mandatory for all standardized over the counter derivatives ([17]). In the EU, the clearing obligation under article 4 of EMIR has taken effect on 21 June 2016, which mandates clearing for certain interest rate and credit default derivative contracts ([25]).

The table below gives an overview over clearing obligations for the United States, Japan and the EU for the following products:

- IRS - 'Plain vanilla' interest rate swaps
- Basis - Basis swaps where both cashflows are based on variable rates
- FRAs - Forward rate agreements
- OIS - Swaps based on the overnight index
- CDS indices - CDS index contracts providing protection against the default of any member of a list of entities

which is taken from [43]:

Table A Clearing obligations for the United States, Japan and the EU[(a)]

Jurisdiction	Asset class	Effective from	Currencies[(b)]	Maturities
United States	IRS	11 March 2013	USD, EUR, GBP, JPY	28 days–50 years (30 years for JPY)
	Basis			
	FRA			3 days–3 years
	OIS		USD, EUR, GBP	7 days–2 years
	CDS indices		USD, EUR	Mainly 5 years, some 3, 7, 10 years
Japan	IRS	1 November 2012	JPY	Up to 30 years
	Basis			
	IRS	1 July 2014	JPY/EUR	Up to 10 years
	Basis			
	CDS indices	1 November 2012	JPY	5 years[(c)]
EU	*IRS*	*2016*	*USD, EUR, GBP, JPY*	*28 days–50 years (30 years for JPY)*
	Basis			
	FRA		*USD, EUR, GBP*	*3 days–3 years*
	OIS			*7 days–3 years*
	CDS indices		*EUR*	*5 years*
	IRS	*In consultation*	*SEK*	*28 days–15 years*
			CZK, DKK, HUF, NOK, PLN	*28 days–5 years*
	FRA		*SEK*	*3 days–2 years*
			NOK, PLN	*3 days–1 year*

(a) The complete list of clearing obligations already in place around the world also includes: China (IRS), Korea (IRS) and India (FX Forwards).
(b) Currency abbreviations: USD = US dollar, EUR = Euro, GBP = Pound sterling, JPY = Japanese yen, SEK = Swedish krona, CZK = Czech koruna, DKK = Danish krone, HUF = Hungarian forint, NOK = Norwegian krone and PLN = Polish zloty.
(c) For Japanese CDS index contracts, maturity is not specified in primary legislation, but currently only five-year contracts are centrally cleared.

Figure 1: Clearing Obligations for the United States, Japan and the EU as of 2015 Q3

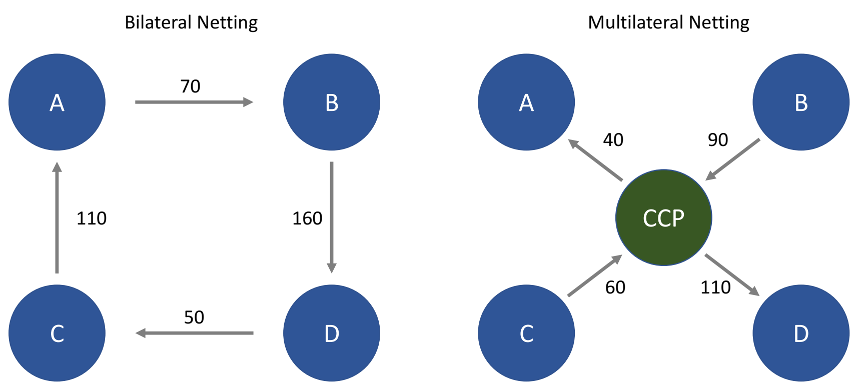
Besides the requirements given above, the Basel Committee also requires "appropriate margining practices [. . .] with respect to all derivatives transactions that are not cleared by CCPs" ([9]).

We will now describe what central counterparties (CCPs) are, what benefits can be gained and which risks to consider when increasing the volume cleared through such CCPs.

1.2 An overview of central counterparties and their functions

For exchange traded products, central counterparties (CCPs) have already existed for over a century ([29]). Each entity that clears its products through a CCP is called a clearing member. In each centrally cleared trade, the central counterparty assumes an intermediary role between the trading parties and hence acts as a seller to every buyer and as a buyer to every seller. The clearing members are required to make an initial margin payment to the CCP at the beginning of each trade followed by variation margin payments during the life of the trade. Hereby variation margins reflect the change in trade mark-to-market value between the days on which the variation margin is paid. Variation margin payments are thus paid to the entity whose exposure has increased due to market movements. While the variation margins received and paid to the CCP by various clearing members cancel each other out - there are always two clearing members to each trade - , the initial margins are held by the CCP and act as an insurance against the default of clearing members.

The central clearing process allows the netting of all trades executed through CCPs for each clearing member as seen in the graph below:



A downside however is that the multilateral netting can only occur with products that are cleared via the same CCP. Hence the multilateral netting comes at the expense of reduced bilateral netting across asset classes. Interest rate swaps for example are cleared through LCH Clearnet, credit default swaps though CME and fixed-income OTC derivatives through Fixed Income Clearing Corp ([17]). Duffie and Zhu have shown that adding a central counterparty can reduce netting efficiency ([19]). However, Cont and Kokholm have produced evidence against this by showing that when adjusting model parameters to more plausible and realistic values we do observe a reduction in total expected exposure when using CCPs to clear derivatives ([17]).

In the event of default of one clearing member, the central counterparty steps in and continues to make variation margin payments to all non-defaulted clearing members and closes out all the positions of the defaulting clearing member. The first financial resource the CCP can draw on to pay the remaining clearing members are the initial margin payments of the defaulted clearing member. If those do not suffice, the central counterparty can use the defaulting member's default fund contribution. The default fund is a "mutualized pool of resources that is available to cover defaults" ([45]). Each member's default fund contribution size usually depends on its trade volume and/or the overall initial margin requirement.
If the loss due to the clearing member's default exceeds initial margin payments and the member's default fund contribution, the CCP "makes a limited (capped) contribution to offset the remaining loss" ([16]). More specifically, EMIR requires CCPs to contribute at least 25% of their minimum regulatory capital requirement in these cases, which is often referred to as "skin-in-the-game". ([26]). After all these resources are depleted, the default fund contribution of other members may be used ([16]).

If the loss exceeds the size of all the above mentioned financial resources, the CCP may take to either of the following recovery measures ([16]):

- request an additional default fund contribution from non-defaulting members
- implement variation margin haircutting: non-defaulting members continue to pay variation margins owed to the CCP in full while the CCP only transfers

part of these margin payments to the respective counterparties

If these measures fail to cover the loss caused by the defaulting clearing member or if the CCP or its members choose not to proceed with any recovery measures, the CCP may enter failure resolution ([16]).
This way of dealing with defaulting clearing members reduces the contagion risk within the financial system and the counterparty risk for each clearing member since their new counterparty is now the CCP. Contagion risk might also be reduced in another sense as the introduction of a CCP could lower the cases where "rumor becomes reality": If an institution is thought to be experiencing financial difficulties, its counterparties might demand larger collateral and margin payments as insurance against default. This will drain the institution's resources and it may indeed start to struggle. Since a CCP should ignore rumors when calculating margin payments, this kind of situation should be less likely to occur ([21]).

Furthermore, the central clearing process brings more transparency into OTC derivative markets and trades will be easier to unwind. This makes it also easier for regulators to observe potential risks within the OTC derivative markets and act accordingly to mitigate them.

Even though some argue that central clearing could have prevented some of the losses incurred during the financial crisis ([45]) - specifically the losses incurred by the American International Group (AIG) - it is doubtful whether the credit derivatives that caused AIG's downfall would have fallen under the standardized derivatives for which central clearing is mandatory now ([30]). Before the financial crisis hit, AIG sold credit default swaps (CDS) which protected its buyers from losses on subprime mortgage products. The default of AIG was then caused by its downgrade and the subsequent demand of large amounts of collateral from the buyers of those CDS's which AIG could not comply with. However, as figure 1 shows, central clearing so far is only required on CDS index products. But with effect of 4 February 2017, OTC derivatives that are not cleared centrally are also subject to variation margin payments for financial institutions with over €3 trillion of derivative notional under EMIR ([26]).

A downside of the central clearing process is that it concentrates systemic risk at the central counterparties, potentially creating new "too big to fail" institutions and a need to monitor and regulate these financial entities. Nevertheless, CCPs existent before the 2007/8 financial crisis have "proved resilient during the crisis, continuing to clear contracts even when bilateral markets had dried up" ([2]).
Another drawback of central clearing is the pressure put on clearing members' liquidity resources by the initial and variation margin payments required by the CCP. This is the focus of this paper, and in the following sections we will analyze how a banks' liquidity resources are affected by central clearing.

But before we go further into liquidity issues caused by central clearing, we will look into a side effect of central clearing on the clearing members' balance sheets and regulatory capital that was most certainly not intended by the regulators when they introduced mandatory central clearing.

1.3 How central clearing can lead to balance sheet and capital reductions

In recent years, there has been a move from collateralized-to-market (CTM) to settled-to-market (STM) contracts for centrally cleared over-the-counter (OTC) derivatives. While the mechanics of paying variation margins to account for changes in the mark-to-market value of the derivative contracts is the same for both contract types, their main difference is how these margin payments are treated from an accounting and regulatory perspective.

In the CTM case, variation margin payments are made in the form of posted collateral, which means that ownership of the assets used to pay the variation margin is not transferred to the collateral receiving entity. Only in the case of default of one trading party, the collateral can be used by the non-defaulting entity to set off potential losses ([33]). At any point in time, the CTM contract would thus have "a cumulative mark-to-market value with an equal amount of collateral posted by the counterparty holding the loss position" ([33]).

For STM contracts on the other hand, variation margins are viewed as settlement payments, so the mark-to-market value of the contract is reset to zero after each variation margin payment. If one party defaults, the non-defaulting entity will calculate the mark-to-market value change since the last variation margin payment and will request the resulting difference to be paid by the defaulting party. Overall, the cash flows of CTM and STM contracts in timing and amount are the same, but in the case of STM, there is no collateral posted and the mark-to-market value will always be zero after each settlement date ([33]).

At the end of 2014 and 2015 respectively, the Chicago Mercantile Exchange and LCH Clearnet proposed exactly this shift from CTM to STM on trades cleared through their institutions, i.e. to treat margin payments as "daily settlement of the outstanding [mark-to-market] value of the derivative contract, rather than posted collateral" ([33]). In 2017, the US bank regulators approved of this shift provided that "the transferor of the variation margin has relinquished all legal claims to the variation margin" and the margin payment does indeed settle the mark-to-market value in the eyes of the CCP, "any other applicable agreements governing the derivative contract and applicable law" ([42]).

Even before the endorsement by the US regulators, UBS has adopted this new treatment of variation margin for its interest rate swaps cleared through LCH and subsequently reported savings of $300 million in capital in the second quarter of 2016 ([13]). The savings were a result of two main factors:

1. Reduction of exposure due to the treatment of margin payments as settlements rather than collateral and

2. change in maturity of the centrally cleared interest rate swaps as settlement dates are taken as the new maturity dates.

While the first factor obviously leads to a reduction in the accounting value of trading assets and liabilities and thus to a reduction in balance sheet and exposure of the bank, the savings resulting from the second factor are less obvious. To explain how the second factor can result in capital savings we first have to explain about the leverage ratio.

To supplement the risk-based capital requirements, Basel III also introduced the leverage ratio to "restrict the build-up of leverage in the banking sector to avoid destabilising deleveraging processes" that also expedited the financial crisis ([10]). The leverage ratio is defined as

$$\text{Leverage ratio} = \frac{\text{Tier 1 capital}}{\text{Total Exposure}},$$

where total exposure is the sum of on-balance sheet, derivatives, and securities financing transaction exposures as well as off-balance sheet items.

The important thing to note here is that when calculating the derivatives exposure, the maturities of the derivatives have to be taken into account as add-on factors:

Add-on factors for determining potential future exposure

1. The following add-on factors apply to financial derivatives, based on residual maturity:

	Interest rates	FX and gold	Equities	Precious metals except gold	Other commodities
One year or less	0.0%	1.0%	6.0%	7.0%	10.0%
Over one year to five years	0.5%	5.0%	8.0%	7.0%	12.0%
Over five years	1.5%	7.5%	10.0%	8.0%	15.0%

Figure 2: Add-on factors for different maturities to calculate derivatives exposure taken from [10]

By switching to STM contracts, the residual maturity of a derivative now becomes the next reset date, on which "any outstanding exposure is settled and the terms are reset so that the fair value is zero" ([42]). So even a "30-year swap would be treated as one with less than one year to run" ([14]). This reduces the add-on factor to be applied to the cleared interest rate swaps and hence the regulatory capital that has to be held to satisfy minimum requirements of the leverage ratio.

The adoption of STM contracts also enabled Barclays to reduce both their trading assets and their trading liabilities on their balance sheet by 25% ([14]). According to Barclays, these reductions were caused by "the adoption of STM rules at CME, as well as an increase in major interest rate forward curves and depreciation of the dollar against sterling" ([14]).

Now, after the endorsement of the regulatory entities, we can expect many more banks to follow into the footsteps of Barclays and UBS, reducing their balance sheet and their Tier 1 Capital as a consequence of the shift of CTM to STM. An increase in the amount of centrally cleared products can therefore lead to less regulatory capital being held by banks', a most surely unintended consequence of imposing central clearing on financial institutions.

Besides the leverage ratio, Basel III also put other minimum requirements into effect, some of which are discussed in the next section.

1.4 Minimum liquidity requirements set by the regulatory environment

Looking back once again on the financial crisis it can be observed that many precarious situations were caused by financial institutions not being able to pay their bills rather than a lack of assets/equity capital. When Lehman Brothers defaulted in 2008, they still had $639 billion worth of assets and only $619 billion worth of debt ([34]). It defaulted on September 15 because it had to pay $3 billion on that day but was unable to find enough cash ([46]). The same is true for Bear Stearns: Even though the firm had capital well above what was required by Basel II at that time, it defaulted due to the fact that its liquidity pool dried up ([18]).

These two cases show that illiquidity has been an important problem in the past and has lead to default even though the company was still solvent. As a result, the Basel Committee has begun to focus more on liquidity risk and published their "Principles for Sound Liquidity Risk Management and Supervision" in September 2008, and further strenghtened its liquidity requirements when it introduced the liquidity coverage ratio (LCR) and the net stable funding ratio (NSFR) in Basel III. The Federal Reserve has introduced a similar requirement in 2014 ([23]).

The minimum requirement for the liquidity coverage ratio is defined as:

$$\text{LCR} = \frac{\text{Stock of High quality liquid assets}}{\text{Total net cash outflows over the next 30 calendar days}} \geq 100\%$$

Assets qualify as high quality liquid assets (HQLA) if "they can be easily and immediately converted into cash at little or no loss of value" ([8]). HQLA therefore also includes, besides cash, central bank reserves, certain bonds, mortgage backed securities and other low risk securities and equities ([1]).

The excess amount of HQLA securities and equities that has not to be retained to satisfy minimum regulatory requirements can therefore also be used as collateral for repurchase agreements. If a bank does not have sufficient cash to satisfy its obli-

gations on any given day, it can enter into a repurchase agreement. A repurchase agreement - or repo for short - is an agreement between two parties in which one party - called the "seller" in the following - sells the asset/collateral to the other party - the "buyer" - while committing to buy it back at a fixed price and future time which is typically the next day. The difference between the sell and buy price is quoted as a percentage per annum rate and is called the repo rate.
In most cases, repos are used to obtain cash for a short term in a timely manner and can thus be used to provide short term liquidity for the seller. The repo rate therefore represents liquidity raising costs to the seller and the return on the cash for the buyer.
During the life of the repurchase agreement, the seller still holds legal ownership to the collateral and hence receives all associated dividends, interests and other income associated with holding the collateral. The amount of HQLA that is available thus sets an upper limit to the amount of cash the bank can obtain through the use of repos.

Total net cash outflows is defined as the total expected cash outflows minus the minimum of total expected cash inflows and 75% of total expected cash outflows over the next 30 calendar days ([8]). An important point to note is that margin payments do not have to be considered when calculating the expected cash in- and outflows. On the contrary, Basel III, paragraph 119 states the following:

"Observation of market practices indicates that most counterparties [...] are required to secure the mark-to-market valuation of their positions and that this is predominantly done using cash [or other Level 1 liquid asset secuirities]. When these Level 1 liquid asset securities are posted as collateral, the framework will not require that an additional stock of HQLA be maintained [...]." ([8])

Aside from the minimum requirement on the liquidity coverage ratio, the Federal Reserve also requires banks to hold a certain amount of funds against customer deposits. These funds have to be either cash or funds deposited at the domestic central bank. As of 3 August 2017, the reserve requirements are as follows:

Net transaction amounts	Requirement in % of liabilities	Effective date
$0 to $15.5m	0	19 January 2017
More than $15.5m to $115.1m	3	19 Jan 2017
More than $115.1m	10	19 January 2017
Non-personal time deposits	0	27 Dec 1990
Eurocurrency liabilities	0	27 Dec 1990

Table 1: Reserve Requirements of the Federal Reserve, taken from [22]

Deposits with maturity $\leq$ 2 years	Deposits with maturity $>$ 2 years	Effective Date
1 %	0%	18 Jan 2012

Table 2: Reserve Requirements of the ECB, taken from [20]

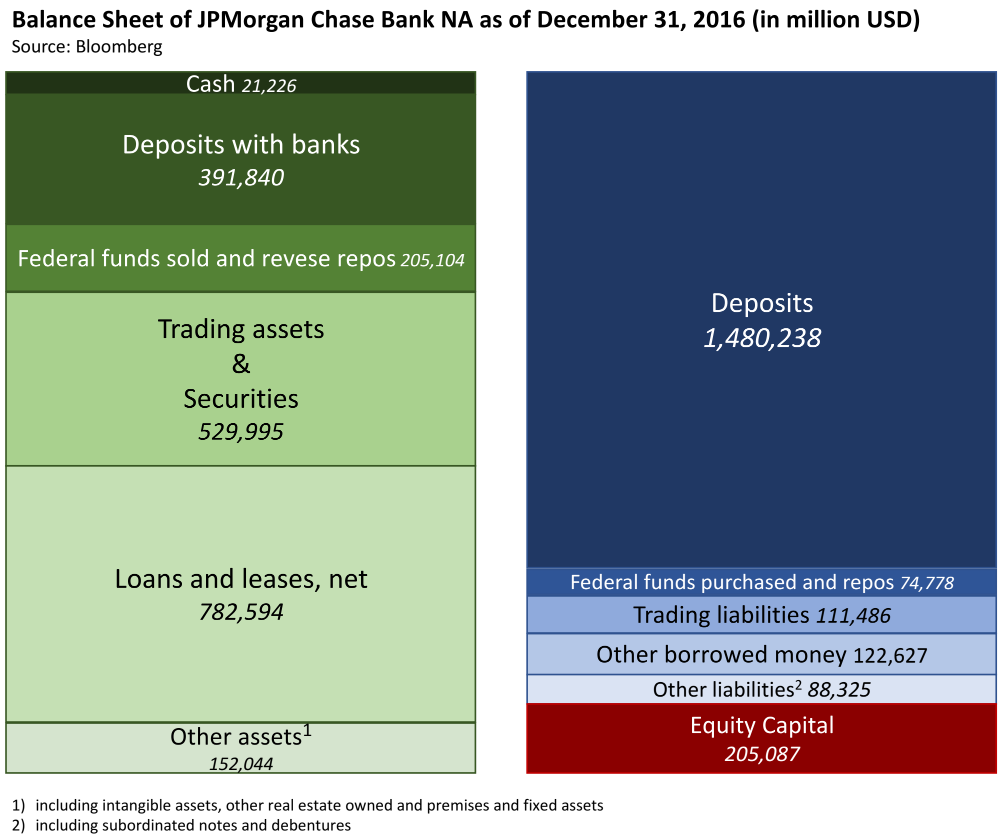
These liquidity requirements as well as the additional cash flows associated with more OTC derivatives being subject to central clearing and margin payments will put a strain on banks' liquidity resources.

In the following, we will first illustrate the impact margin payments have on liquidity using a simple interest rate swap example in section 2. Afterwards, we will construct proxy portfolios based on data that is displayed in section 3.1. The dynamics and assumptions underlying our simulations used to analyze the impact of margin payments on the liquidity of several banks can be found in section 3.2. More detail about the algorithm used to construct the proxy portfolios is given in section 3.3. Finally, the results are presented in section 3.4 followed by conclusions in section 4.

2 The impact of margin payments on liquidity - an example

2.1 The issue with balance sheet data

One possible source of information about a bank's portfolio is its balance sheet. As an example, when looking at the balance sheet of JPMorgan Chase Bank in the figure below, one could assume that roughly 25% of the company's assets are tied up in trading assets and securities, henceforth called the trading book.



However, the balance sheet only captures the bank's situation at one point in time and at market value. It therefore does not give any information about JPMorgan's daily trading activities, the nature and underlyings of its trading derivatives or the sensitivity of its portfolio to changes in market risk factors.

To illustrate this, consider an interest rate swap where JPMorgan pays a counterparty USD 3 months LIBOR rate plus 2% and receives 3.4% from its counterparty with annual payments for ten years with a notional of USD 100 million.

As of 17 July 2017, the USD 3 months LIBOR rate is at 1.306%. Hence the market value of the swap is:

Pay each year	$100,000,000 \times (1.306\% + 2\%) =$	$3,306,000$
Receive each year	$100,000,000 \times 3.4\% =$	$3,400,000$
Net cash inflow each year		94,000
Value of IRS on 17 July 2017		940,000

Table 3: Value of IRS 10Y maturity, pay LIBOR+2%, receive 3.4%

Thus the market value of the swap would be 940,000 on 17 July 2017 if we ignore discounting. If the LIBOR curve moves up by 0.1% before the first payment is due and remains on this level, the market value would change to $-60,000$, and the trading asset would become a trading liability.

As this trade would have only appeared as $940,000$ in trading assets on the balance sheet, this example shows how little data obtained from the balance sheet can help us understand a bank's market position or the potential changes to its trading book value triggered by market movements.

2.2 Cashflow in the case of margin payments vs. no margin payments

Let us consider the above example further from the point of view of margin requirements.
To do this, we not only have to take into account the effects of changes in the LIBOR rate on the swap value and swap payments, but also the subsequent margin payments.

2.2.1 Calculation of Margin payments

Initial Margin
If a trade is cleared through a central counterparty (CCP), the CCP will require an initial margin payment of both trading parties at the beginning of the trade. There are many models currently used to calculate initial margins, one of which is the standardized portfolio analysis of risk (SPAN) model developed by CME, the chicago mercantile exchange. In this model, the profit and loss of the considered portfolio arising from 16 different scenarios is calculated to obtain "the largest potential loss, which is charged as initial margin" ([37]).
Another approach is historical simulation which simply uses historical data to determine the confidence interval of each position included in the portfolio. In this case one can for example improve the model by adding more weight to recent price movements or "scale returns by ratio of current volatility [to] volatility at the time of shock" ([40]).

In the interest rate swap example, we will use the historical simulation approach. According to the standard initial margin model proposed by the international swaps and derivatives association (ISDA), the initial margin should "meet a 99% confidence level of cover over a 10-day standard margin period of risk" [31].

We thus fit a Student t distribution to the returns of the USD 3 month LIBOR in the period of 9 January 2001 to 2nd January 2004, which yields the following results:

Mean	Standard deviation	Degrees of freedom
$-5.60\text{e}-04$	$2.38\text{e}-04$	1.11

Table 4: Student t fitted to USD 3 month LIBOR returns 2001-01-09 to 2004-01-02

By simple calculations, one can show - as in [28] - that the standard deviation used for the n-day quantile should be $\sqrt{n}$ times the standard deviation of one day, assuming the returns are independent and identically distributed.
The initial margin that the trading parties have to pay to the CCP for the interest rate swap on the starting day t of the trade is therefore calculated as follows:

$$\begin{aligned}&\text{initial margin} = \\ &\text{10 day quantile}\times\text{LIBOR on day } t \times \text{Swap notional} \times \text{Number of swap payments}\end{aligned} \tag{2.1}$$

Variation Margin

The aim of variation margins is to reduce the counterparty risk by paying the change in the mark to market value of the trade between variation margin dates to the party whose exposure increases as a consequence to the change. Assuming that variation margins are paid on days $VM_1, VM_2, \dots$, the variation margin payment of JPMorgan to its counterparty on day VM_t is therefore simply the difference of the value of the swap on VM_t and its value on VM_{t-1}:

If no swap payment occurs between VM_{t-1} and VM_t:

$$\begin{aligned}\text{Variation Margin on } VM_t = &\ \text{Swap notional} \\ &\times (\text{LIBOR on } VM_t - \text{LIBOR on } VM_{t-1}) \\ &\times \text{ No. of outstanding swap payments on } VM_t\end{aligned} \tag{2.2}$$

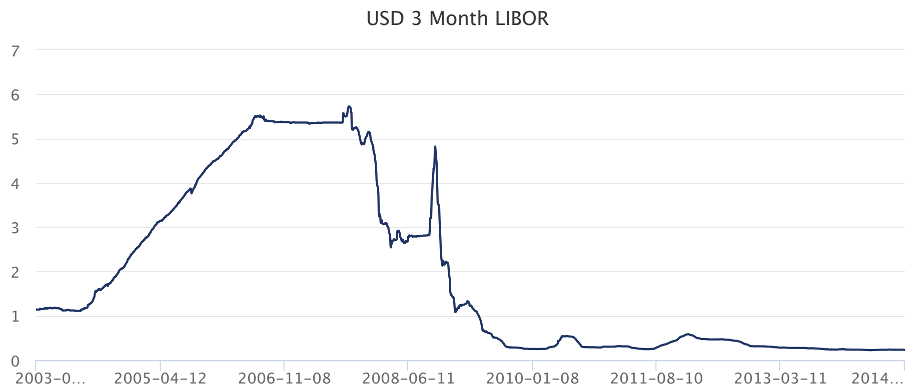
If a swap payment occurs between VM_{t-1} and VM_t:

$$\begin{aligned}\text{Variation Margin on } VM_t &= \text{Swap notional}\\ &\times [\text{LIBOR on } VM_t \times \text{No. of outstanding swap payments on } VM_t\\ &- \text{LIBOR on } VM_{t-1} \times \text{No. of outstanding swap payments on } VM_{t-1}]\end{aligned} \tag{2.3}$$

Since JPMorgan is paying the floating rate in our interest rate swap example, the variation margin that it has to pay its counterparty when there is no swap payment between the consecutive margin payment days would be positive if the LIBOR rate increased and negative if it decreased.

2.2.2 Visualization using swap example

In the years from 2004 to 2014, the USD 3 month LIBOR rate has increased significantly until it reached more than five times its initial value of 2004 before it dropped again below 1%:



If we had entered the above described swap agreement on the 2nd of January 2004, we would have had the following cash flows if the swap would not have been subject to margin payments:

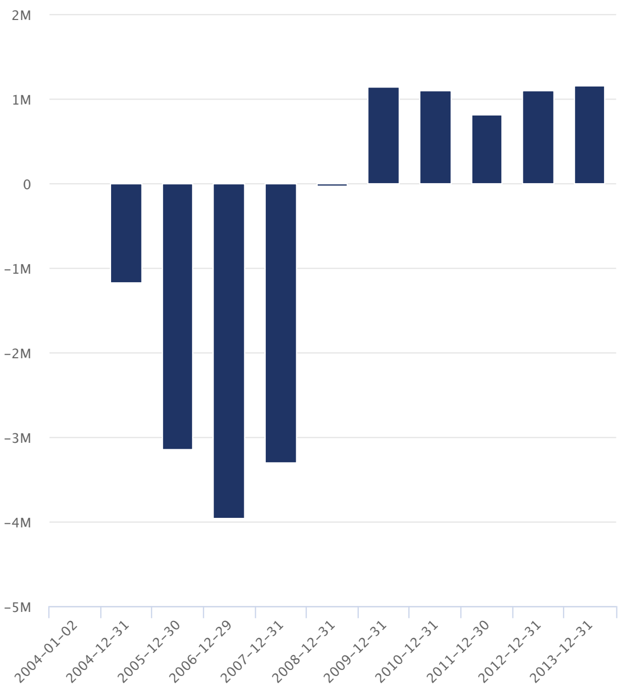


Figure 3: Interest Rate Swap net cash flows (no margin payments)

The following graph shows all margin payments that would have had to be made if the swap had been cleared, with variation margin payments every 90 trading days:

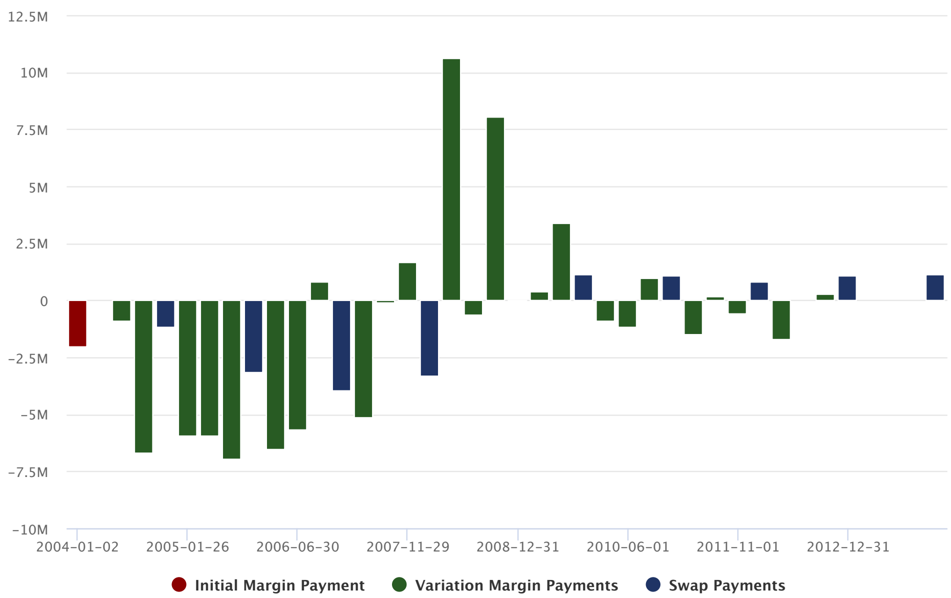
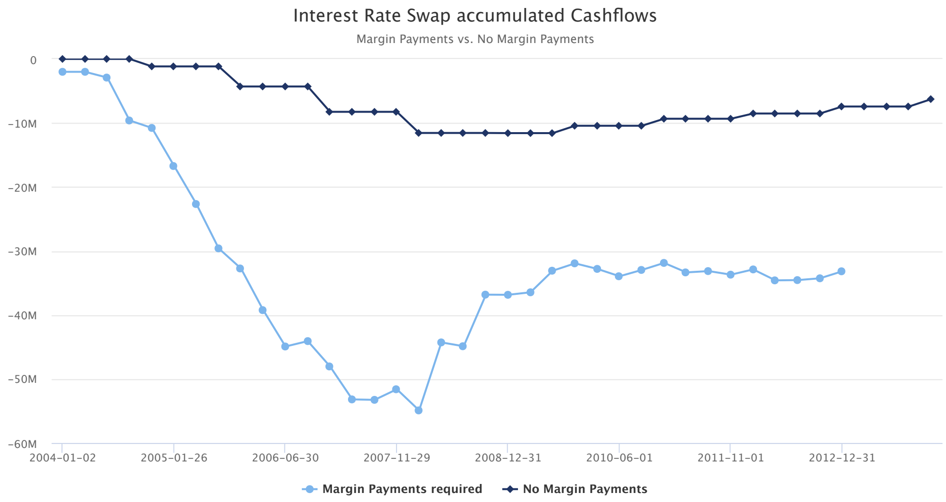


Figure 4: Interest Rate Swap net cash flows (margin payments required)

The next figure demonstrates more clearly the effect of margin payments on liquidity as it shows the accumulated cash flows in both cases:



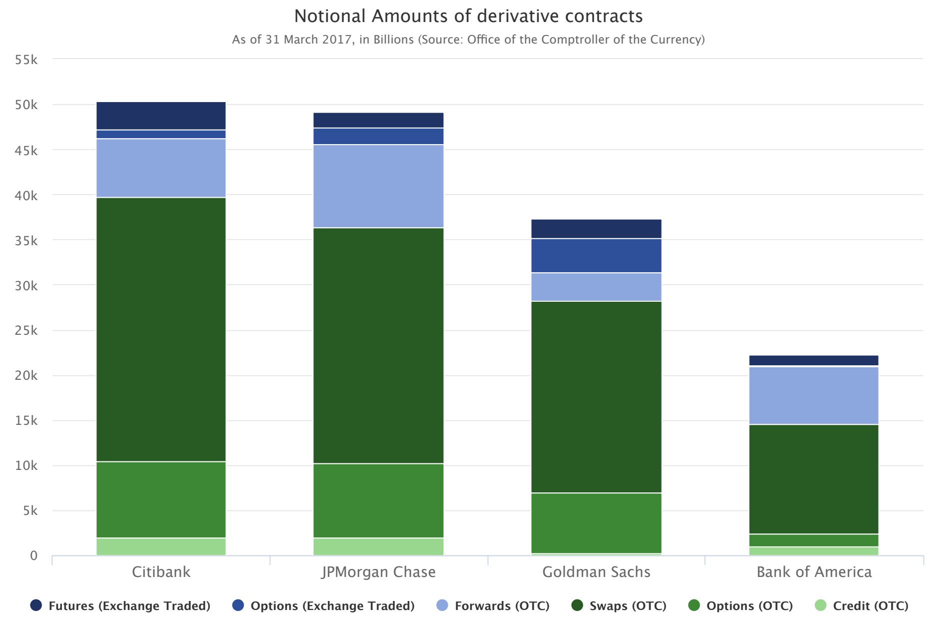
Clearly, in the case of margin payments the bank needs much more cash to satisfy all their obligations.

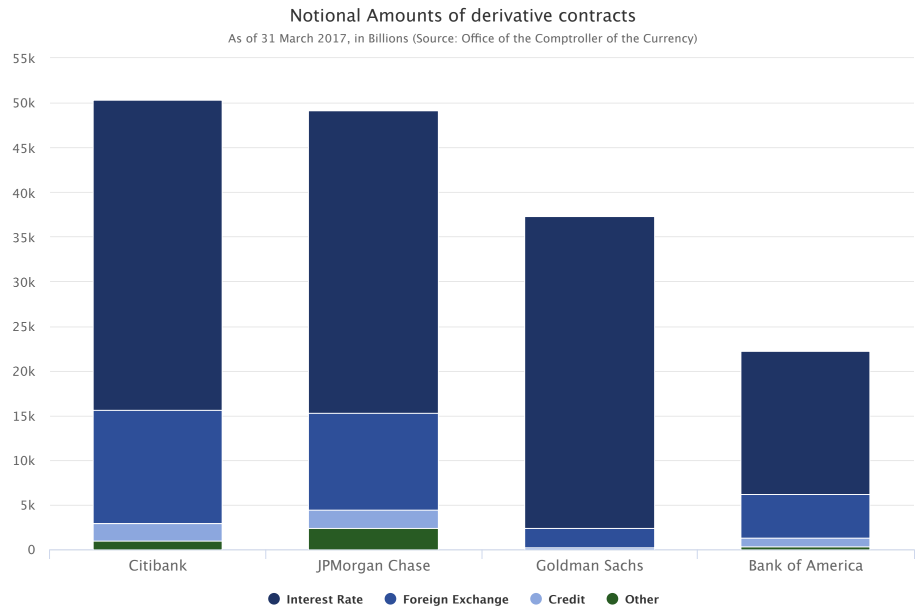
In the following section we will consider different proxy portfolios to look further into the effects of margin payments on liquidity.

3 Modelling trading portfolios

3.1 Data

The following figures featuring the composition of derivative contracts held by the four biggest US derivatives dealers as of 31st March 2017 forms the base of our trading portfolios:





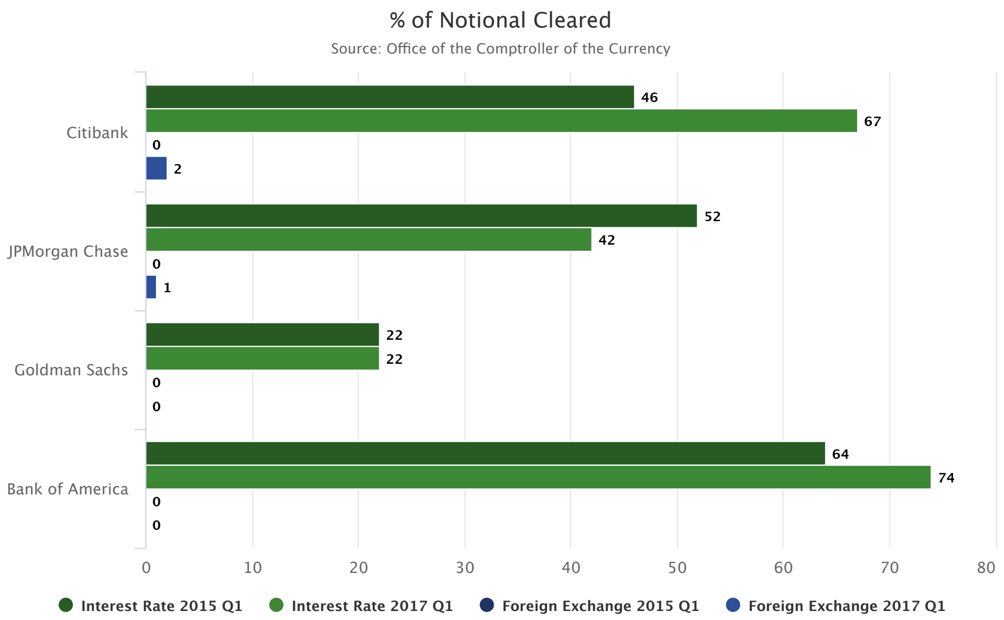
We can make the following observations from the figures above:

1. Only a small portion of the banks' total derivatives are exchange traded.
2. Among the OTC derivative contracts, swaps make up the biggest proportion of the notional.
3. For each bank, interest rate and foreign exchange derivative contracts account for more than 90% of the notional.

Due to the fact that the majority of the banks' derivatives are traded over the counter, the impact of mandatory central clearing for OTC derivatives has had and will still have a big impact on the ratio of centrally cleared to non-centrally cleared derivative contracts.

Over the past few years, the proportion of centrally cleared OTC derivatives, i.e. the derivatives that are subject to margin payments, has already risen: As of June 2016, 75% of dealers' outstanding OTC interest rate derivatives and 37% of credit derivatives were centrally cleared, up from 65% and 23% in 2013 respectively ([3],[32]). Despite this increase, there still remains potential for further increases in central clearing volume. As of end-June 2016, only 65% of the estimated notional amount of outstanding interest rate derivatives transactions that could theoretically be centrally cleared were actually centrally cleared ([27]). Thus there still remained around US$103 trillion in notional outstanding that had not been centrally cleared, but theoretically could be as of end-June 2016 ([27]). For credit derivatives, the ratio of the gross notional outstanding that was indeed central cleared end-June 2016 and the amount that was theoretically clearable was at roughly 40% ([27]).

This tells us that the proportion of OTC trading derivatives subject to central clearing has already increased in recent years, but still has the potential to grow even further. The changes in the proportion of derivatives contracts centrally cleared by the four biggest US derivatives dealers in the past two years is illustrated in the graph below:



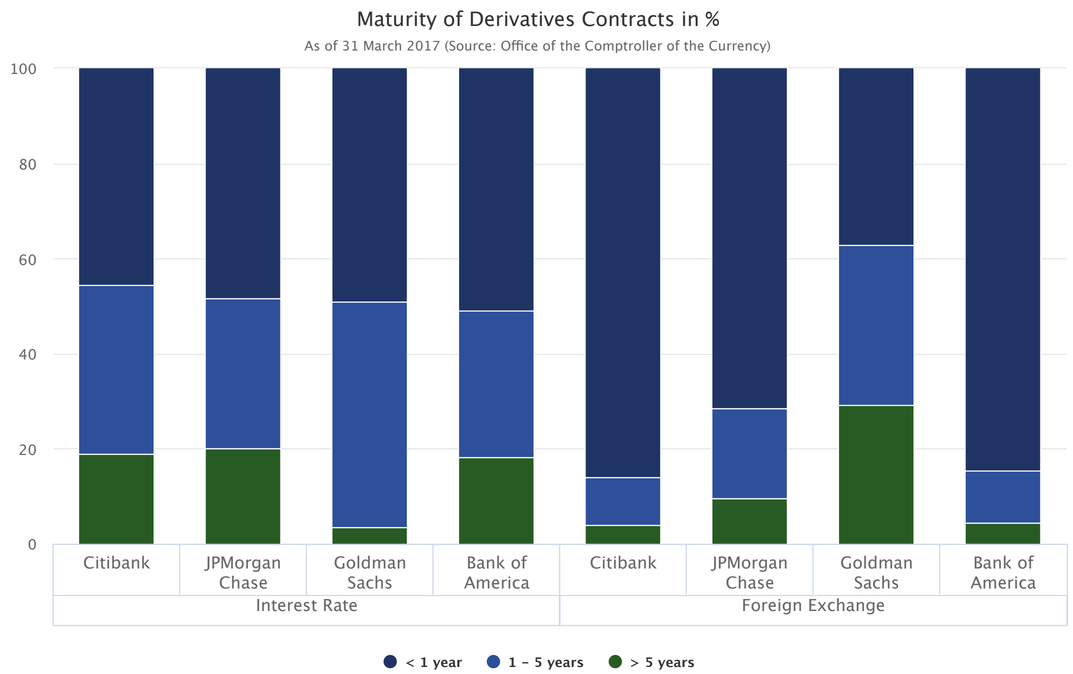
In the following, we will only consider interest rate and foreign exchange derivatives since taken together they make up more than 90% of the four banks' trading portfolio.
Seeing that we want to evaluate the effects of central clearing on cash flow, we will also exclude derivatives already traded on exchanges from our portfolio and focus on forwards and swaps since they together account for the majority of OTC derivatives of the four banks. The reason we also exclude options is that it is not possible to determine what percentage of options on the respective underlyings is exchange traded and what percentage is traded over-the-counter.

Assumption 3.1. For simplicity, we assume that interest rate and foreign exchange derivatives consist only of forwards, swaps and options, i.e. we ignore the proportion of futures since they only make up a small amount of the notional.

Assumption 3.2. We assume that the ratio of the instruments - i.e. the ratio between options, forwards and swaps - are the same for interest rates and foreign exchange instruments as they are bank wide.

By 'forwards' we mean forward rate agreements for interest rate derivatives and forex swaps for foreign exchange derivatives. Swaps in the foreign exchange derivatives case are cross-currency swaps.

The following graph gives more details about the composition of the trading portfolios into maturities for each bank:



We will assume that the relation between the different maturities in the figure above is the same for both forwards and swaps.
To put the impact of margin payments on liquidity in context, we will compare it to the liquid assets available to every bank. An overview over the liquidity situation as of 31 December 2016 of each of the considered four banks' is given below:

Institution	Amount of Cash	High quality liquid assets (thereof cash on deposit)
Citibank N.A.	$21.8bn	$341.2bn ($68.3bn)
JPMorgan Chase Bank N.A.	$21.2bn	$524bn ($323bn) [1]
Goldman Sachs Bank USA	$194m	$235.1bn ($107bn) [2]
Bank of America N.A.	$25.5bn	$499bn ($106bn)[3]

Table 5: Cash and high quality liquid assets of considered banks
Sources: Annual reports, Federal Financial Institutions Examination Council([21])

In the table above, we have further distinguished between cash on deposit and other high quality liquid assets (HQLA). The other HQLA are usually U.S. Treasury and U.S. agency securities, mortgage-backed securities and other low-risk securities.
An important thing to note for all banks except Citibank is that the HQLA given is that of the parent institution as bank specific data is not publicly reported for these three banks. As an example, roughly one fifth of the HQLA we have given in the table for Goldman Sachs belongs to the group and not the bank itself, for Bank of America it is roughly 15% (see annual reports, [21]).

Next, we calculate the amount of liquid assets a bank has to retain as a proportion of their net transaction amounts according to the regulations imposed by the Federal Reserve. The minimum requirement is 10% of liabilities for banks with more than $115.1 million of net transaction amount. Since only a portion of a banks' total deposits falls under net transactions, we will multiply the amount of deposits of each bank by 7% to obtain an estimate of how much liquid assets they have to hold:

[1] HQLA from JPMorgan Chase & Co.
[2] Global Core Liquid Assets (GCLA) of Goldman Sachs Group, Inc. and subsidiaries
[3] Global Liquidity Source of Bank of America Corporation

Institution	Total Deposits	Amount to be retained (estimate)
Citibank N.A.	$945.7bn	$66.2bn
JPMorgan Chase Bank N.A.	$1,480bn	$103.6bn
Goldman Sachs Bank USA	$114.8bn	$8.0bn
Bank of America N.A.	$1,334bn	$93.4bn

Table 6: Amount to be retained

Sources: Annual reports, Federal Financial Institutions Examination Council([21])

If we subtract the amount to be retained due to regulatory requirements from the amount of cash on deposit, we obtain the amount of cash equivalent that can be used to meet payment obligations.

Institution	Amount of cash equivalent available (estimate)
Citibank N.A.	$2.1bn
JPMorgan Chase Bank N.A.	$219.4bn
Goldman Sachs Bank USA	$99bn
Bank of America N.A.	$12.6bn

Table 7: Estimate of cash on deposit available

The amount of cash equivalent available appears to be extraordinarily high for JP-Morgan Chase as well as Goldman Sachs. Therefore we further multiply the amount of cash on deposit of both companies by the factor

$$\frac{\text{Total assets of considered bank}}{\text{Total assets of parent group/corporation}}$$

since the amount of HQLA given in table 5 are for JPMorgan Chase & Co. and Goldman Sachs Group, respectively. If we take this factor into account, the estimated amounts of cash equivalent available become:

Institution	Amount of cash equivalent available (estimate)
Citibank N.A.	$2.1bn
JPMorgan Chase Bank N.A.	$166.5bn
Goldman Sachs Bank USA	$11.9bn
Bank of America N.A.	$12.6bn

Table 8: Estimate of cash on deposit available (adjusted by asset ratio)

The data used for JPMorgan and Goldman Sachs are given below:

Institution	Total Assets	Total Assets Parent Group/Corporation
JPMorgan Chase Bank N.A.	$2,083bn	$2,491bn
Goldman Sachs Bank USA	$160bn	$860bn

Table 9: Total Assets JPMorgan and Goldman Sachs
Sources: Annual reports, Federal Financial Institutions Examination Council([21])

Even after considering the fact that the amount of high quality liquid assets of JP-Morgan Chase (JPMC) bank are less than its parent group's, our estimation of cash equivalent available to JPMorgan is very high compared to the other three banks. One possible explanation is a concern raised by the Federal Reserve in a letter to James Dimon, the CEO of JPMorgan Chase ([24]) about their resolution plan:

"[...] JPMC does not have appropriate models and processes for estimating and maintaining sufficient liquidity at, or readily available to, material entities [...]" ([24])

It criticizes JPMorgan's liquidity profile to be "vulnerable to adverse actions by third parties" and that it relies "on funds in foreign entities that may be subject to defensive ring-fencing during a time of financial stress" ([24]). This suggests that the amount of HQLA of JPMorgan could in fact be smaller than reported. Results using the above estimated available cash on deposit should therefore be regarded with care.

As described in section 1.4, the excess amount of HQLA that does not have to be retained to satisfy minimum regulatory requirements can be used by the bank to refinance itself using repurchase agreements. The liquidity coverage ratio of the four banks, which is defined as HQLA over total net cash outflows, can be found in the table below (taken from [12],[44],[4],[36]):

Institution	Average liquidity coverage ratio in Q2 2017
Citigroup Inc.	125%
JPMorgan Chase & Co.	115%
Goldman Sachs Group Inc.	128%
Bank of America Corporation	125.8%

Therefore 25%, 15%, 28% and 25.8% of the HQLA of Citibank, JPMorgan Chase, Goldman Sachs and Bank of America respectively are available as collateral for repurchase agreements, where we assumed that the banks' LCR are the same as their parent groups'. As before, we adjust for the fact that the HQLA of JPMorgan and Goldman Sachs represent the parent group's HQLA by multiplying with the asset proportion that belongs to the banks:

Institution	Amount of HQLA available for repurchase agreements (estimate)
Citibank N.A.	$85.3bn
JPMorgan Chase Bank N.A.	$65.7bn
Goldman Sachs Bank USA	$12.2bn
Bank of America N.A.	$128.7bn

To model the change of risk factors and the subsequent changes in the portfolio value of each of the above four banks, we will use historic LIBOR and exchange rates obtained from Bloomberg.

The following section explains the model assumptions and dynamics, in particular how the variation margin payments are calculated for each of the four considered products: forward rate agreement, interest rate swap, forex swap and cross-currency swap.

3.2 Model Assumptions and Dynamics

We will consider different portfolios for every bank and assume throughout that variation margins are exchanged every day based on the changes in underlying (exchange) rates.

Assumption 3.3. We will assume that variation margins have to be paid on each trading day until contract maturity. In the following, $(t-1)$ will therefore denote the trading day preceding trading day t.

Assumption 3.4. Furthermore, we assume that the portfolio remains unchanged during our considered time period, which is 100 trading days.

Moreover, we will ignore initial margin payments, since we have no data on how the starting date of the derivative contracts is distributed over time.

3.2.1 Interest Rate Derivatives

For interest rate derivatives, we further distinguish between payer and receiver forward rate agreements and swaps. Since a bank would like to hedge itself against adverse market movements, it would probably take opposite positions in interest rate swaps and forwards. Therefore we will also construct sample portfolios where each long LIBOR position is always offset by a short LIBOR position.

Assumption 3.5. We assume that all interest rate derivatives have the LIBOR as underlying floating interest rate.

Forward rate agreements (FRAs)

For forward rate agreements, variation margins are based on the changes of the underlying interest rate of the floating leg. The variation margin payment that the bank has to pay its counterparty on day t is therefore:

Payer FRA (pay fixed rate):

$$\text{Variation Margin on day } t = \text{FRA notional} \times (\text{LIBOR on day } (t-1) - \text{LIBOR on day } t) \tag{3.1}$$

Receiver FRA (pay floating rate):

$$\text{Variation Margin on day } t = \\ \text{FRA notional} \times (\text{LIBOR on day } t - \text{LIBOR on day } (t-1)) \tag{3.2}$$

Interest rate swaps

For interest rate swaps, we have to enhance the above equations (3.1) and (3.2) to take into account the net present value (NPV) changes occurring on each swap payment date in addition to the NPV changes based on rate movements. The variation margin payment on each swap payment date t that the bank pays to its swap counterparty is thus calculated as follows (with NPV denoting the net present value from the point of view from the bank):

Payer interest rate swap (pay fixed rate)

$$\begin{aligned} &\text{NPV of swap on day } (t-1) - \text{NPV of swap on day } t \\ &\quad = \text{Notional}\times \\ &\quad [\text{Outstanding swap payments on } (t-1) \times (\text{LIBOR on day } (t-1) - \text{fixed rate}) \\ &\quad - \text{Outstanding swap payments on } t \times (\text{LIBOR on day } t - \text{fixed rate})] \end{aligned} \tag{3.3}$$

Receiver interest rate swap (pay floating rate)

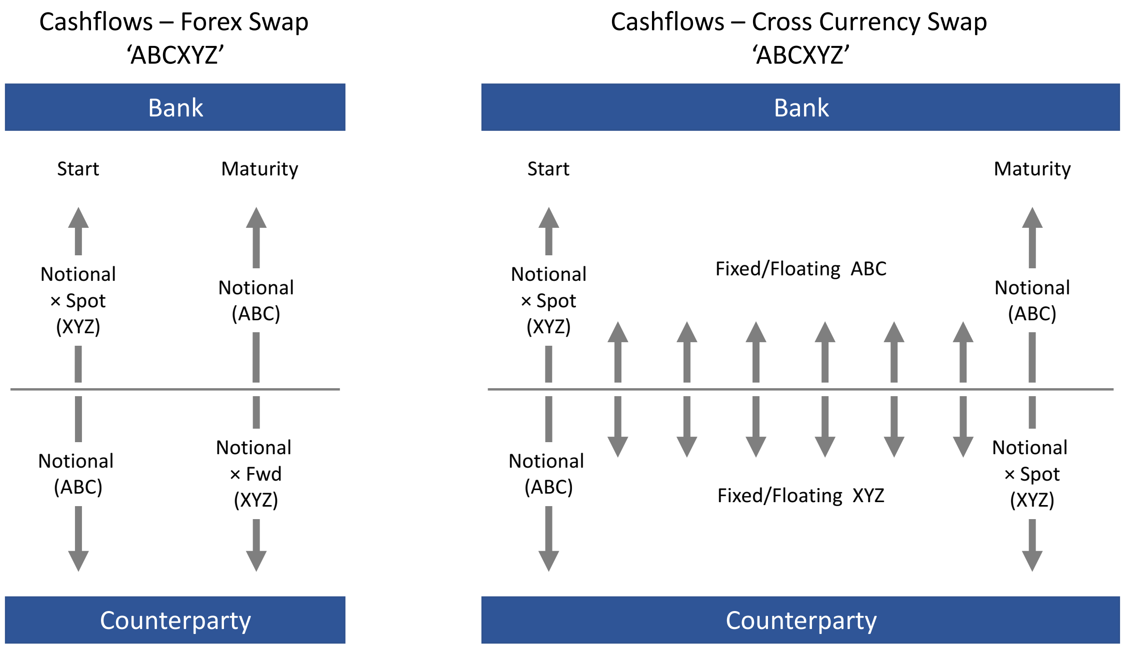
$$\begin{aligned} &\text{NPV of swap on day } (t-1) - \text{NPV of swap on day } t \\ &\quad = \text{Notional}\times \\ &\quad [\text{Outstanding swap payments on } (t-1) \times (\text{fixed rate} - \text{LIBOR on day } (t-1)) \\ &\quad - \text{Outstanding swap payments on } t \times (\text{fixed rate} - \text{LIBOR on day } t)] \end{aligned} \tag{3.4}$$

In the above equations (3.3) and (3.4), the outstanding payments on day $(t-1)$ will always be greater by one than the outstanding payments on day t due to the swap payment being settled on day t.

One important thing to note is that the swap payment reduces the exposure of the entity to whom the payment is made to. Therefore, if the swap payment received on a given day t is negative, the variation margin payment received on the same day will almost certainly be positive - unless the market experiences a strong adverse movement in interest rates - and vice versa. The variation margin and swap payments will therefore offset each other to some extent. This shows another advantage of the introduction of margin payments: payments are distributed over time, large payments become less common and the default risk of a trading party due to the fact that it suddenly has to make a large amount out to its counterparties is reduced.

3.2.2 Foreign Exchange Derivatives

The following figure shows the cash flows of the two foreign exchange instruments we will consider in our portfolios:



Forex Swap

In the portfolios below, a foreign exchange forward - i.e. a forex swap - denoted by "ABC/XYZ" has the following cash flows:

1. At the beginning of the contract, the bank pays the counterparty the notional in currency ABC and receives the notional times the spot rate in currency XYZ.

2. At maturity, the bank receives the notional in currency ABC and pays the notional times the forward rate in currency XYZ to its counterparty.

In theory, the mark to market value of a forex swap at the beginning of the trade is therefore zero. In practice, however, the value of the forex swap for the respective trading parties depends on their financing costs in each currency. For details, see for example chapter 3 in [38].

The variation margin payment the bank has to pay on day t to its counterparty is therefore:

$$\begin{aligned}&\text{Variation Margin on day } t\\&\qquad = \text{Notional} \times (\text{Exchange rate on day } (t-1) - \text{Exchange rate on day } t)\end{aligned} \tag{3.5}$$

Where 'Exchange rate' is the exchange rate between currencies ABC and XYZ. So if the currency ABC becomes more valuable relative to currency XYZ, i.e. the exchange rate in the above equation (3.5) increases, the bank's book value of the forex swap increases and the variation margin the bank has to pay its counterparty is negative and vice versa.

To calculate the cash flows on each day t, we furthermore convert the mark to market value of the forex swap into US Dollar at the prevailing exchange rate.

Cross-currency swaps

Cross currency swaps differ from forex swaps since the bank additionally receives interest payments in currency ABC and pays interest payments in XYZ. Unlike interest rate swaps, both interest payment legs of the cross currency swap can be either fixed or floating. Furthermore, the payment of the notional to the counterparty at contract maturity is made at the spot rate, not the forward rate. In the portfolio descriptions below, the nature of the interest payments is indicated in the brackets after currencies ABC and XYZ.

The variation margin calculations are thus very similar to the ones of an interest rate swap besides the fact that we also have to consider changes in the exchange rate between currencies ABC and XYZ. If there are no interest rate payments exchanged on day t, the variation margin payment of the bank to its counterparty is therefore:

$$\begin{aligned}
&\text{NPV of swap on day } (t-1) - \text{NPV of swap on day } t \\
&\quad = \text{ Notional} \times \text{Outstanding swap payments on } t \\
&\quad \Big([\text{Receive rate on } (t-1) \times \text{Exchange rate ABC to USD on } (t-1) \\
&\qquad - \text{pay rate on } (t-1) \times \text{Exchange rate XYZ to USD on } (t-1)] \\
&\quad - [\text{Receive rate on } t \times \text{Exchange rate ABC to USD on } t \\
&\qquad - \text{pay rate on } t \times \text{Exchange rate XYZ to USD on } t] \Big)
\end{aligned} \tag{3.6}$$

If there are interest rate payments exchanged on day t, we also have to consider the change in number of outstanding swap payments as in the case of interest rate swaps. As for the forex swaps above, we convert all margin payments into USD.

Adding all the variation margin payments of each instrument together, we obtain the net cash flow that the bank has to pay to the central counterparty on each trading day. However, netting the cash flows is only allowed if all interest rate and foreign exchange forwards and swaps are cleared through the same counterparty, which we will assume here. We further assume that all payments not associated with the margining process, i.e. the swap and forward payments themselves, can be netted as well. This makes it possible to focus on the net cash flows, obliterating the fact that individual payments may have to be paid to various counterparties.

3.3 Construction of proxy portfolios

To construct the trading portfolios, we first determine the notional amount of interest rate forwards and as well as the amount of foreign exchange forwards and swaps by multiplying the interest rate and foreign exchange notionals of each bank by the amount of forwards and swaps divided by the total amount of forwards, swaps and options, since these make up the interest rate and foreign exchange portfolios.
To simplify the portfolio construction, we will assume that all interest rate and foreign exchange derivatives are based on the below listed interest and exchange rates:

- USD, EUR and GBP LIBOR (3 months, 6 months and 12 months)
- Exchange rates between the currencies USD, EUR and GBP

We have chosen these particular currencies because they were the largest by notional outstanding of all clearing volumes according to LCH as of 30 August 2017.
We will follow two different approaches to construct the portfolios:

1. Explicitly, by listing each forward and swap in the portfolio. Here, we choose each notional and each receive/pay rate as well as the type 'ABCXYZ' of the foreign exchange derivatives at will or
2. randomly, using an algorithm.

For both approaches, we make sure that the notionals and the breakdown in maturities and instruments of the final portfolio correspond to the data in subsection 3.1.
Since the first way of constructing the portfolio is fairly straightforward, we will now focus on describing the algorithm to generate portfolios randomly.
As an example, we first consider the algorithm to generate a portfolio of forward rate agreements. As mentioned above, each long LIBOR rate position is always offset by a corresponding short LIBOR rate position in the same currency. Furthermore, we make the following assumptions for the forward rate agreements:

Assumption 3.6.

1. Half of the contracts are payer, the other half receiver contracts, where each payer is offset by a receiver in the same currency.

2. When choosing the receive floating rate, each interest rate (USD 3m, USD 6m, USD 9m, EUR 3m, ..., GBP 12m) is equally likely to be picked.

3. After the receive floating rates are determined for the payer contracts, the pay floating rate of each of the corresponding receiver contracts is equally likely chosen to be the 3 month, 6 month or 12 month rate in the same currency, regardless of the exact corresponding receive floating rate.

4. For each floating rate, the corresponding fixed rate is in the range of $\pm 0.5\%$ of the floating rate at the selected starting date of our simulations. Hereby the deviation from the floating rate is uniformly distributed between $\pm 0.5\%$.

5. All notionals are the same ($1 billion) unless the total notional of forward rate agreements in billions is uneven, in which case the contracts of the last two offsetting contracts are set to $1.5 billion (see algorithm below).

6. All forward rate agreements have maturities below 1 year and the maturities 3 months, 6 months and 9 months are equally likely with 1/3 probability each.

Algorithm 1: Algorithm to generate Portfolio of Forward Rate Agreements

```
   Input : FRA notional in billion USD fra
1  if (fra mod 2 = 0) then
2      Number of contracts n = fra
3      Notional of each contract = $1bn
4      Assign floating rate as receive rate to first n/2 contracts randomly
5      Assign fixed rate as pay rate to first n/2 contracts in a range ±0.5% of
         floating rate at start date
6      for i in 1: n/2 do
7          if Receive Rate of Contract i in currency ABC then
8              Assign floating rate as pay rate to contract n/2 + i randomly from
                 currency ABC
9              Assign fixed rate as receive rate as in line 5
10         end
11     end
12     Choose maturity for all contracts randomly from
         {3 months, 6 months, 9 months}
13 else
14     Number of contracts n = fra − 1
15     Notional of contract n/2 and n = $1.5bn
16     Notional of all other contracts = $1bn
17     continue as above from line 4
18 end
```

The algorithms for the portfolios of the remaining three instruments is similar to the above with the corresponding assumptions listed in Appendix A.

The next section presents results achieved by using the portfolio construction algorithm described in this section and the data presented in section 3.1.

3.4 Results

The focus in this section is to show the differences in cash flows between the case in which margin payments have to be made along the side of the swap/forward contract payments themselves, and the case in which we assume that no margin payments are required. We will see that introducing mandatory margining processes into the OTC market does make a substantial difference. To put the resulting additional cash flows arising from margin payments into context, we will compare them with the liquidity resources available to each of the four considered banks.

The proxy portfolios below are based on the actual composition of the derivatives held by each bank and as such should give us some indication on the order of magnitude of the real cash flows resulting from margin payments being imposed on the OTC trading portfolios of each bank.

3.4.1 Proxy for Citibank

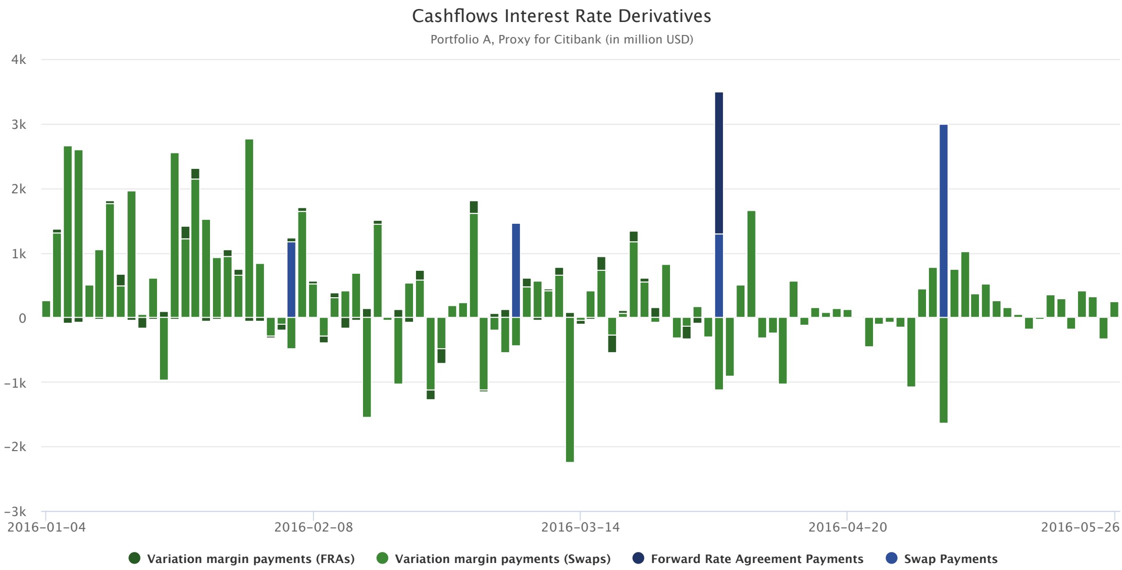
Portfolio A - starting date: 4 January 2016

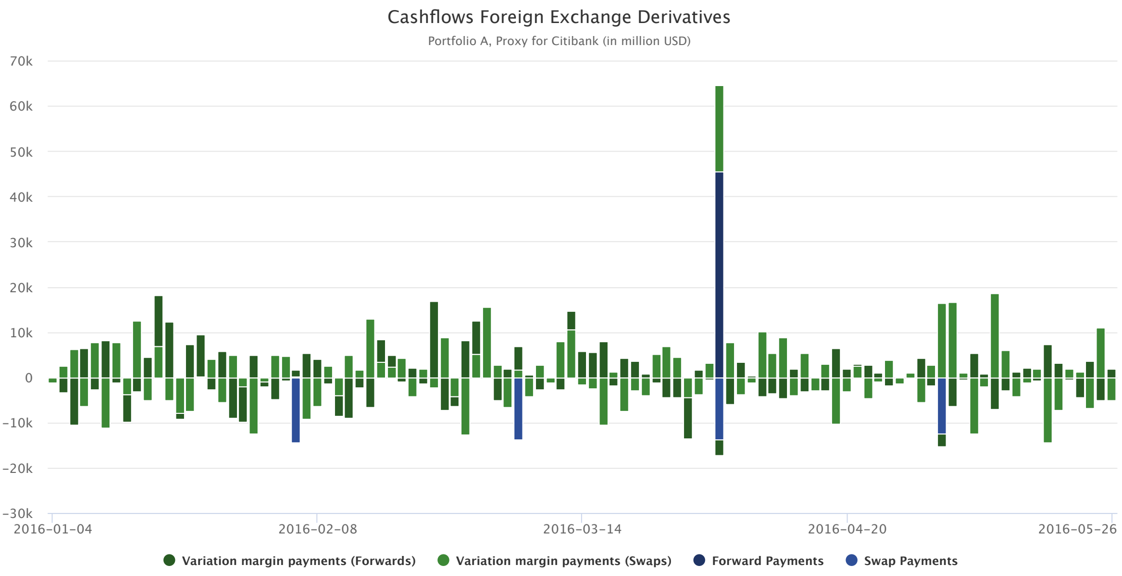
Interest rate derivatives

Instrument	Maturity	Receive	Pay	Payment frequency	Notional (USD)
FRA	3 months	0.7%	USD 3M LIBOR		3 trillion
FRA	3 months	USD 6M LIBOR	0.9%		2.5 trillion
Swap	6 months	0.6%	USD 6M LIBOR	monthly	2 trillion
Swap	6 months	USD 3M LIBOR	0.6%	monthly	1 trillion
Swap	10 months	0.1%	EUR 6M LIBOR	monthly	3 trillion
Swap	15 months	EUR 12M LIBOR	0.1%	quarterly	3 trillion
Swap	18 months	0.7%	USD 3M LIBOR	quarterly	3 trillion
Swap	24 months	USD 6M LIBOR	0.8%	quarterly	2.8 trillion
Swap	6 years	1.1%	USD 12M LIBOR	yearly	1 trillion
Swap	7 years	USD 6M LIBOR	0.9%	yearly	1.2 trillion
Swap	8 years	1%	GBP 12M LIBOR	yearly	1.5 trillion
Swap	10 years	GBP 6M LIBOR	0.8%	yearly	1 trillion

Foreign exchange derivatives

Instrument	Maturity	Details	Payment frequency	Notional (USD)
Forward	3 months	EUR/USD		1 trillion
Forward	6 months	USD/GBP		1 trillion
Swap	6 months	USD (6M LIBOR) / EUR (6M LIBOR)	monthly	1 trillion
Swap	8 months	EUR (0.5%) / GBP (2%)	monthly	1 trillion
Swap	9 months	GBP (12M LIBOR) / USD (1.1%)	monthly	1 trillion
Swap	9 months	USD (12M LIBOR) / EUR (0.6%)	monthly	0.9 trillion
Swap	10 months	EUR (6M LIBOR) / USD (6M LIBOR)	monthly	0.9 trillion
Swap	3 years	USD (1%) / GBP (3M LIBOR)	quarterly	0.9 trillion
Swap	10 years	GBP (6M LIBOR) / EUR (3M LIBOR)	yearly	0.4 trillion





We can observe that for both interest rate and foreign exchange derivatives, the forward and swap payments only make up a very small proportion of the cash flows, while the majority originates from variation margin payments.

Furthermore, the two graphs above illustrate that the notional amount is not necessarily indicative of the size of variation payments: while the notional of foreign exchange derivatives is only 36% of the interest rate counterpart, the absolute variation margin payments of the foreign exchange contracts are on average more than five times larger.

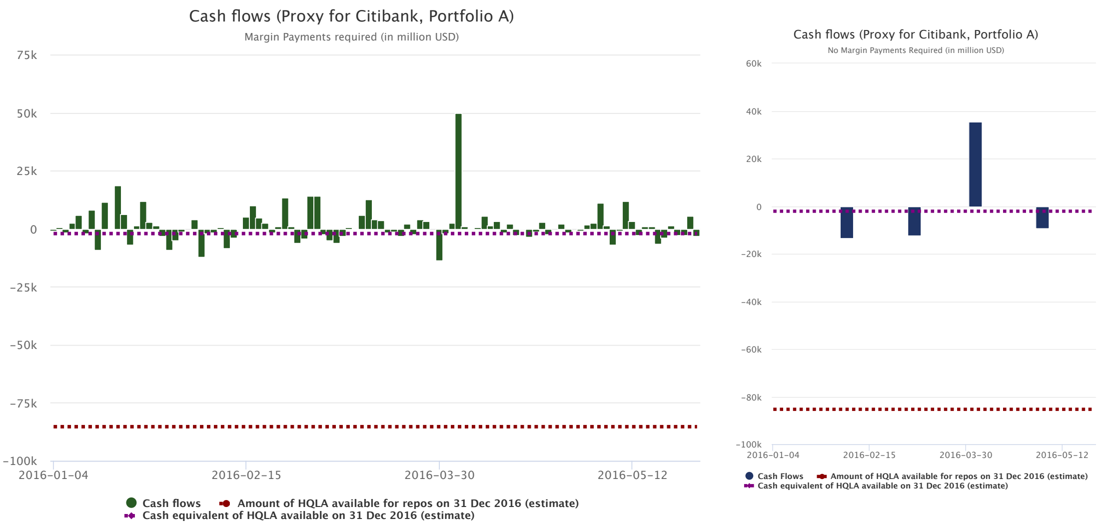


Figure 5: Cash flows with (left) and without (right) margin payments - Portfolio A, Proxy for Citibank

Figure 5 shows that for Portfolio A, the net cash outflows are repeatedly larger than the amount of cash equivalent available to Citibank in the case where variation margin payments need to be made. The size of the variation margin payments relative to the available HQLA however is rather small in this proxy portfolio. In any case, we can easily observe that the strain on liquidity is much more pronounced in the case where margin payments are required.

Portfolio B - starting date: 4 January 2016

Portfolio constructed using algorithm described in section 3.3.

Interest rate derivatives

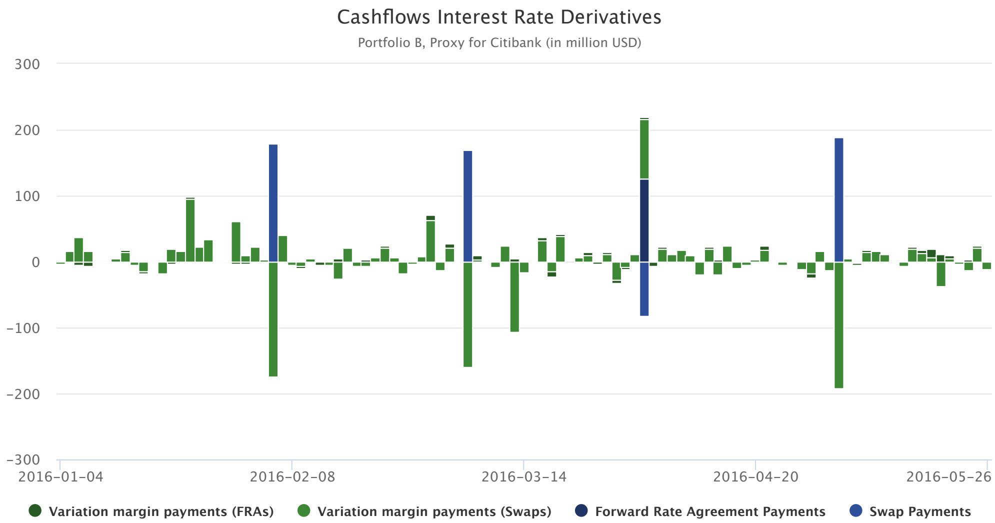
Row no.	Instrument	Maturity	Receive	Pay	Notional (USD)
1	FRA	6 months	GBP 12M LIBOR	1.37%	1 billion
2	FRA	3 months	USD 6M LIBOR	1.34%	1 billion
3	FRA	6 months	USD 3M LIBOR	0.61%	1 billion
⋮	⋮	⋮	⋮	⋮	⋮
2760	FRA	3 months	EUR 6M LIBOR	0.36%	1 billion
2761	FRA	9 months	-0.05%	GBP 6M LIBOR	1 billion
2762	FRA	9 months	0.8%	USD 12M LIBOR	1 billion
⋮	⋮	⋮	⋮	⋮	⋮
5220	FRA	9 months	-0.97%	EUR 3M LIBOR	1 billion

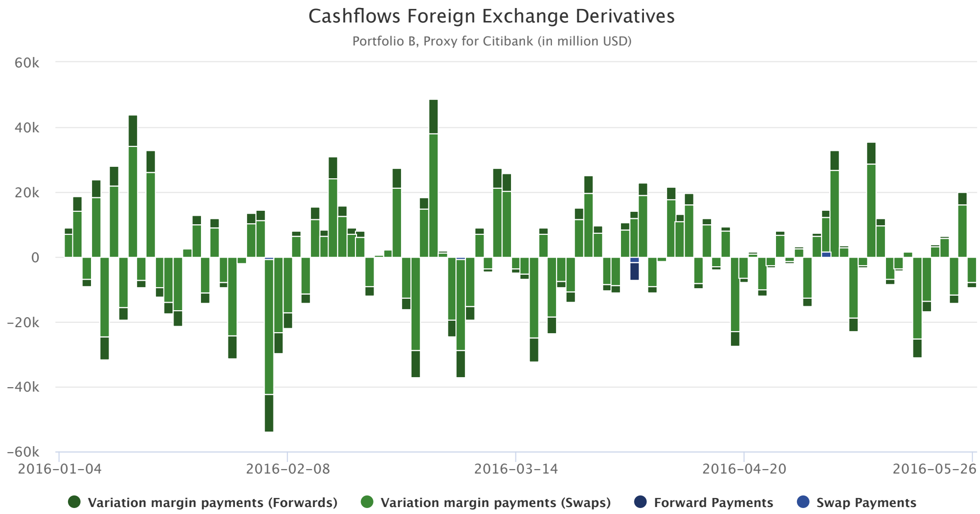
Row no.	Instrument	Maturity	Receive	Pay	Payment freq	Notional (USD)
1	Swap	9 months	USD 12M LIBOR	1.67%	monthly	1 billion
2	Swap	5 months	USD 6M LIBOR	0.44%	monthly	1 billion
3	Swap	9 months	USD 12M LIBOR	1.27%	monthly	1 billion
⋮	⋮	⋮	⋮	⋮	⋮	⋮
9660	Swap	7 years	GBP 12M LIBOR	0.77%	yearly	1 billion
9661	Swap	10 years	USD 12M LIBOR	1.60%	yearly	1.5 billion
9662	Swap	7 months	0.78%	USD 3M LIBOR	monthly	1 billion
9663	Swap	9 months	1.39%	USD 12M LIBOR	monthly	1 billion
⋮	⋮	⋮	⋮	⋮	⋮	
19321	Swap	8 years	0.12%	GBP 3M LIBOR	yearly	1 billion
19322	Swap	6 years	0.25%	USD 3M LIBOR	yearly	1.5 billion

Foreign exchange derivatives

Row no.	Instrument	Maturity	Details	Notional (USD)
1	Forward	6 months	EUR/USD	1 billion
2	Forward	3 months	EUR/USD	1 billion
⋮	⋮	⋮	⋮	⋮
2004	Forward	3 months	USD/EUR	1 billion
2005	Forward	3 months	GBP/USD	1 billion

Row no.	Instrument	Maturity	Details	Payment freq	Notional (USD)
1	Swap	8 months	EUR (12M LIBOR) / USD (3M LIBOR)	monthly	1 billion
2	Swap	6 months	GBP (3M LIBOR) / USD (12M LIBOR)	monthly	1 billion
3	Swap	3 months	GBP (12M LIBOR) / EUR (6M LIBOR)	monthly	1 billion
⋮	⋮	⋮	⋮	⋮	⋮
7017	Swap	6 years	GBP (12M LIBOR) / EUR (6M LIBOR)	yearly	1 billion
7018	Swap	8 years	USD (12M LIBOR) / EUR (-0.13%)	yearly	1 billion
7019	Swap	10 years	GBP (0.74%) / USD (12M LIBOR)	yearly	1 billion





The previously described disproportionate effect of margin payments on cash flow generated by foreign exchange derivatives in contrast to those originating in interest rate contracts is even more prominent in the portfolio B than in portfolio A. Furthermore, the net cash outflows make up a much bigger proportion of the HQLA available than in the previously constructed portfolio, as can be seen in figure 6 below:

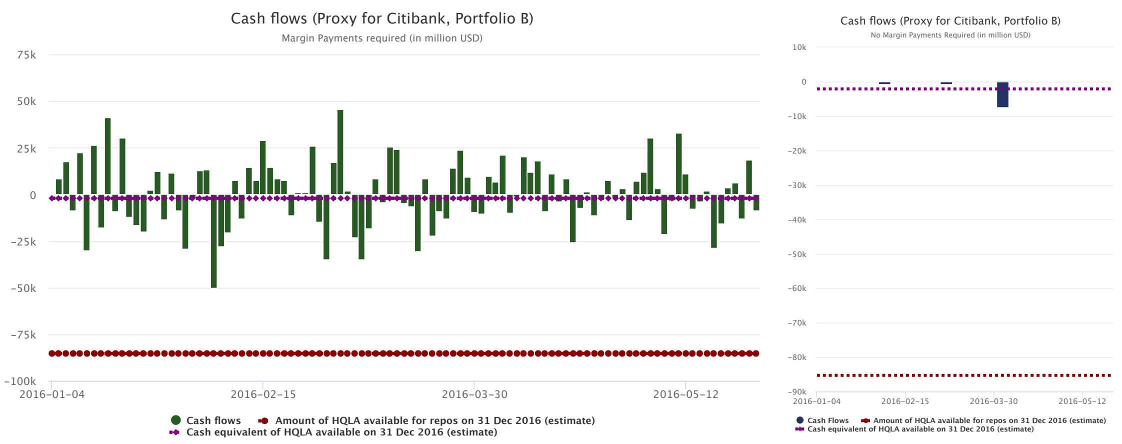


Figure 6: Cash flows with (left) and without (right) margin payments - Portfolio B, Proxy for Citibank

The increased impact on liquidity becomes even more apparent if we construct more proxy portfolios using the algorithm described in 3.3:

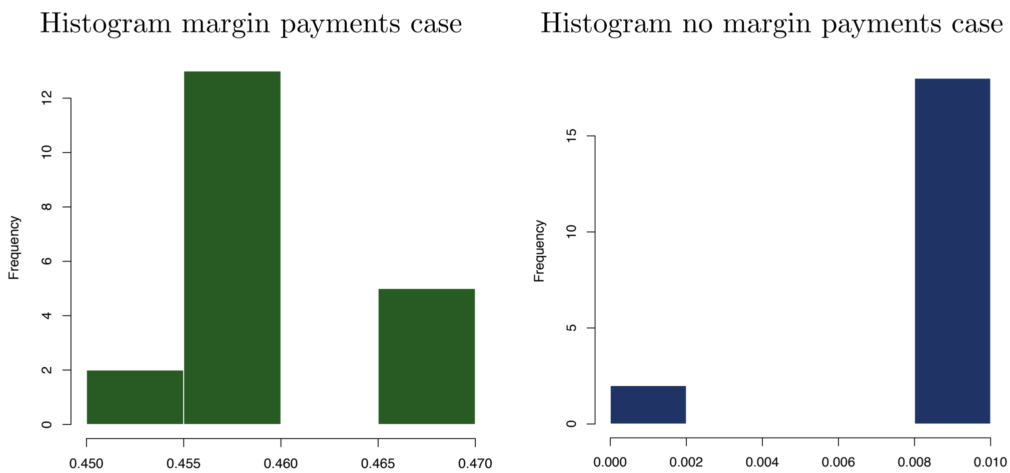


Figure 7: Percentage of trading days where cash outflow exceeds cash equivalent available (31 Dec 2016)

20 proxy portfolios over period of 100 trading days

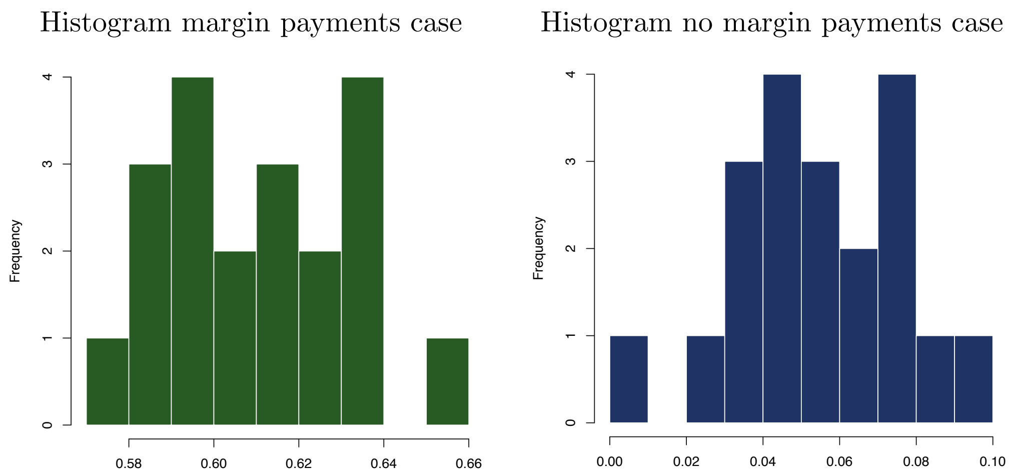


Figure 8: Largest net cash outflow as proportion of HQLA available for repos (31 Dec 2016)

20 proxy portfolios over period of 100 trading days

All in all, it is important to note that while the trading book only makes up around 33% of total assets of Citibank ([21]), the largest net cash outflow in our proxy portfolios was on average more than 60% of the HQLA available for repurchase agreements, i.e. short-term refinancing. Without margin payments, this proportion would have been only a little above 5%.

3.4.2 Proxy of JPMorgan Chase

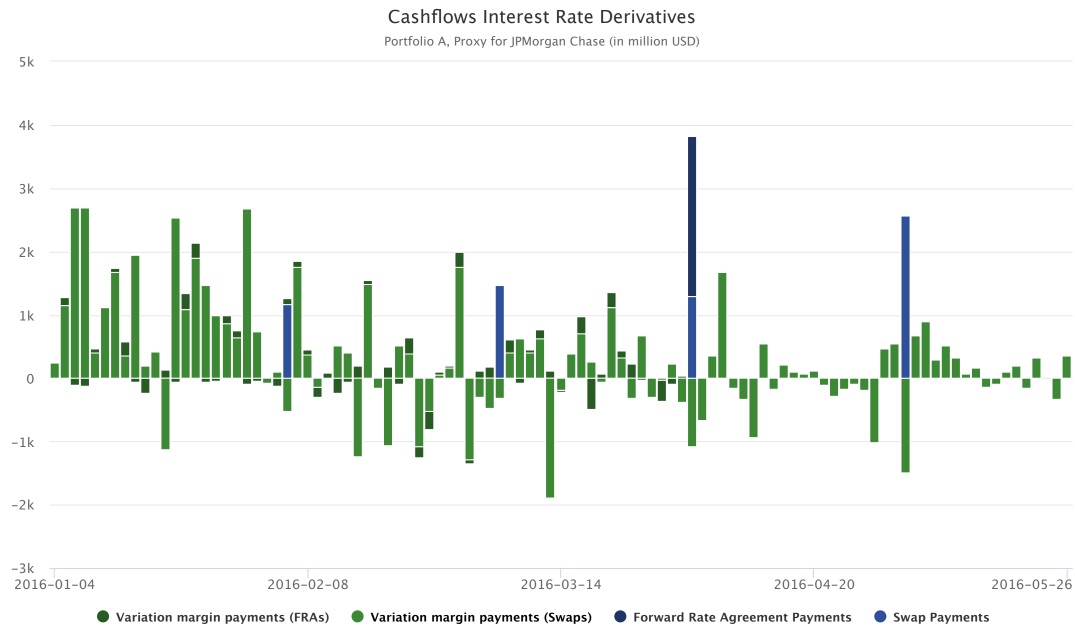
Portfolio A - starting date: 4 January 2016

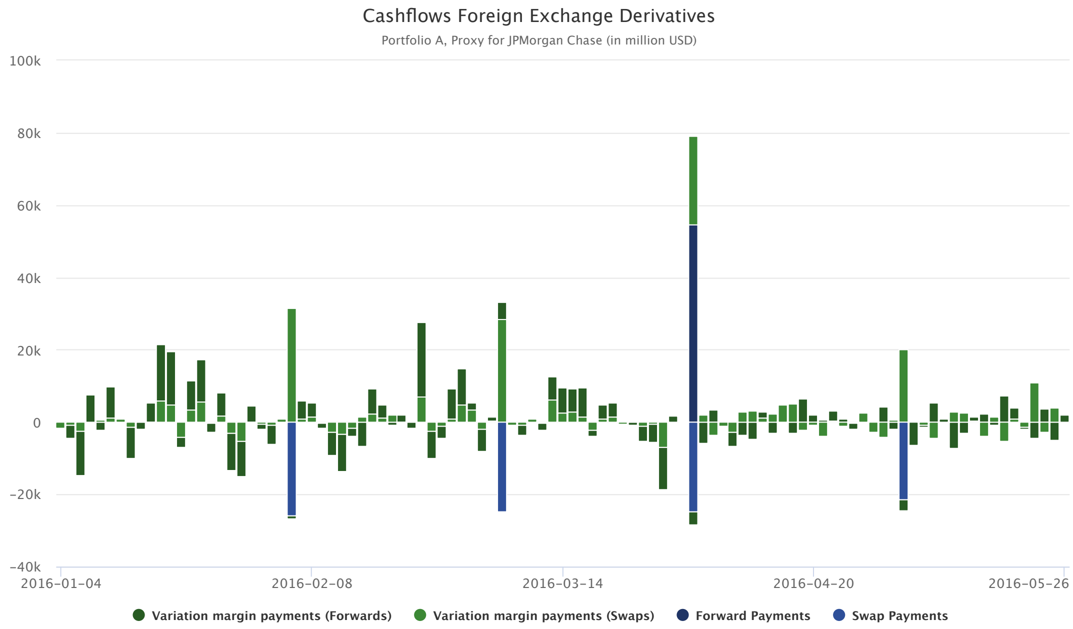
Interest rate derivatives

Instrument	Maturity	Receive	Pay	Payment frequency	Notional (USD)
FRA	3 months	0.7%	USD 3M LIBOR		3.4 trillion
FRA	3 months	USD 6M LIBOR	0.9%		3.5 trillion
Swap	6 months	0.6%	USD 6M LIBOR	monthly	2 trillion
Swap	6 months	USD 3M LIBOR	0.6%	monthly	1 trillion
Swap	10 months	0.1%	EUR 6M LIBOR	monthly	3 trillion
Swap	15 months	EUR 12M LIBOR	0.1%	quarterly	3 trillion
Swap	18 months	0.7%	USD 3M LIBOR	quarterly	3 trillion
Swap	24 months	USD 6M LIBOR	0.8%	quarterly	2.4 trillion
Swap	6 years	1.1%	USD 12M LIBOR	yearly	1 trillion
Swap	7 years	USD 6M LIBOR	0.9%	yearly	1.3 trillion
Swap	8 years	1%	GBP 12M LIBOR	yearly	1.5 trillion
Swap	10 years	GBP 6M LIBOR	0.8%	yearly	1.5 trillion

Foreign exchange derivatives

Instrument	Maturity	Details	Payment frequency	Notional (USD)
Forward	3 months	EUR/USD		1.2 trillion
Forward	6 months	USD/GBP		1 trillion
Swap	6 months	USD (6M LIBOR) / EUR (6M LIBOR)	monthly	2 trillion
Swap	9 months	EUR (0.5%) / GBP (2%)	monthly	2 trillion
Swap	2 years	GBP (12M LIBOR) / USD (1.1%)	quarterly	1 trillion
Swap	4 years	USD (12M LIBOR) / EUR (0.6%)	yearly	0.6 trillion
Swap	10 years	EUR (6M LIBOR) / USD (6M LIBOR)	yearly	0.8 trillion





As in the case of the Citibank proxy portfolios, we can observe that forward and swap payments only make up a small amount of the cash in- and outflows, whereas the majority is due to variation margin payments. Similarly, the variation margin payments from foreign exchange derivatives are on average more than five times as large than those from interest rate derivatives, even though the notional of foreign exchange derivatives is only 32% that of interest rate derivatives.

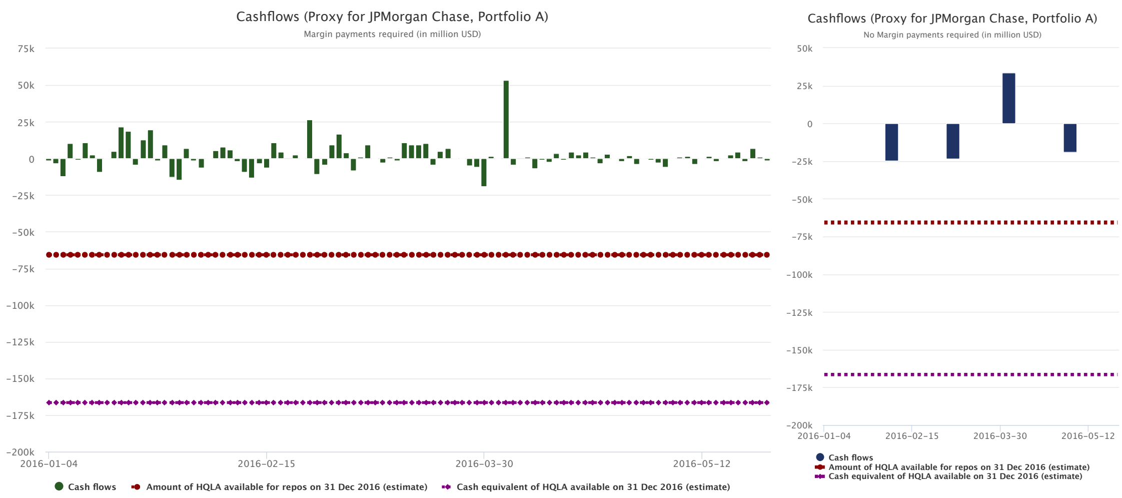


Figure 9: Cash flows with (left) and without (right) margin payments - Portfolio A, Proxy JPMorgan

In contrast to the portfolios constructed based on Citibank's data, the cash outflows never surpass the cash equivalent or the HQLA available for repo for this portfolio. The same is true for portfolios constructed using the algorithm, as we can see below.

Portfolio B - starting date: 4 January 2016

Portfolio constructed using algorithm described in section 3.3.

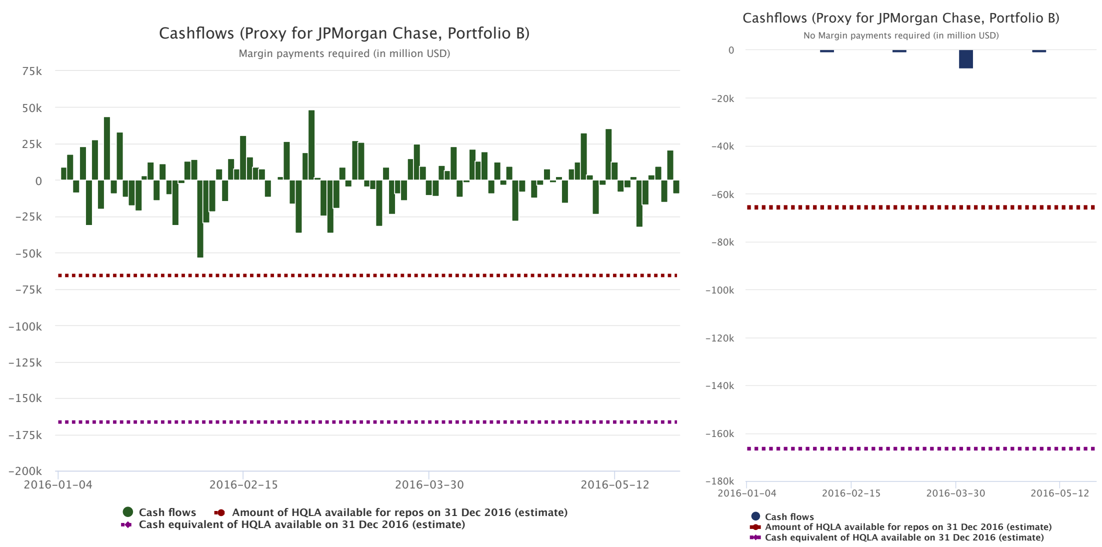


Figure 10: Cash flows with (left) and without (right) margin payments - Portfolio B, Proxy JPMorgan

If we generate 20 proxy portfolios with starting date 4 January 2016, in none of the 20 portfolios does the cash outflow exceed the amount of cash equivalent available on any given trading day. However, the cash outflows still put a significant strain on the banks' liquidity:

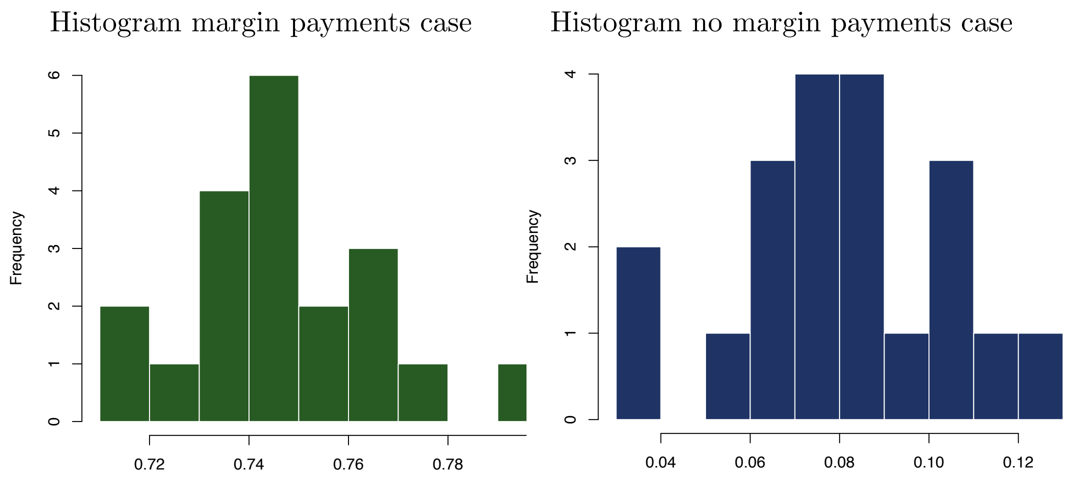


Figure 11: Largest net cash outflow as proportion of HQLA available for repos (31 Dec 2016)

20 proxy portfolios over period of 100 trading days

But as mentioned in section 3.1, concerns have been raised about the data reported by JPMorgan Chase and we also always have to bear in mind that the amount of HQLA available for repurchase agreements as well as the cash equivalent available are nothing but estimates.

Nevertheless, even though trading assets and securities make up a mere 25% of JPMorgan's assets ([21]), we can observe that at times the cash outflow triggered by margin payments exceeds 75% of the available HQLA. This shows that trading derivatives can potentially drain a disproportionately large amount of the bank's refinancing resources compared to their share of total assets.

3.4.3 Proxy of Goldman Sachs (GS)

Portfolio A - starting date: 4 January 2016

Portfolio constructed using algorithm described in section 3.3.

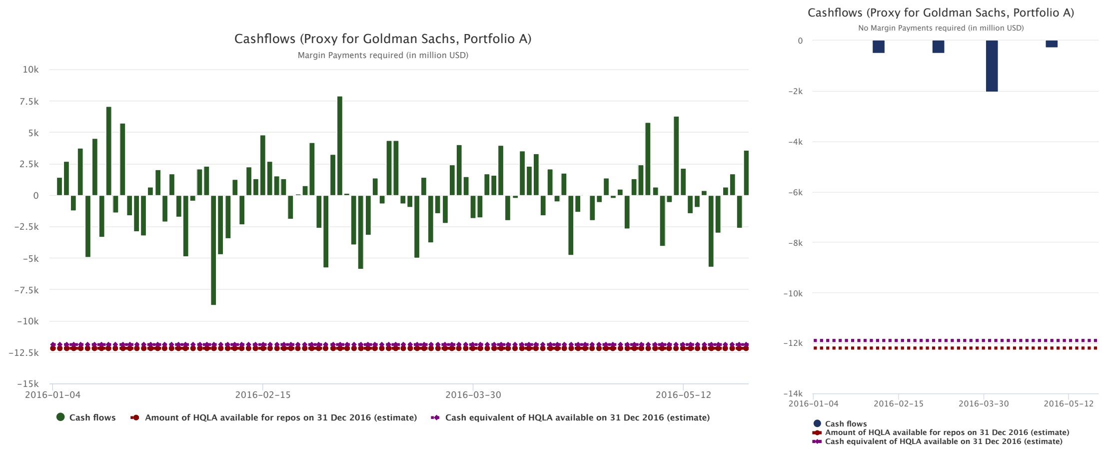


Figure 12: Cash flows with (left) and without (right) margin payments - Portfolio A, Proxy for GS

Just like in the JPMorgan proxy portfolios, none of the cash outflows surpasses the amount of cash equivalent available on any given trading day if we generate 20 proxy portfolios with starting date 4 January 2016. Again, considering the fact that trading assets and securities only make up roughly 20% of Goldman Sachs total assets, the proportion of HQLA needed in times of stress to pay variation margins can be more than three times that number of the total HQLA available to Goldman Sachs:

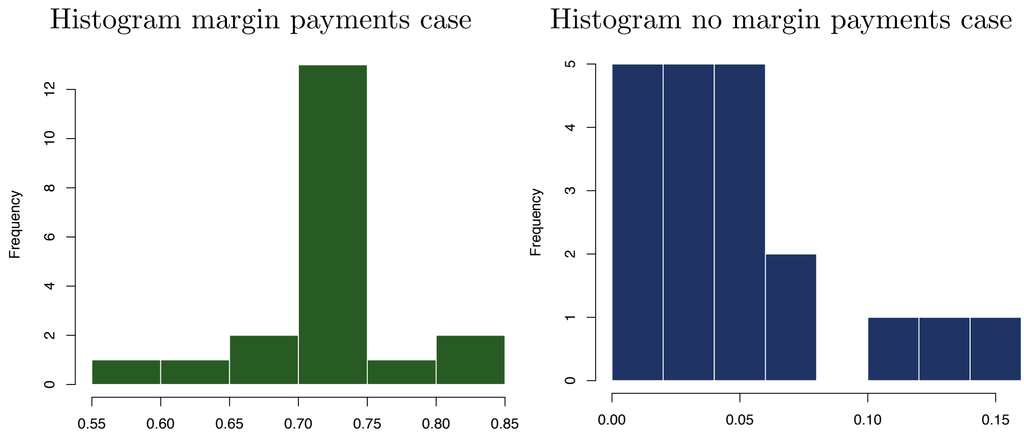


Figure 13: Largest net cash outflow as proportion of HQLA available for repos (31 Dec 2016)

20 proxy portfolios over period of 100 trading days

3.4.4 Proxy of Bank of America (BoA)

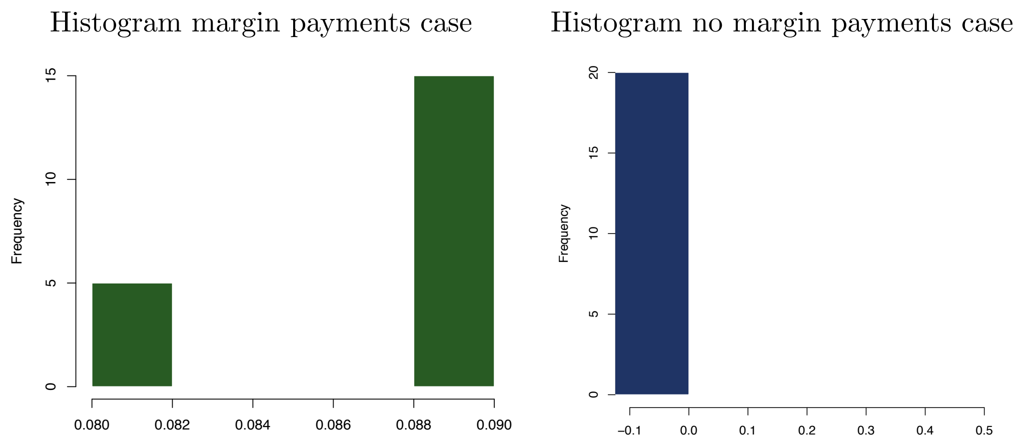


Figure 14: Percentage of trading days where cash outflow exceeds cash equivalent available (31 Dec 2016)

20 proxy portfolios over period of 100 trading days

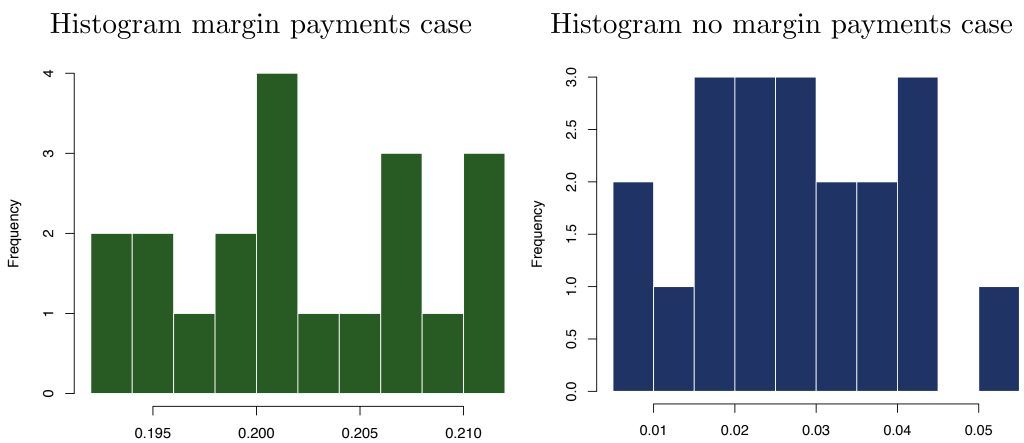


Figure 15: Largest net cash outflow as proportion of HQLA available for repos (31 Dec 2016)

20 proxy portfolios over period of 100 trading days

For Bank of America, the trading book makes up roughly 28% of their balance sheet. In the above histograms, we have not yet considered the fact that the reported HQLA is that of the parent corporation, not that of Bank of America N.A:

Institution	Total Assets
Assets Bank of America N.A.	$1,677bn
Assets Bank of America Corporation	$2,189bn

If we multiply the amount of HQLA by the ratio of the total assets of both institutions, the total estimated amount of HQLA of Bank of America available for repurchase agreements becomes $98.6bn, and the histograms that sets the cash outflows in relation to the available HQLA change to the following:

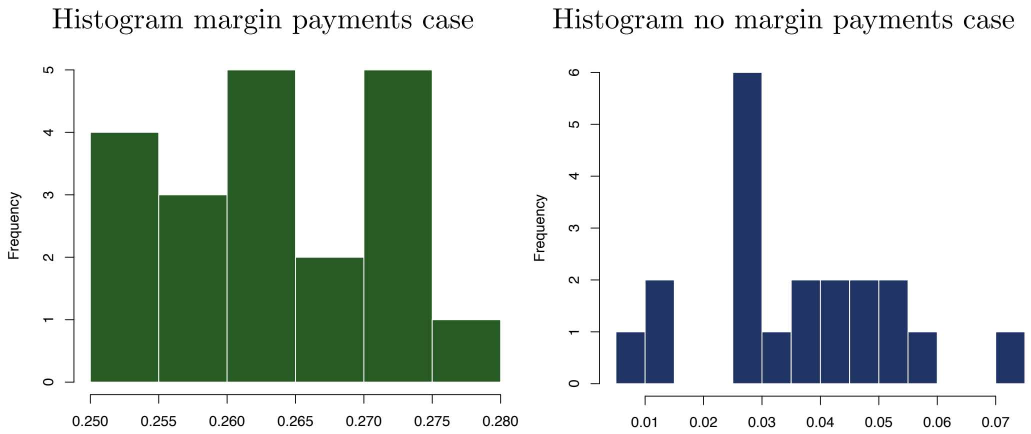


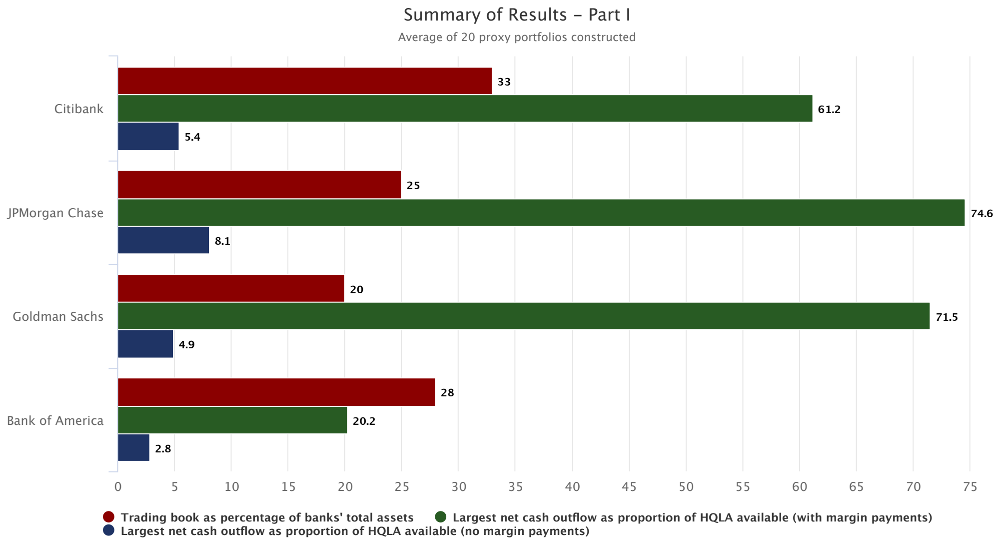
Figure 16: Largest net cash outflow as proportion of HQLA available for repos adjusted (31 Dec 2016)

20 proxy portfolios over period of 100 trading days

In this case, the proportion of trading assets and securities on the balance sheet is around the same as the percentage of HQLA needed in times of stress to pay variation margins.

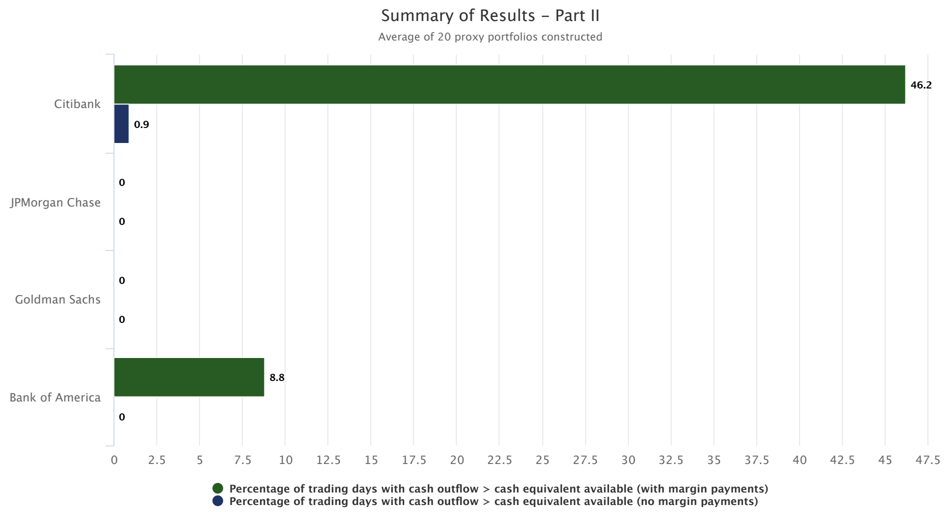
4 Conclusions

We have seen that the proportion of the trading book relative to total assets on the balance sheet does not necessarily give an indication about the percentage of HQLA and cash equivalents needed to pay variation margins associated with these derivative contracts:



For all banks except for Bank of America, the trading derivatives in the proxy portfolios we constructed utilize a much higher proportion of HQLA than their share on the balance sheet in the case of margin payment requirements. In absence of the margining process, the proportion of HQLA needed is always below the proportion of the trading book on the respective banks' balance sheets and does not even exceed 10% of the HQLA available for repurchase agreements.

For Citibank and Bank of America, the required variation margins even exceed their available cash equivalents on multiple trading days:



The introduction of obligatory margin payments therefore does put a significant strain on banks' liquidity and indicates that the liquidity risk associated with central clearing and bilateral OTC margin requirements is far from negligible.

Regulators have considered margin requirements and central clearing mandates through the sole angle of counterparty risk reduction. Our results illustrate the fact that, while reducing counterparty risk, margin requirements may result in a significant increase in the liquidity risk of banks. The liquidity risk associated with central clearing and bilateral OTC margin requirements should therefore be accounted for by regulators and banks in their stress testing and risk management frameworks.

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Appendices

A Assumptions for construction of proxy portfolios

A.1 Assumptions for Interest Rate Swaps

1. Half of the contracts are payer, the other half receiver contracts, where each payer is offset by a receiver in the same currency.

2. When choosing the receive floating rate, each interest rate (USD 3m, USD 6m, USD 9m, EUR 3m, ..., GBP 12m) is equally likely to be picked.

3. After the receive floating rates are determined for the payer contracts, the pay floating rate of each of the corresponding receiver contracts is equally likely chosen to be the 3 month, 6 month or 12 month rate in the same currency, regardless of the exact corresponding receive floating rate.

4. For each floating rate, the corresponding fixed rate is in the range of $\pm 0.5\%$ of the floating rate at the selected starting date of our simulations. Hereby the deviation from the floating rate is uniformly distributed between $\pm 0.5\%$.

5. The notional of each swap is \$1bn, unless the number of swaps with maturity in any of the buckets $\{< 1\text{y}, 1-5\text{y}, > 5\text{y}\}$ is uneven. If that is the case, the number of swaps in that bucket is reduced by one and the notional of the last two offsetting swaps is \$1.5bn.

6. All swaps with maturity < 1 year are equally likely to mature in $3, 4, \ldots, 11, 12$ months, swaps with maturity between 1 and 5 years are equally likely to mature at the end of any quarter in that period and swaps with maturity over 5 years at the end of each year up to 10 years.

7. The payment frequency is monthly for swaps with maturity < 1 year , quarterly

for swaps with maturity between 1 and 5 years and yearly for swaps with maturity > 5 years.

A.2 Assumptions for Forex Swaps

1. Since we only consider three currencies, all foreign exchange forwards fall into one of the following types:

   - EURGBP
   - GBPEUR
   - EURUSD
   - USDEUR
   - GBPUSD
   - USDGBP

   and each of the above types is equally likely to be selected by the algorithm. This feature makes the need of 'offsetting one contract with another' - needed in the case of interest rate derivatives - unnecessary since on average, 1/6 of the contracts will be EURGBP and 1/6 GBPEUR and similarly for EURUSD and USDEUR as well as GBPUSD and USDGBP.

2. All forex swaps have notional of $1 billion and maturities below 1 year. Hereby the maturities 3 months, 6 months and 9 months are equally likely to be chosen.

A.3 Assumptions for Cross Currency Swaps

1. Since we only consider three currencies, all foreign exchange swaps fall into one of the types EURGBP, GBPEUR, EURUSD, USDEUR, GBPUSD or US-DGBP and each of the types is equally likely to be selected by the algorithm. This feature makes the need of 'offsetting one contract with another' - needed in the case of interest rate derivatives - unnecessary since on average, 1/6 of

the contracts will be EURGBP and 1/6 GBPEUR and similarly for EURUSD and USDEUR as well as GBPUSD and USDGBP.

2. The receive and pay rates are floating with probability 2/3 and fixed with probability 1/3.

3. If the interest payment of a contract involves a fixed rate in currency XXX, the rate is in the range of $\pm 0.5\%$ of the 6 month LIBOR in currency XXX at the selected starting date of our simulations. Hereby the deviation from the 6 month LIBOR is uniformly distributed on the interval $[-0.5\%, 0.5\%]$.

4. All notionals are $1 billion.

5. All cross currency swaps with maturity < 1 year are equally likely to mature in $3, 4, \ldots, 11, 12$ months, swaps with maturity between 1 and 5 years are equally likely to mature at the end of any quarter in that period and swaps with maturity over 5 years at the end of each year up to 10 years.