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Building an Optimal Execution Plan for Liquidity Management Using SAS®

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ABSTRACT

Liquidity risk management is the management of the bank's ability to meet its obligations as they come due, without incurring losses. Liquidity risk management is seen to be of paramount importance and a subject of great interest for the regulators because a liquidity shortfall at a single significant institution can lead to system-wide effects. In contrast to risk based capital for other forms of risks such as market and credit risk, the cushion for liquidity risk is not created through additional capital. Since the main purpose of the cushion for liquidity risk is to mitigate the net cumulative cash outflows, it is done by using a pool of high-quality liquid assets that can be sold immediately or used in collateral for short-term loan (repo) transactions to raise funds. Given a sufficient liquidity hedging portfolio banks also need to consider strategizing its response to liquidity crisis in advance. Most notably, this includes having a strategy for liquidity execution. That is, building a plan for optimal liquidity execution. Liquidity execution is therefore one of the core functions in the bank and management of liquidity risk has become even more important after the recent financial crisis. In a liquidity execution, apart from the financial cost of the execution itself, a firm must also take into account reputational and opportunity cost. When multiple liquidity distress stages are anticipated banks can be more willing to hold on to the most liquid assets, and not risk a fire sale of illiquid assets, in later more severe distress stages. This is clearly a decision making process based on a long term survival strategy. Therefore an important aspect of liquidity management and in particular liquidity execution is to recognize the fact that a liquidity distress period usually evolves in multiple stages, and, when the funding liquidity shortage evolves so does the borrowing cost and market liquidity as well. An institutions liquidity execution plan should therefore incorporate this multi-stage nature of the liquidity distress and the fact that execution costs, liquidity depth and other market factors vary across stages.

INTRODUCTION

Banks hold liquidity capacity to prepare for mitigation of unfavorable funding gaps. Such unfavorable funding gaps can arise due to bank-specific stress such as an increase in funding withdrawal of consumer's deposits with the bank and a cancellation of the bank's committed lines of credit. Unfavorable funding gaps can also arise in a general economic downturn such as an adverse market scenario to the bank causing increased derivatives margin requirements and increased collateral posting due to reduced value of collateral. Liquidity risk is in general a consequential risk, following a troubled situation with losses. Indeed, the recent credit crisis compounded itself quickly into a major liquidity crisis (or funding problem), leading to insolvency of major financial institutions. During the crisis it became obvious that many banks had inaccurate and ineffective management of liquidity risk and, in particular, were not adequately prepared in planning for mitigating actions. Moreover, many banks did not have a dedicated liquidity buffer or liquidity portfolio that was managed for the sole purpose of mitigating liquidity gaps. The response from the regulators came almost immediately after the crisis.

The new Basel III liquidity risk regulation (Bank for International Settlements (2010, 2011)) underscores the importance of managing a liquidity contingency buffer in much the same way as capital. The focus is on maintaining a high quality liquidity portfolio that can hedge liquidity outflows under stress scenarios. This is formalized in the new regulation by requiring banks to report so-called liquidity coverage ratios (LCRs) that test the sufficiency of the liquidity hedging portfolio under behavioral, market, and bank-specific stresses. Under these stresses the bank's liquidity portfolio needs to hedge the stressed net funding outflow over the time horizon of 30 days under a going concern assumption (that is, contractual maturity is not necessarily the assumed maturity and the expected behavior of rollover of funding and assets are modeled under the stress). This test becomes the regulatory test whether a bank has a sufficient short-term liquidity buffer. Of course, a bank can be solvent under short-term liquidity stress, by adjusting the liquidity buffer accordingly, but still have a structural funding liquidity problem (for example, if a large proportion of long-term assets are funded relatively short-term). The so-called net stable funding ratio (NSFR) measures the 1-year structural funding mismatch of the balance sheet by dividing the amount of available stable funding with the amount of required stable funding. Basel III provides banks with the regulatory factors to multiply the balance sheet items in the computation of the numerator and denominator. A bank is deemed to satisfy the regulatory long-term structural funding mismatch test if the ratio is above 100%. In addition to the test of a sufficient short-term liquidity portfolio, through the liquidity coverage ratio, and the test of the long-term structural funding mismatch, through the net stable funding ratio, banks are required to monitor liquidity risks through reporting on areas such as funding concentrations, market monitoring, and traditional run-off maturity mismatch. Figure 1 displays the Basel III regulatory liquidity reporting measures, liquidity coverage ratio, and net stable funding ratio, as well as the new regulatory monitoring standards.

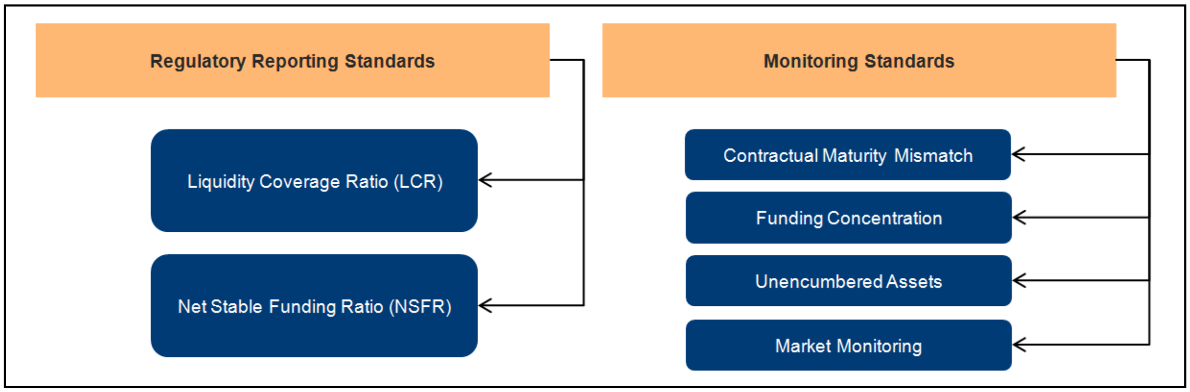

Figure 1. The Basel III regulatory measures and the monitoring standards

In the regulatory test of the liquidity coverage ratio, the bank's dedicated liquidity hedging assets of high quality unencumbered assets are available to hedge the cash outflow from encumbered assets and liabilities. The underlying stress scenarios for encumbered assets and liabilities contain both institution-specific shocks (for example, downgrade) as well as systemic liquidity crisis. This includes a loss of deposits and a loss of unsecured funding, as well as increases in margin calls for derivatives and calls on the bank's committed credit lines. The counterbalancing capacity of the unencumbered assets should neutralize any negative outflows from the encumbered assets and liabilities under the stress scenario. The stock of counterbalancing capacity assets should be assets that retain liquidity even under severe stress conditions, and the Basel III eligible buffer of liquidity hedging assets includes so-called level 1 and level 2 assets. Level 1 assets have a zero haircut and include items such as cash, central bank reserves, and premium government and municipal bonds. Level 2 assets have a regulatory haircut of 15% and include, for example, high quality corporate and covered bonds.

Figure 2 illustrates three scenarios on net funding requirements for the encumbered assets and liabilities (that is, the base case, stress scenario 1, and stress scenario 2). In both stress scenarios there are negative outflows that need to be hedged although the stress scenario 2 has significantly more outflows. Figure 2 also displays the counterbalancing capacity raised through liquidation or collateralized borrowing of the unencumbered assets. In the net cash flow maps for the base case and stress scenarios 1 and 2, we can observe the total net outflow after the counterbalancing capacity has been applied to the net funding requirements. In both the base case and stress scenario 1 the counterbalancing capacity is sufficient to hedge out the negative cash flows for the time period considered (that is, 6 months). However, for stress scenario 2 the net cash outflow is expected to be negative after 1 month. While this would still keep the institution regulatory eligible for the liquidity coverage ratio, having a measurement time period of 30 days, a review of the sufficiency of the counterbalancing capacity portfolio is called for.

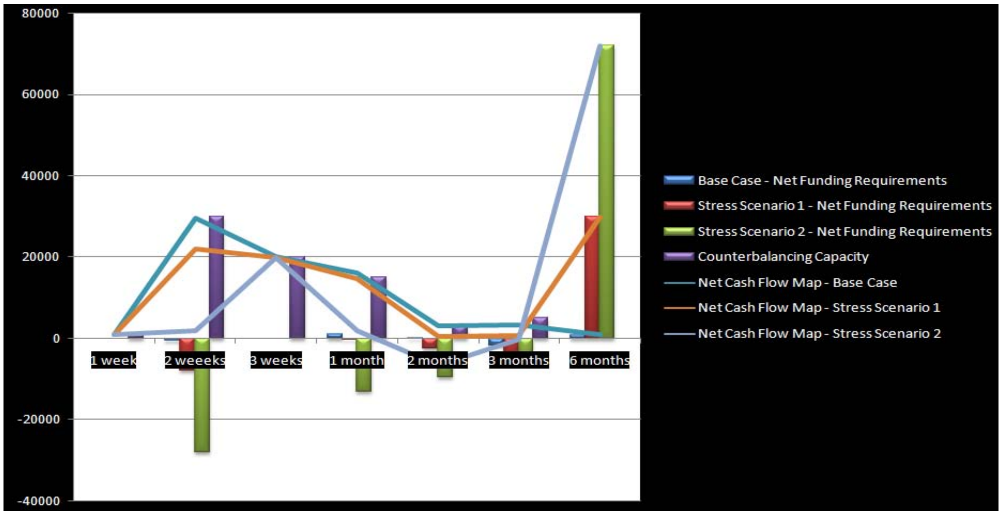

Figure 2. Base case and stress scenarios for net funding requirements of encumbered assets and liabilities as well as counterbalancing capacity of unencumbered assets and the net cash flows after liquidity hedging

The regulatory requirement to hold a dedicated liquid buffer to mitigate fund outflows has naturally been driving institutions to also price costly liquidity. For example, should the institution offer a large liquidity facility to another institution then, effectively, a liquidity buffer needs to be defined should the institution draw a large unused amount. Indeed, this extended withdrawal is expected in a stressful situation and the opportunity cost of holding the needed buffer should hence be priced on the facility user. For details about Basel III liquidity measures, stress testing of liquidity risk, as well as liquidity pricing, we refer the reader to the SAS white paper on liquidity risk management after the crisis (Skoglund and Mathur (2011)).

Given a sufficient counterbalancing capacity portfolio of unencumbered assets, Basel III also requires banks to strategize its response to liquidity crisis in advance through contingency funding plans. Such a contingency funding plan includes having a strategy for liquidity execution. While the simplest way to build a liquidity portfolio is to hold affluent cash at hand, this is not optimal for a profit-seeking institution. In general, high liquidity assets, such as cash, are most costly to hold (that is, have a higher opportunity cost) but are less costly in terms of execution cost when needed to create liquidity. When liquidity creation depends on non-cash assets such as corporate bonds, asset liquidity is often measured by the market depth of an asset. In this paper we use the multi-stage minimal cost optimization model developed in Chen, Skoglund, and Cai (2012) to quantify the decision on the liquidity execution for a portfolio of liquidity hedging unencumbered assets. Chen, Skoglund, and Cai (2012) consider several models for liquidity execution – including a model that includes collateralized borrowing through repo. However, in this paper we restrict ourselves to the application of a model that considers a tiered execution cost with no collateralized borrowing. The liquidity optimization model not only provides a solution at the time of liquidity execution (that is, in a liquidity distress period) but also helps banks in building an a priori practical liquidity plan consistent with Basel III required contingency funding plans. In addition, the model can be used to test the sufficiency of the firm's liquidity hedging portfolio under realistic business or regulatory assumptions on haircuts, execution costs, and eligible liquidity supplying assets.

PLANNING FOR OPTIMAL LIQUIDITY EXECUTION

For the optimal liquidity execution plan we consider one of the models developed in Chen, Skoglund, and Cai (2012). The model accommodates a multi-stage liquidity need where the liquidity gap and execution cost can be different across stages. In our model setting there are therefore K consecutive liquidity distress stages that a firm faces. This multi-stage nature is an important aspect for a liquidity management decision making process, because in reality, when funding liquidity starts to show distress, a firm's borrowing capacity and cost will worsen across stages. The model assumes a linear price dependency on the volume and also assumes that an asset can be traded within a trading period up to a certain trading threshold v known as "market depth" at a market bid-ask spread c_0. In order to execute the trading in a bigger volume, market price moves unfavorably at a cost rate c_1 where $\mathrm{c}_1 > \mathrm{c}_0$ in excess to the market trading cost due to the bid-ask spread. The higher execution cost c_1 can be interpreted as fire sale cost. The total liquidity gap across all distress stages is divided into stage $\mathrm{k} = 1, \ldots, \mathrm{K}$ specific gaps. Any fund raised during any transaction period in a stage is immediately applied to reduce the gap. Effectively, this means we make no distinction between cash raised at the beginning or end of a distress period. What matters is how cash is raised across distress stages, $\mathrm{k} = 1, \ldots, \mathrm{K}$, to fill the distress stage gap. However, within a distress period k naturally execution limits might differ since the limit is not necessarily triggered by the distress stage but could be exogenous. For example, cash withdrawal might be subject to deposit institution cash availability on a certain day and credit line drawdown might be subject to a daily limit.

To introduce the model we let

$\mathrm{c(x)} = \mathrm{c}_1(\mathrm{x} - \mathrm{v}) + \mathrm{c}_0(\mathrm{v})$ if $\mathrm{x} < v$ and $\mathrm{c}_0(\mathrm{x})$ otherwise.

The cost function can be equivalently written as

$\mathrm{c(x)} = (\mathrm{c}_1 - \mathrm{c}_0)(\mathrm{x} - \mathrm{v})_+ + \mathrm{c}_0(\mathrm{x})$ where $(\mathrm{x} - \mathrm{v})_+ = \mathrm{x} - \mathrm{v}$ if $\mathrm{x} < v$ and 0 otherwise

which can be further be expressed as

$\mathrm{c(x)} = (\mathrm{c}_1 - \mathrm{c}_0)\mathrm{y} + \mathrm{c}_0(\mathrm{x})$

with constraints $\mathrm{y} \geq 0$ and $\mathrm{y} \geq \mathrm{x} - \mathrm{v}$, where y is an auxiliary variable.

Each distress stage k has M_k execution periods when the firm can raise funds. A new liquidity gap G_k incurs at each stage k. The firm has a portfolio of N_i $\mathrm{i} = 1, \ldots, \mathrm{N}$, instruments available to deploy. Each instrument i has a market value or principal A_i with an execution limit $\mathrm{l}_{\mathrm{ijk}}$ at a given execution period, $\mathrm{j}_\mathrm{k} = 1, .., \mathrm{M}_\mathrm{k}$, within a stage k. The firm's objective is to minimize the execution cost while raising the needed cash for the liquidity gap, G_k, for all $\mathrm{k} = 1, \ldots, \mathrm{K}$ from the given portfolio of liquidity supplying instruments. We define the cost function for each stage as

$$\mathrm{f}_\mathrm{k} = \sum_{\mathrm{i}=1}^{\mathrm{N}} \sum_{\mathrm{j}_\mathrm{k}=1}^{\mathrm{M}_\mathrm{k}} \left[(\mathrm{c}_{1\mathrm{ik}} - \mathrm{c}_{0\mathrm{ik}})\mathrm{y}_{\mathrm{ij}_\mathrm{k}} + \mathrm{c}_{0\mathrm{ik}}\mathrm{x}_{\mathrm{ij}_\mathrm{k}}\right]$$

A minimal cost optimization problem can hence be defined as

$$\min \sum_{k=1}^{K} f_k$$

subject to the following constraints for $i = 1, \ldots, N$, $j_k = 1, .., M_k$, $k = 1, \ldots, K$

$$x_{ij_k} \geq 0$$

$$x_{ij_k} < l_{ijk} \quad (1)$$

$$y_{ij_k} > 0$$

$$y_{ij_k} \geq x_{ij_k} - v_{ij_k}$$

$$\sum_{k=1}^{K} \sum_{j_k=1}^{M_k} x_{ij_k} \leq A_i \quad (2)$$

$$\sum_{i=1}^{N} \sum_{j_k=1}^{M_k} x_{ij_k} - f_k \geq G_k \text{ for all } k \quad (3)$$

where constraint (1) is the execution limit for each instrument at period j_k within liquidity distress stage k. This limit can be either due to a cash withdrawal limit allowed for the period imposed by the deposit institution or a trading limit imposed by a security exchange authority to prevent market crash. Constraint (2) indicates the total executed amount cannot be more than what is available. Finally, constraint (3) is the liquidity gap to be met in each distress stage, $k = 1, \ldots, K$. The execution cost, f_k, is added to the gap in each stage.

As a concrete example, consider a firm that is expecting two liquidity distress stages $k = 1$ and $k = 2$, respectively, where distress stage $k = 1$ has a duration of three days and distress stage $k = 2$ has a duration of two days. We assume that the cash that needs to be raised in each of the distress stages is 2,000,000 units of currency. Figure 3 illustrates the specification for the liquidity distress stages and the corresponding gap amounts that need to be covered.

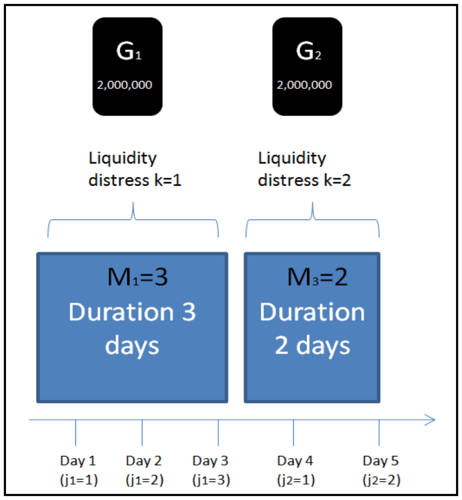

Figure 3. Specification for liquidity distress stages and gap amounts

Each liquidity facility can be executed up to a certain limit within a distress stage (in this case a day). When a liquidity facility is not available to convert to cash the limit is set to zero. Table 1 displays the available liquidity sources together with their available amounts and liquidity type. The portfolio of liquidity supplying facilities includes cash or cash equivalents, bonds, a facility, and equities.[1]

[1] While in a regulatory context there are constraints on the liquidity buffers that can be used for testing an institution's liquidity coverage, in practice, in a liquidity stress the institution will consider all assets eligible for sale. This means that assets such as equities, facilities, and core assets might be part of a liquidity execution analysis even though the assets are not regulatory eligible in defining the size of the liquidity buffer. If the model is instead used to test the sufficiency of the regulatory counterbalancing capacity portfolio in the liquidity coverage ratio, then naturally, only regulatory eligible assets are included in the model.

Liquidity	Available amount	Liquidity type
Cash 1	500,000	Small cost
Cash 2	1,000,000	Small cost, not available immediately
Bond 1	700,000	Small cost
Bond 2	800,000	Medium to large cost
Facility	500,000	Small to medium cost, might be constrained
Equity 1	600,000	Medium cost
Equity 2	300,000	Large cost

Table 1. Liquidity sources and their available amounts

Table 2 displays the available liquidity facilities with their fixed execution constraints in each of the days in the liquidity distress stage of $k = 1$ and $k = 2$. Table 2 also shows the tiered execution costs of the liquidity facilities for each of the liquidity distress periods. For most of the liquidity facilities, execution costs are higher in the second stage - reflecting a more severe liquidity distress in the second stage. In practice, one can interpret the execution cost as including an asset haircut - capturing the fact that the firm's liquidity execution will most likely have to be performed under a combination of general market stress and the firm-specific liquidity stress. The market stress will cause significant haircuts on non-cash equivalent liquidity due to a general 'flight to quality' market behavior. In addition, the bank-specific stress will most likely cause other banks to try to constrain the bank's usage of outstanding facilities and other committed lines of credit.

Liquidity	Liquidity stage k=1					Liquidity stage k=2			
	Cost (C_0)	**Cost (C_1)**	$j_1 = 1$	$j_1 = 2$	$j_1 = 3$	**Cost (C_0)**	**Cost (C_1)**	$j_2 = 1$	$j_2 = 2$
Cash 1	0 bp	0 bp	500,000	500,000	500,000	0 bp	0 bp	500,000	500,000
Cash 2	10 bp	10 bp	0	0	1,000,000	10 bp	10 bp	1,000,000	1,000,000
Bond 1	20 bp	250 bp	700,000	700,000	700,000	40 bp	450 bp	700,000	700,000
Bond 2	100 bp	400 bp	800,000	800,000	800,000	200 bp	1000 bp	500,000	500,000
Facility	10 bp	200 bp	0	500,000	500,000	20 bp	400 bp	150,000	50,000
Equity 1	80 bp	300 bp	600,000	600,000	600,000	180 bp	400 bp	600,000	600,000
Equity 2	180 bp	550 bp	0	300,000	300,000	300 bp	1250 bp	100,000	100,000

Table 2. Available liquidity at tiered costs for each of the days in distress stage 1 and 2

Table 3 displays the tradable limits for liquidity facilities for the tiered execution cost c_0. After this limit and up to the total available limits in Table 1 the execution cost is c_1. For most of the liquidity facilities, tiered execution costs are higher in the second stage - reflecting a more severe liquidity distress in the second stage.

Liquidity	Liquidity stage k=1	Liquidity stage k=2
Cash 1	500,000	500,000
Cash 2	1,000,000	1,000,000
Bond 1	500,000	300,000
Bond 2	300,000	100,000
Facility	250,000	50,000
Equity 1	200,000	100,000
Equity 2	150,000	20,000

Table 3. Available liquidity at first tier cost

APPLICATION

Using SAS, we solve the linear programming model with tiered execution cost using the sample data. That is, Table 1 displays the available liquidity sources together with their available amounts and liquidity type. Further, Table 2 displays the total available liquidity facilities in each of the days in the liquidity distress stage of $k = 1$ and $k = 2$. It also displays the tiered execution constraints, c_0 and c_1 respectively, for the liquidity facilities. Table 3 displays the tradable limits for liquidity facilities for the tiered execution cost c_0. We also assume that the cash that needs to be raised in each of the distress stages is 2,000,000 units of currency. The optimal execution amounts are shown in Table 4. The optimal execution cost across stage 1 and 2 is 15,763 units of currency and the execution cost paid in each of stage 1 and 2, respectively, is 12,952 and 2,811 units of currency. For example, the stage 2 execution cost is realized by executing an additional 2,811 units of currency of the liquidity facility Bond 1.

Liquidity	Available amount	Optimal amount, k=1			Optimal amount, k=2	
		$j_1 = 1$	$j_1 = 2$	$j_1 = 3$	$j_2 = 1$	$j_2 = 2$
Cash 1	500,000	0	0	0	500,000	0
Cash 2	1,000,000	0	0	0	0	1,000,000
Bond 1	700,000	0	0	297,189	102,811	300,000
Bond 2	800,000	115,763	300,000	300,000	0	0
Facility	500,000	0	250,000	150,000	50,000	50,000
Equity 1	600,000	200,000	200,000	200,000	0	0
Equity 2	300,000	0	0	0	0	0
		Raised = 2,000,000			**Raised = 2,000,000**	

Table 4. Optimal liquidity plan

From Table 4 we note that the liquid cash position Cash 1 is sold at stage 2 in full to raise the needed funds of the stage 2 liquidity distress. This behavior of not using the cash position Cash 1 in distress period 1 is expected as the cost of executing the cash position is null in all stages, while other assets typically have an increasing execution cost in stage 2. That is, since the cash position does not come with an increasing execution cost as the liquidity tightens up across stages it is natural to hold the cash positions and liquidate first the positions that have an increasing execution cost as the liquidity distress becomes worse. We also observe the same behavior for the cash position Cash 2 as for Cash 1 (that is, the Cash 2 position is executed in full in stage 2). Next, observe the liquidation behavior of the bond positions. That is, in Bond 1 and Bond 2 we note that for bond position Bond 1 liquidation is spread out over the liquidity distress stages 1 and 2. The Bond 1 position is sold in chunks, day by day, below the first tier market depth limit of 300,000. Since there is not a significant difference in first tier execution cost between stage 1 and 2, going from 20 bp to 40 bp, the Bond 1 position is used to obtain liquidity also in distress stage 2 together with the cash positions. The stage 2 distress gap of 2,000,000 is almost fully covered by the 2 cash positions and Bond 1 as their second stage execution raises about 1,900,000. Note also that slightly less than 300,000 is sold of Bond 1 in distress stage 1 to allow the use of the remaining Bond 1 funds to cover both the gap and the execution cost in stage 2.The bond position Bond 2 has significantly higher first and second tier execution costs than Bond 1, and can be thought of as a lower quality bond with higher haircuts. Bond 2 has a first tier execution limit in stage 1 of 300,000 and a stage 2 first tier limit of 100,000. The increasing execution cost across stages as well as the significantly reduced first tier execution limit makes it optimal to sell an amount of 715,763 of the bond (total amount is 800,000) in the days of liquidity distress stage 1. Nothing is sold of the Bond 2 position in stage 2. This is because the firm can sell off significant amounts of Bond 2 at low first tier market costs only in stage 1. In addition, Bond 2 has a significant increase in execution costs in stage 2 and hence liquidating the position in stage 1 rather than later is a better option to escape higher execution costs. This trade-off can be made for execution of Bond 2 because there are other liquidity facilities in the portfolio such as the cash positions and Bond 1 that do not have a significant diminishing value as the liquidity distress becomes more severe, and hence, can be used in stage 2 to cover the gap with very low execution cost. It is therefore cheaper to hold on to the low execution cost items of the cash positions and the high quality Bond 1 and instead execute Bond 2 to raise funds initially. The facility liquidity source has a relatively low execution cost at first tier market depth of 250,000 in stage 1 and a total of 350,000 is used of the facility in stage 1. The facility has still relatively low execution costs in stage 2 but the usage limit is getting much more constrained. However, the usage limit is still enough to cover using the limit at 50,000 per day raising the final needed 100,000 to cover the liquidity gap in stage 2. The equity position Equity 1 has a first tier market depth in stage 1 of 200,000 while the first tier market depth in stage 2 is reduced to 100,000 together with increased execution costs. This makes it optimal to use the Equity 1 position fully up to the first tier market depth of the days in stage 1 (that is, 200,000 per day) to get a relatively low execution cost to cover the remaining gap in liquidity distress stage 1. Finally, the equity position Equity 2 is not used to cover the gap in either of the stages. This is because there are liquidity facilities with lower execution amounts that can cover the gap in both stage 1 and stage 2.

Analyzing this optimal execution behavior we note that highly liquid sources, such as cash and cash equivalents, which remain liquid with low execution cost and haircut even in further distress, are optimal to hold until further distress stages and then execute at a still low cost. This is because their values do not diminish as stress increases across stages. High quality instruments with low and not significantly increasing execution costs and haircuts across stages, such as Bond 1, are spread evenly in sales across liquidity stages as the market impact across liquidity stages is low for premium quality assets. Hence, the cost of waiting to deploy such an asset is feasible from a cost perspective and the assets used to obtain funds can be spread out over liquidity distresses. The facility, which has low first tier market depth costs but a significant constraint in the usage limit across the days in the stages, resembles Bond 1 in that it is used across liquidity stages up to the first tier market depth limit which has low execution cost. In the case of the facility, however, the stage 2 significant usage constraint causes small amounts to be drawn in each day of stage 2 (that is, 50,000). The fact that liquidity facilities have relatively low execution costs across distress stages, and is a preferred way to raise funds, means that the counterparty offering the facility will try to close or significantly limit committed lines of credit as soon as possible in a liquidity distress to prevent this drawing behavior from the stressed firm. Considering instead liquidity raising assets with an execution cost and haircut that is significantly worsening across stages we note that those are sold in the beginning of distress. This is because their liquidity values are higher in the initial phases of the distress when execution costs and haircuts are not as severe. The assets Bond 2 and Equity 1 are examples of such assets. In our case the position with the highest execution cost, Equity 2, was not used at all since cheaper liquidity execution can be done by the other assets. In our model setting this means that a firm that plans for the 2 stage liquidity distress - but ends up realizing a longer distress - will find itself holding only the lowest quality assets in the unanticipated continuation of the liquidity distress.

In Table 4 enough funds could be raised from other assets than Equity 2. However, it is interesting to observe the liquidity behavior when we increase the first stage gap to 2,300,000 units of currency as this will force at least part of Equity 2 to be used to raise funds. Table 5 displays the result when an additional cash amount of of 300,000 needs to be raised in distress stage 1. The total execution cost in this case is 20,575 units of currency with cost in distress stage 1 of 17,764 and distress stage 2 has the same execution cost as before (2,811 units of currency).

Liquidity	Available amount	Optimal amount, k=1			Optimal amount, k=2	
		$j_1 = 1$	$j_1 = 2$	$j_1 = 3$	$j_2 = 1$	$j_2 = 2$
Cash 1	500,000	0	0	0	500,000	0
Cash 2	1,000,000	0	0	0	0	1,000,000
Bond 1	700,000	0	0	297,189	102,811	300,000
Bond 2	800,000	200,000	300,000	300,000	0	0
Facility	500,000	0	250,000	150,000	50,000	50,000
Equity 1	600,000	200,000	200,000	200,000	0	0
Equity 2	300,000	0	70,576	150,000	0	0
		Raised = 2,300,000			**Raised = 2,000,000**	

Table 5. Optimal liquidity plan – increased gap amount in stage 1

In this case the bond position Bond 2 is used in an additional approximately 75,000 in day 1 of distress stage 1. This uses all the available liquidity facility of Bond 2. We also note that now the firm has to use the liquidity facility Equity 2 to raise all the funds needed across stages- selling it in the first liquidity distress stage at the last 2 days of the stress. The asset is executed at or below the first tier market depth at 150,000 to raise the additional needed funds in stage 1. Due to the significant increase in execution cost and the significant decrease in the first tier market depth for equity 2 in stage 2, it is better for the firm to sell Equity 2 in the first stage rather than using any other asset that has a lower time cost of holding on to and deploying in stage 2 to generate liquidity.

In summary we can therefore conclude that if the firm thinks it has to use all its liquidity facilities to survive the liquidity distresses then it will sell the less quality assets first because their value will deteriorate over time as the liquidity distress worsens and their maximum value in raising funds is at the beginning of distress. On the contrary, high quality assets with low haircuts and execution costs, even in later and more severe stages of a liquidity distress, do not diminish in value significantly and are held on to in order to raise funds in later more severe stages.

CONCLUSION

The optimal behavior of a liquidity supplying instrument of either selling it early in a liquidity distress stage or holding on to the asset to the end of the stage is determined by the asset's relative cost of execution across stages versus other liquidity supplying instruments. This means for example that stressing the execution cost uniformly across all assets does not change the optimal liquidity plan significantly. Only the total execution cost of the plan changes. It is optimal to hold on to high quality assets until later more severe stages of a distress as their value does not diminish significantly. However, if the firm misjudges the severity and length of the liquidity distress it might end up only holding low quality assets with high execution costs and haircuts in the later stage of a distress. This is because the firm refrained from using low quality assets in the beginning of the stress because it thought it would not have to use them to raise funds and hence executed cheaper liquidity sources. While the model in this paper is useful for both quantifying execution costs and planning liquidity execution, the model is also useful for testing the viability of a specific hedging portfolio under realistic assumptions on haircuts and execution costs. The situation of insufficient counterbalancing capacity, under business or regulatory assumption on haircuts and eligible hedging portfolio, can be quickly revealed by the model solution as "infeasible". This helps the bank to quickly identify such a scenario and prepare for the acquisition of further liquid funds.

This paper has focused on one aspect of liquidity management in banks (that is, the best execution plans for the banks hedging portfolio). However, the new regulation for liquidity management in banks involves institutionalizing better systems and controls for liquidity risk in general. This includes a comprehensive solution for cash flow generation and projection, stress testing behavioral and market uncertainties to project potential future cash flows and funding gaps. This is in addition to complying with a specific set of regulations for calculation of key measures (for example, liquidity coverage ratio and net stable funding ratio) and reporting, stress testing, and monitoring of liquidity ratios and limits. Finally, institutions need to price liquidity risk in order to decentralize the incentives to raise stable funds and liquid assets. This includes extending the bank's current funds transfer pricing process to include term liquidity charges as well as charges for contingency liquidity for the encumbered assets and liabilities as well as price the market liquidity charge into unencumbered instruments.[2]

Liquidity risk is not an 'isolated' risk. The interrelation of funding liquidity risk and credit risk, market risk, and market liquidity, and other firm-wide risk must be adequately considered in an effective liquidity measurement and management system. A comprehensive view of the liquidity condition of a bank is a prerequisite to using the optimal liquidity execution plan model that is introduced in this paper. SAS® Risk Management for Banking is an integrated solution for market risk, credit risk, asset and liability management, and firm-wide risk management. The liquidity management functionality in SAS Risk Management for Banking is currently being used by banks to measure and manage liquidity risk as well as report to regulators the new required liquidity measures. For information about SAS Risk Management for Banking see http://www.sas.com/industry/banking/risk-management.html.

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[2] See the SAS white paper (Skoglund (2010)) on funds transfer pricing for an in-depth discussion of funds transfer pricing and risk based performance measurement.