Estimating Liquidity Risk Using The Exposure-Based Cash-Flow-at-Risk Approach: An Application To the UK Banking Sector

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Abstract

This paper uses a relatively-new quantitative model for estimating UK banks' liquidity risk. The model is called the Exposure-Based Cash-Flow-at-Risk (CFaR) model, which not only measures a bank's liquidity risk tolerance, but also helps to improve liquidity risk management through the provision of additional risk exposure information. Using data for the period 1997-2010, we provide evidence that there is variable funding pressure across the UK banking industry, which is forecasted to be slightly illiquid with a small amount of expected cash outflow (i.e. £0.06 billion) in 2011. In our sample of the six biggest UK banks, only the HSBC maintains positive CFaR with 95% confidence, which means that there is only a 5% chance that HSBC's cash flow will drop below £0.67 billion by the end of 2011. RBS is expected to face the largest liquidity risk with a 5% chance that the bank will face a cash outflow that year in excess of £40.29 billion. Our estimates also suggest Lloyds TSB's cash flow is the most volatile of the six biggest UK banks, because it has the biggest deviation between its downside cash flow (i.e. CFaR) and expected cash flow.

Keywords: Liquidity risk, Exposure-based CFaR, Risk Management, Funding Pressure

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1. Introduction

Even though liquidity management is a core activity of banks, it has not received much attention in recent decades, as liquidity has not been perceived as scarce[3]. However, this perception has completely changed since the global financial crisis of 20008/09. Both financial regulators and academic researchers realized that the most serious crisis in the last hundred years ultimately was due to liquidity events. However, up to the present, only very simple reports are used for disclosing banks' liquidity management. For instance, statistically calculating the funding gap between assets and liabilities under different maturity ladders, or listing both secured and unsecured funding channels, which banks can specify without testing the quality of these resources in crisis situations, tend to be the height of sophistication.

The development of modeling bank liquidity has thus been rather slow, despite bankers ranking liquidity risk as one of the top five risks to consider (CSFI, 2010). Contrasting with the advanced techniques applied for other risks, such as credit and market risk, Fiedler (2007) argues that there is no sophisticated method to capture a bank's liquidity position by testing whether there will be sufficient cash to pay future bills. This paper measures banks' liquidity risk by calculating downside risk known as Cash-Flow-at-Risk (or CFaR). It is an extension of Value-at-Risk (or VaR). While VaR focuses on market risk by forecasting changes in the overall value of an asset or portfolio, CFaR is focused on variations in cash flow during a given period.

The first contribution of this paper is to clarify the difference between VaR and CFaR. Researchers typically choose VaR as the basis for risk management systems within financial institutions, and CFaR when assessing risk management among non-financial firms, because there is an argument that a financial institutions's VaR is also their CFaR, since portfolio holdings by financial firms are marked-to-market (Shimko, 1998). But, VaR, unlike CFaR, will capture only a small part of the firm's overall exposure since it ignores the risk of its underlying commercial cash flow. Moreover, this paper will demonstrate that reducing the maximum shortfall of value cannot fully reflect the volatility of cash flow. Therefore, VaR is not an efficient tool to manage liquidity risk. Banks should develop more advanced cash flow models to control liquidity risk.

The second contribution of this paper is to summarize a bank's liquidity risk exposure

[3] As noted by the FSA (2008), however, the failure of Barings Bank, due to the fraudulent activities of one of its traders, threatened the liquidity position of UK banks due to a general loss of confidence in the robustness of the UK banking system. Moreover, the collapse of Long Term Capital Management(LTCM), due to panic selling and divergence in the prices of US and Japanese/European bonds which led to LTCM incurring massive losses, triggered investor panic and a general flight to liquidity in the market.

in a single number (CFaR), which is the maximum shortfall given the targeted probability level; it can be directly compared to the bank's risk tolerance and used to guide corporate risk management decisions.

The third contribution of this paper is to estimate exposure-based CFaRs for UK banks, which involves the estimation of the set of exposure coefficients that provide information about how various macroeconomic and market variables are expected to affect the banks' cash flow, and that also attempt to take account of inter-dependencies and correlations among such effects. For these reasons, they can also be used to predict how a hedging contract or change in financial structure will affect a bank's risk profile.

We use annual data over the period 1997 to 2010. The bank-specific data was collected from Bankscope and banks' annual reports. The macroeconomic data was collected from the Datastream database, the Bank of England, the International Financial Statistics (IFS) database, and the IMF (Fund, 2010).

We forecast that, by the end of 2011, the (102) UK banks' average CFaR at the 95% confidence level will be -£5.76 billion, Barclays Bank's (Barclays') CFaR will be -£0.34 billion, the Royal Bank of Scotland's (RBS's) CFaR will be -£40.29 billion, HSBC Bank's (HSBC's) CFaR will be £0.67 billion, Lloyds TSB Bank's (Lloyds TSB's) CFaR will be -£4.90 billion, National Westminister Bank's (Natwest's) CFaR will be -£10.38 billion, and Nationwide Buidling Society's (Nationwide's) CFaR will be -£0.72 billion. Moreover, it is clear that Lloyds TSB and Natwest are associated with the largest risk, according to the biggest percentage difference between downside cash flow and expected cash flow (3600% and 816% respectively).

The structure of the paper is as follows. Section 2 is the literature review. Section 3 describes the data. Section 4 outlines the methodologies adopted. Section 5 presents the empirical results and risk analysis. And section 6 summarises and concludes.

2. Literature Review

2.1. Value-at-Risk VS Cash-Flow-at-Risk

Essentially, VaR measures how much market value might be lost over a defined period for a given confidence interval. For example, if the VaR on an asset is £100 million at a one-week, 95% confidence level, then there is only a 5% chance that the value of the asset will drop by more than £100 million over any given week. Therefore, it has the intuitive interpretation of the amount of economic or equity capital that must be held to support that level of risky business activity. Likewise, an annual CFaR of £100 million with 95% confidence can be explained as there being only a 5% probability that cash flows will drop by more than £100 million during the next year. It is clear that VaR specifies the maximum amount of the total value of an asset that a firm is expected to lose under a given level of statistical confidence, whereas CFaR determines the maximum short-fall of cash the firm is willing to tolerate with a given confidence level (Andrn et al., 2005).

In terms of the early history of VaR, Leavens (1945) offered a quantitative example to measure bonds' default risk, which may be the first VaR measure ever published. Markowitz (1952) and Roy (1952) then independently published surprisingly similar VaR measures, each of whom was working to develop a means of selecting portfolios that would optimize reward for a given level of risk. Lietaer (1970) later described a practical VaR measure for foreign exchange risk. His work may be the first instance of the Monte Carlo method being employed in a VaR measure. Garbade (1986) subsequently presented sophisticated measures of Value at Risk for a firm's fixed income portfolios, based upon the covariance in yields on bonds of different maturities.

By the early 1990s, many financial service firms had developed rudimentary measures of VaR, generally following Markowitz's (1952, 1959) approach to allocate capital or monitor market risk limits. A portfolio's value would be modeled as a linear polynomial of certain risk factors. A covariance matrix would then be constructed for the risk factors and, from this, the standard deviation of portfolio value would be calculated. If portfolio value were assumed normal, a quantile of loss could be calculated. Wilson (1993) was the first to attempt to address leptokurtosis and heteroskedasticity in the practical VaR measures used on trading floors; while Morgan (1996) pioneered the use of Value-at-Risk to measure downside risk. The key contribution of the latter paper was that it made the variance and covariances across different asset classes freely compute the VaR for a portfolio.

Gupta and Liang (2005) argued that the definition of VaR is completely compatible with the role of equity capital[4], as perceived by financial institutions. A VaR-based capital adequacy measure is also being increasingly adopted by regulators and supervisors. The Securities and Exchange Commission (SEC) has required securities firms to estimate one-month, 95% VaR and hold enough capital to cover the potential losses since the 1980s. While the Basel Committee on Banking Supervision (BCBS) in 1995 allowed commercial banks, subject to certain safeguards, to use their own internal VaR estimates to determine their capital requirements for market risk under an amendment to the Basel Capital Accord (Holton, 2002). Finnaly, the SEC in 1997 also issued a ruling that requires companies to disclose quantitative information about the risks associated with derivatives and other financial instruments in financial reports filed with the SEC (Jorion, 2007).

Banks face a serious liquidity risk if their net cash flows cannot meet their liabilities as they fall due. But taking market liquidity for granted, financial institutions are not particularly interested in cash flows over decades. Shimko (1998) argues that a bank's VaR is also its CFaR, because banks' marked-to-market portfolios are generally converted into cash at short notice; any gain or loss in value immediately affects reported earnings and cash flow. However, this argument would not hold in 'thin' markets and challenges fundamental accounting principles. In thin markets, assets would become less marketable and wouldn't be readily converted into cash as the markets provide little chance of matching (Lippman and McCall, 1986). A liquidity crisis, unlike other crises, can make the markets become even thinner, possibly for years. It is quite possible that a well-capitalized bank would be forced into bankruptcy, because very thin markets would not allow banks to transfer marketable securities into cash in time. Moreover, under accounting theory, for a bank that has to make contractual payments during a particular period, the drying up of cash flow income might put the bank at risk of default, even though its net worth remain relatively stable. And, Returns on a bank's assets and liabilities (or Net Incomes), as the key VaR matrix, cannot provide a more accurate picture of the bank's current cash holding without taking account of non-cash expense items. Changes in a bank's profit and loss might not always capture the changes in cash flow, especially during stressed periods. Therefore, in these studies, CFaR will be more useful than VaR in terms of measuring liquidity risk. Despite VaR being a method to determine capital requirements for absorbing investment loss, it has nothing to do with estimating sufficient cash holdings for financial institutions. Besides, the VaR computes over only days or weeks, whereas the CFaR is measured over quarters or years.

[4]The equity capital is held to provide a capital cushion against any potential unexpected losses.

2.2. A Short History of Cash-Flow-at-Risk

CFaR is gaining in popularity among industrial companies for easily summing up all of their risk exposures in a single number that directly reflects the firm's risk tolerance. The calculation of the single risk statistic requires a forecast of the probability distribution of cash flow at some future point in time. There are two dominant methods to simulate such distributions. One is the bottom-up approach, the other is the top-down approach.

RiskMetrics (1999), using the bottom-up approach, begins with a pro forma cash flow in which production volumes, prices, and costs are the key factors. The conditional value of cash flow distribution can be calculated by random prices and rates generating their own variance-covariance matrix. The basic assumption of this approach is that there is a direct link between production prices and exchange rates on the one hand and cash flow on the other. But this assumption appears to be contradicted by one of the main conclusions coming out of more than 20 years of research into how and why firms are exposed to macroeconomic and market risks (Oxelheim and Wihlborg, 1997). It is dangerous to use a pro forma statement because total corporate risk exposures are so complex and multifaceted. How, for example, would one model the effect on corporate cash flow of an exchange rate change that influences both the firm's and its competitors' input and output prices and their future sales volumes due to consumers' responses to price changes, while at the same time affecting interest rates, which in turn affect the firm's interest expense and consumers' willingness to spend money on consumption goods? Andrn et al. (2005) believe that the use of pro form a cash flow statements to model risk exposures would yield biased results since it cannot deal with more than one exposure at a time. Even when bottom-up modeling attempts to reflect such competitive exposures by introducing more complex relationships between changes in rates and cash flow, such modeling has a tendency to ignore the simultaneous impact of exchange rates and the effects of other macroeconomic market variables such as interest rates, inflation, and asset prices. Because of these complex linkages and interactions, the exposures that can be meaningfully captured in a pro forma statement are generally only a small part of a firm's total exposure.

Stein et al. (2001) use, instead, a top-down approach based on the assumption that total cash flow volatility is the ultimate variable of interest. Such volatility can be estimated from a company's historical cash flows when such data exists. But because the data on any given company's cash flow might be insufficient to provide a statistically-significant estimate of volatility, they call for pooling of cash flow data for a large number of firms, and then identify four characteristics with significant explanatory power for predicting patterns in unexpected changes in cash flow in their sample: size, profitability, riskiness of industry cash flow, and stock price volatility. On the basis of these key characteristics, Stein et al. (2001) sort all the firms into pools of comparable companies. The pooled cash flows for the comparable companies are then used to calculate each firm's cash flow distribution. Thus, even though this approach aggregates data for a large number of companies, the results are applied to individual firms in a way to reflect these four key characteristics. Andrn et al. (2005) point out a limitation in that the firm in question could be very different from the 'average' company in the sample. Moreover, the top-down approach does not provide an estimation of CFaR conditional on market risks.

Given the limitations of both bottom-up and top-down methods, Andrn et al. (2005) use a third approach, called exposure-based CFaR. Different from Stein et al. (2001), Andrn et al. (2005) estimate a company's cash flow volatility by taking account of its own corporate macroeconomic exposure and the various channels through which such variables affect corporate cash flow. They begin with a fundamental analysis of the company's exposure to changes in the macro economy. Such analysis attempts to provide answers to important questions about the current composition of the company's operating activities, and the structure of its financial positions. The conditional CFaR, in turn, can tell managers how much cash flow is at risk, given the specified probabilities associated with fluctuations in macroeconomic and market factors such as interest rates, exchange rates, and other key (e.g. commodity) prices. Therefore, CFaR can also be used to evaluate how the expected future distribution of cash flow would be affected if, for example, an option contract were used to reduce a specific exposure. The exposure-based cash flow model can also provide information about the relative contribution of macroeconomic and market risks to volatility compared with that of other sources of cash flow volatility.

The exposure-based cash flow at risk model, involving a process of mapping out the firm's exposure and the asking of difficult questions about how and through what channels the firm's cash flow is exposed to risk, is one of the key benefits of having a risk management program. With this in mind, we follow Andrn et al. (2005) and use a exposure-based CFaR model to measure UK banks' downside risk. It establishes a framework for banks to control their own liquidity risk by undertaking a more careful analysis of the drivers of corporate macroeconomic exposure.

3. Data description

3.1. Cash Flow

A bank's cash receipts and payments are classified on the cash flow statements as either operating, investing, or financing activities (See Table 1). Therefore, its total cash flows are the sum of the operational cash flow (or CFO), the investment cash flow (or CFI), and the financing cash flow (or CFF). However, our analysis can only use profit before tax as the target cash flow variable. There are three main reasons for this. Firstly, in order to analyze the liquidity risk of UK banks, we collect all the relevant bank information from Bankscope, the standard database for both private and public banks. However, since the database only contains balance sheets and income statements, the best cash flow data we can get from Bankscope is for profit before tax, starting from the end of 1997 and running through to the end of 2010. Secondly, even though some public banks release their own annual cash flow data on their official websites, the series of accurate cash flow is only available after 2002. The sample is too small to accurately estimate the relationships between banks' cash flow and macroeconomic risk variables. Thirdly, we also notice that despite some major banking groups[5] providing both annual and half-yearly cash flow data after 2005, even the future cash flow distribution estimated from this information cannot represent the 102 UK banks' average cash flow distribution[6].

Besides measuring, annually, cash flow volatility, we also need to estimate quarterly volatility or at least half-yearly volatility, since a liquidity crisis usually lasts between 3 months and 1 year. The significant data limitation problem does not only prove that both regulators and banks' managers have ignored liquidity risk for a long time, but also deters the development of bank liquidity modeling . We also argue that it will jeopardize academic research if regulators still refuse to release banks' historical cash flow information, at least for the last decade.

3.2. Risk Exposure Factors

It is obvious that the market and macroeconomic risks faced by banks are from their own operational activities. The risk factors we choose are based on each UK bank's own business models. Based on the saving/lending business, banks' cash flows are sensitive to uncertainty of interest rates. 3-month or 90 day interbank lending rates (i.e. UK LIBOR) and 10-year government bond yields are widely used as leading short-term and long-term interest rates respectively. Banks use these interest rates to decide what they want to earn from loans

[5] These are Barclays Plc, HSBC Group, and Lloyds Banking Group.

[6] We included 102 out of a total of 190 UK banks because of the unbalanced data limitation. There were 121 incorporated banks operating in the UK, according to the FSA, on 30 June 2011, and 69 building societies. Together, they accounted for 98.9% of UK banking sector assets in 2010. However, this sample does not include banks incorporated outside the UK but accepting deposits through a branch in the UK.

and what they will pay for deposits. Some interest rates on special savings products, like Certificates of Deposit and Eurodollar Deposits, are highly correlated with those two interest rates in various maturities. Therefore, we chose 3-month short-term interbank lending rates (SI) and 10-year long-term government bond yields (LI) as the interest rate risk exposure factors.

Banks need to manage their exposure to debt securities, equities and derivatives traded in their investment business. Both RBS and Barclays Bank suffered huge losses during the 2008/09 banking crisis because of the collapse of derivative markets. At that time, RBS's net exposure to asset-backed-securities was £64,130 million, which represented 84.29% of its investment assets. And Barclays's net exposure to asset-backed-securities (£42,052 million) was 64.34% of its investment assets. We therefore chose the UK bond market index (UB)[7] and spreads of US asset-backed securities (ABS)[8] as the leading indices to represent the risk exposure factors for debt securities. For the equity and derivatives markets, we chose the price volatility index (PV)[9] and Euro area swap spreads (Swap) as the relevant exposure factors since banks were holding significant amounts of options and swaps in their asset portfolios over the sample period.

Taking market funding for granted, banks became much more reliant on the wholesale funding market in the run up to the recent global crisis. Merton (2005) states that the large components of a commercial bank's financing are short-term, not least sticky deposits. By the summer of 2007, for example, 77% of Northern Rock's funding came from non-retail funding (Shin, 2009). However, it had to rely on government guarantees for funding when the private wholesale funding markets closed in the wake of the US sub-prime crisis. Between 2008 and 2009, even stronger banks across the world hardly obtained any funding in any major currency. We therefore chose market liquidity indices (LQ) [10] and repo spreads (Repo)[11] to measure the funding ability effect on cash flow.

Beyond their domestic trading business, the main overseas trading businesses of these major banks are in the Americas, Asia and Europe, more than 80% of which are traded in

[7]The reason for not also choosing the global bond market index is that both indices are highly correlated (i.e. cor=0.79).

[8]Even though UK banks are heavily exposed to the UK ABS market and EU ABS market, the relevant indices are only available after 2004. Hence the choice of the US ABS index.

[9]The asset price volatility index uses implied volatility derived from options from stock market indices, interest and exchange rates. A higher value indicates more vulnerable asset markets.

[10]The funding and market liquidity indices use the spreads between yields on government securities and interbank rates, the spreads between term and overnight interbank rates, currency bid-ask spreads, and daily return-to-volume ratios of equity markets. A higher value indicates tighter market liquidity conditions.

[11]Repo spreads are the difference between yields on three-month Gilt Repos and on three-month UK treasury bills.

US dollars and Euros. In 2009, the sterling equivalents of total trading products priced in US dollars and Euros by HSBC, Barclays, and RBS were £14.66 bn, £23.45 bn, and £16.78 bn repectively. Therefore, we selected two sources of exchange rate exposure for UK banks, namely the British pound against the US dollar exchange rate ($/£) and the British pound against the Euro exchange rate(€/£).

Banks' risk exposures also arise from the domestic macroeconomic environment. Banks will gain , for example, from exposure to relatively low inflation and high economic growth because of lower expenses and higher investment income. For example, without significant inflationary pressures, the major UK banks' growth rate of assets was close to the growth of nominal GDP in 1999. We thus chose the inflation rate (π) and real GDP growth rate (g) to capture the macroeconomic risk effect on banks' cash flow.

To summarize, we used eleven risk factors within the exposure-based cash-flow-at-risk model. These are the short-term interest rate (SI), the long-term interest rate (LI), the UK bond market index (UB), the price volatility index (PV), the Euro area swap spreads (Swap), the market liquidity index (LQ), Repo spreads (Repo), the British pound-US dollar exchange rate($/£), the British pound-Euro exchange rate (€/£), the inflation rate (π), and the real GDP growth rate (g). The reason for not also using spreads of US asset-backed-securities (ABS) is because they are highly correlated with LQ, PV, Repo, Swap, and π (see Table 2). Table 3 describes where the data was obtained from.

4. Methodology

4.1. Exposure-Based Model

From a managerial perspective, the total variability of cash flow can be attributed to a number of different factors. Therefore, in assessing exposures, total cash flow variability is decomposed into several fluctuations which are independent of the changes of cash flow. The exposure model is a multivariate regression of relevant macro and market variables on corporate cash flow that looks as follows:

$$CF_t - E(CF_t|I_{t-1}) = \beta_0 + \sum_{i=1}^{n} \beta_i (X_{it} - E(X_{it}|I_{t-1})) + \varepsilon_t \tag{1}$$

where CF_t is the cash flow in period t, and X_t=[SI, LI, UB, PV, Swap, LQ, Repo, $/£, €/£, π, g]. $E_{t-1}[.]$ are included to capture forecasted or expected developments of the variables in each period. Because risk derives from random and unexpected deviations from the expected or forecasted values, the above regression implies that the risk of cash flow $[CF_t - E(CF_t|I_{t-1})]$

is dependent on the risks associated with the relevant macro and market variables $[X_{it} - E(X_{it}|I_{t-1})]$.

The relative importance of selected macroeconomic exposure is indicated by the goodness of fit statistic (R^2) of the exposure model, while the relative importance of other risk factors, including non-macroeconomic and market risk, is given by $(1 - R^2)$. The coefficients produced by such a regression provide measures of exposure which could determine the size of investment contracts to reduce or eliminate the banks' exposures, adjust historical cash flows to filter out the impact of macroeconomic and market risks, and provide the basis for a CFaR calculation.

Given the use of annual data, we assume that all variables included follow random walks, which means that all changes are unexpected. The martingale model (or rational expectation model) principle implies that the information $t-1$ needed for a rational expectation of the value of price at time t is already contained in price at $t-1$. Therefore, we can get:

$$E(CF_t|I_{t-1}) = CF_{t-1} \tag{2}$$

and

$$E(X_t|I_{t-1}) = X_{t-1}. \tag{3}$$

Then the reduced form of the exposure cash flow model can be interpreted as follows:

$$\Delta CF_t = \beta_0 + \sum_{i=1}^{n} \beta_i \Delta X_{it} + \varepsilon_t. \tag{4}$$

4.2. Simulation of CFaR

To derive a conditional distribution of cash flow, the regression model must be used together with the variance/covariance matrix of the significant macroeconomic and market variables identified in the exposure model. We run simulations in which the values for the various explanatory variables are picked randomly from the variance/covariance matrix. In each of these iterations, the randomly-picked values are inserted into the regression model to generate a simulated value of cash flow conditional on macroeconomic and market variables. 10,000 scenarios were simulated, so we got 10,000 simulated values of cash flow.

To estimate total cash flow, we must also complement the conditional cash flow distribution with a distribution of the error term. If the error term is well behaved it has, by definition, no correlation with any of the explanatory variables or its own past values, and we can simply draw a value from a normal distribution ($\varepsilon \sim N(0, \sigma^2)$) and add that value to the conditional distribution. To summarize, the calculation of Exposure-Based CFaR is a six-step process. Firstly, choosing an annual data set (CF_t, X_{it}) from 1997 to 2010, estimating regressions to get relevant coefficients ($\hat{\beta}_i$). Secondly, calculating the mean and covariance matrix of the first differences (ΔX_{it}). Thirdly, generating 10,000 new ΔX_{i2011} based on the mean and covariance matrix:

$$\Delta X_{i2011} \sim N(\mu, \Omega) \tag{5}$$

where the mean vector:$\mu = E(\Delta X_{1,2011}, \Delta X_{2,2011} ... \Delta X_{n,2011})$ and the covariance vector: $\Omega = COV(\Delta X_{i2011}, \Delta X_{j2011})_{i,j=1,2...n}$.

And then generating 10,000 new error terms (ε_{2011}):

$$\varepsilon_{2011} \sim N(0, \sigma^2). \tag{6}$$

Fifthly, predicting a bank's cash flow volatility in 2011 as a sum of intercepts, the simulated variables multiplied by exposure coefficients, and error terms:

$$\Delta CF_{2011} = \beta_0 + \sum_{i=1}^{n} \beta_i \Delta X_{i,2011} + \varepsilon_{2011}. \tag{7}$$

Finally, deriving the distribution of cash flow in 2011 as follows:

$$\begin{aligned} CF_{2011} &= E(CF_{2011}|I_{2010}) + \Delta CF_{2011} \\ &= CF_{2010} + \Delta CF_{2011}. \end{aligned} \tag{8}$$

5. Results

5.1. Exposure-Based Model

Before analyzing the results of the exposure assessments, we need to check that the effects of different risk factors on banks' cash flow are in accordance with economic theory, since specifying an acceptable exposure model is a combination of art and science. First of all, we use the stepwise regression (Rawlings et al., 1998) to find a subset of independent risk factors (X_i) mentioned above that best predict cash flow. The general idea of stepwise regression is either to start with a simple model and add variables that have significant p-values (i.e. forward stepwise selection) or to start with a large model and keep variables whose p-values are below a certain significance level (i.e. backward elimination). Neither forward selection nor backward elimination takes into account the effect that the addition or deletion of a variable can have on the contributions of other variables to the model. A variable added early to the model in forward selection can become unimportant after other variables are added, or variables previously dropped in backward elimination can become important after other variables are dropped from the model. Therefore, we combine the two selections to test at each step for variables to be included or excluded. We start with a forward selection process that rechecks at each step the importance of all previously-included variables. If the partial sums of squares for any previously included variables do not meet a minimum criterion to stay in the model, the selection procedure changes to backward elimination and variables are dropped one at a time until all remaining variables meet the minimum criterion. Then, forward selection resumes.

According to the results of stepwise regression on each UK bank's cash flow, we get various sizes for the subset of risk factors. For instance, the cash flow of Barclays Bank, HSBC Bank, and Natwest can be predicted using 6 different risk factors. And the cash flow of Lloyds and Nationwide can be predicted using 5 different risk factors[12]. However, with such a small sample of data, we have to balance the numbers of degree of freedom against a high adjusted R^2. We finally choose 4 risk factors as independent variables and leave 8 degrees of freedom for each regression.

Table 4 presents the exposure results for all the UK banks sampled plus individual results for the six biggest banks (which held over 80% of total UK bank assets in 2010). As argued by Andrn et al. (2005), the preferred exposure model should include variables with a strong basis in economic theory which are supported by empirical evidence. In other words, to gain acceptance from management, a risk estimation model must have not only statistical backing, including high significance levels[13], a high goodness of fit statistic (R^2), no serial correlation problems, and well-behaved error terms (ε), but also an emphatic logic as to how one would expect the main variables to affect the banks' cash flow.

Representing the basic price of loans, short-term interbank lending rates should positively affect a bank's cash flows. And the long-term government bond yields, representing a major part of a bank's interest expenses as they determine long-term deposit rates, should have a negative effect on its cash flow. As an indicator of equity market uncertainty, we expect the price volatility index to have a negative effect on a bank's cash flows. But we suggest the UK bond clear price index and swap spreads may have either positive or negative effects on cash flows, dependent on a bank's own investment strategy and portfolio management- i.e. whether it is a seller or a holder of the specified financial instruments. UK Repo spreads, indicating funding pressures, are expected to have a negative effect on a bank's cash flows. A depreciation in foreign currency or appreciation in pounds sterling would increase banks' cash inflow by increasing trading income or reducing trading expense. Inflation effects on banks' cash flows are variable and can be simultaneously positive and negative. High inflation may increase banks' operational costs and lead to low revenues by discouraging aggregate investment and savings. However, positive effects include encouraging banks to offer more credit to industrial

[12] The market liquidity index (LQ) might not be a significant variable to predict UK banks' cash flow since it was deleted under each stepwise regression.

[13] The minimum significance in our model is at the 90% confidence level.

firms and households. Finally, the GDP growth rate should positively affect a bank's assets and profitability. But a bank with expanding assets and high book profits can still face liquidity problems, as Northern Rock demonstrated.

Our UK banks' exposure model indicates a one percentage point short-term interest rate increase, on average, increases the UK banking industry's cash flow by £0.26 billion. It confirms our expectation that banks' cash flow will increase with an increase in the short-term interbank lending rates. Their bond market exposure is £2.59 billion, indicating that banks have a long position in bonds and gain cash inflow from the bond market of around £2.59 billion based on a one percentage point increase in the bond index. However, a one percentage point increase in the price volatility index shrinks cash flow by £0.36 billion, showing that equity market volatility negatively impacts on UK banks' cash flow. Finally, the significant negative relationship (i.e. -2.03) between Repo spreads and banks' cash flow also proves that UK banks face funding pressures when the spreads become bigger.

Barclays' exposure model also confirms that its cash flow will decline with an increase in the price volatility index. A one percentage point increase in the price volatility index shrinks cash flow by £0.87 billion. The positive coefficient (i.e. 3.36) of swaps indicates that Barclays benefits from the use of swaps. Moreover, Barclays also gains cash inflow from its overseas trading activities of £4.62 billion for a one percent point euro deprecation against sterling. Finally, the significant positive coefficient of the inflation rate indicates Barclays also secured cash inflow over the last fourteen years because of this factor.

RBS's cash flow in shown to increase by £2.49 billion with a one percentage point increase in short-term interest rates. A one percentage point increase in Repo spreads, however, shrinks cash flow by £25.99 billion. And there is a big loss on its derivatives portfolio, which were mostly held for hedging purposes, since a one percentage point increase in swap spreads is accompanied by a decrease in cash flow of £21.62 billion. Moreover, the domestic inflation rate has a negative effect on RBS's cash flow, with a one percentage point increase in the inflation rate causing a £3.78 billion cash outflow.

As expected, Lloyds-TSB's cash flow is also affected positively by short-term interest rate increases, but negatively by increases in the long-term interest rate. The short-term interest rate exposure is £0.38 billion but the long-term interest rate exposure is -£1.32 billion. Overseas trading business also contributes £4.3 billion to Lloyds-TSB's cash inflow for a one percent point euro depreciation against sterling. Finally, a one percent point increase in the growth rate will be accompanied by an increase in Lloyds-TSB's cash flow of £0.84 billion.

HSBC's exposure model demonstrated that a one percentage point increase in short-term interest rates will increase its cash flow by £0.33 billion. While a one percentage point increase in Repo spreads will shrink its cash flow by £2.78 billion. Somewhat surprisingly, however, HSBC's cash flow will increase in response to rising inflation, but decline in response to a higher GDP growth rate. This means the bank will loss cash in high GDP growth years, but gain it in an inflationary environment.

Natwest's cash flow is also affected positively by short-term interest rate increases and negatively by increases in the long-term interest rate. The short-term interest rate exposure is £1.5 billion while the long-term interest rate exposure is -£1.74 billion. A one percentage point increase in Repo spreads will also shrink its cash flow by £12.11 billion. Moreover, Natwest faces liquidity problems in periods of rising GDP growth rates.

Finally, for Nationwide, cash flow is also affected positively by short-term interest rate increases and negatively by increases in the long-term interest rate. Its short-term interest rate exposure is £0.14 billion but its long-term interest rate exposure is -£0.26 billion. Like Barclays and HSBC, domestic inflation positively contributes to its cash inflow. However, it lost out in the bond market over the past fourteen years, with cash outlfow amounting to £1.31 billion for each one percentage point increase in the bond index.

5.2. Risk Exposure Analysis

Since the exposure-based model decomposes the cash flow estimates into individual risk exposures, it provides insights into the cash flow dynamics of the company and the key drivers of risk. In particular, the model allows for a clearer view of the portfolio aspects of corporate risk.

First, it suggests banks should take liquidity risk seriously, since the significant negative coefficients of Repo spreads would indicate a significant source of funding pressure across the UK banking industry. Second, it can help to improve the offsetting of risk exposures by focusing on correlated risk factors. A high correlation between two risk factors will have a significant impact on estimated cash flow, and the sign of the exposure coefficients determines whether the overall net impact is positive or negative. For example, the short-term interest rate (SI) and real GDP growth rate (g) are positively correlated (see Table 2), but HSBC is positively exposed to one and negatively to the other; therefore the cash flow risk will be dampened in this case. Third, it may encourage some banks to review their investment strategies by comparing with peers. For instance, in light of the significant cash inflow secured by Barclays' trading in swaps , RBS should limit its exposure by changing its trading business strategies.

Another benefit of the exposure-based model is its ability to inform hedging decisions which can mitigate the impact on cash flow variability.[14] In the Lloyds-TSB's model, the

[14]However, not all the information necessary for deciding the size of the hedge positions is contained in the

indicated exposure to the euro/sterling exchange rate is £4.3 billion for each percentage point depreciation of the euro. This means that if management expects a 1% future appreciation in sterling and wishes to neutralize its exposure to this exchange rate for the next year, it should sell forward exactly this number of pounds.

5.3. Simulation of Cash-Flow-at-Risk

Using the variance/covariance matrix of significant variables identified in Table 4, we firstly programmed a simulation to run 10,000 scenarios of those variables in the forecasting system. Then, following the methodology outlined in the previous section, we apply the software to estimate these commercial banks' cash flow for each of the 10,000 simulations as a function of the simulated macroeconomic and market variables multiplied by the relevant exposure coefficients. By so doing, we end up with a distribution of expected cash flow that reflects not just the cash flow sensitives to each of the individual risk factors, but also to the expected variances and covariances of these risks. And the resulting distribution of cash flow in turn enables us to estimate the CFaR for 2011 for each of the banks.

As shown in Figures 1 and 2, there is a 5% possibility that the UK banking industry's average cash flow will fall below -£5.76 billion, that Barclays' cash flow will fall below -£0.34 billion, that RBS's cash flow will fall below -£40.29 billion, that HSBC's cash flow will fall below £0.67 billion, that Lloyds TSB's cash flow will fall below -£4.90 billion, that Natwest's cash flow will fall below -£10.38 billion, and that Nationwide's cash flow will fall below -£0.72 billion in 2011. Figure 3, comparing these banks' cash flow positions, shows only HSBC contributed positive cash flow to the UK banking industry at the 5% confidence level. The other banks (barring Barclays and Nationwide), with fatter-tailed distributions, face relatively greater downside risk. Table 5 also compares banks' downside cash flow at risk as a percent of expected cash flow. It is clear that Lloyds TSB and Natwest face the largest risks (with figures of 3600% and 816%, respectively).

6. Summary and Conclusions

For a long time of period, the banking industry (and its regulators) considered solvency to be more important than liquidity within their risk management operations. But the global financial crisis of 2008/09 has changed all that (Duttweiler, 2009).

In recognition of the potentially-serious risks associated with illiquidity and the undeveloped state of liquidity risk modeling, this paper uses a cash flow model to estimate UK banks'

coefficients in the exposure model.

liquidity risk. The results demonstrate that the UK banking industry suffers variable funding pressure. The negative forecasted average CFaR (at -£0.06 billion) indicates that the UK banking industry will be slightly illiquid by the end of 2011. Of the six biggest UK banks, only HSBC maintains positive CFaR throughout the 1997-2011 period, while RBS faces the largest liquidity risk, with a 5% chance that CFaR will be less than -£40.29 billion during 2011. Meanwhile, Lloyds TSB and Natwest have the most volatile cash flows, as measured by downside cash flow at risk as a percent of expected cash flow.

We acknowledge, however, that the paper has several limitations. First, with only fourteen years of annual data, the accuracy of the exposure-based cash flow model might be compromised. Second, we are currently only able to estimate annual CFaR because of data limitations; it would be nice to have quarterly and half-yearly data to analyze shorter-term liquidity positions. And third, the estimated future cash flows are sensitive to the selection of target cash flow data (e.g. profit before tax). Notwithstanding this, we do our best to quantify liquidity risk for the UK banking industry with a single number. Our results support the work of the Basel Committee on Banking Supervision which, under Basel III (BCBS, 2010), pays attention to both liquidity and solvency, a major change in emphasis on previous iterations of the Basel Capital Accord.

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Table 1: Make-up of A Typical UK Bank's Consolidated Cash Flow Statement

Profit before tax
Adjustments for:
Change in operating assets
Change in operating liabilities
Non-cash and other items
Tax received
Net cash used in operating activities
Cash flows from investing activities
Purchase of available-for-sale financial assets
Proceeds from sale and maturity of available-for-sale financial assets
Purchase of held-to-maturity investments
Purchase of fixed assets
Proceeds from sale of fixed assets
Acquisition of businesses, net of cash acquired
Disposal of businesses, net of cash disposed
Net cash provided by investing activities
Cash flow from financing activities
Dividends paid to non-controlling interests
Interest paid on subordinated liabilities
Proceeds from issue of subordinated liabilities
Proceeds from issue of ordinary shares
Repayment of subordinated liabilities
Change in stake of non-controlling interests
Net cash provided by financing activities
Effects of exchange rate changes on cash and cash equivalents
Change in cash and cash equivalents
Cash and cash equivalents at beginning of year
Cash and cash equivalents at end of year

Table 2: Correlation of Independent Variables after First Differencing

Δ	SI	LI	π	LQ	PV	\$/£	€/£	Repo	Swap	g	ABS	UB
SI	1.00	0.51	0.35	0.58	0.22	0.75	0.57	0.51	0.59	0.60	0.48	-0.28
LI		1.00	0.20	0.47	0.21	0.48	0.31	-0.07	0.33	0.34	0.18	-0.60
π			1.00	0.56	0.61	0.22	-0.13	0.49	0.44	0.44	0.75	0.17
LQ				1.00	0.71	0.59	0.07	0.54	0.66	0.29	0.79	-0.44
PV					1.00	0.02	-0.20	0.70	0.60	-0.03	0.85	-0.05
\$/£						1.00	0.28	0.23	0.17	0.48	0.29	-0.39
€/£							1.00	-0.17	0.25	0.55	-0.06	-0.06
Repo								1.00	0.59	-0.05	0.77	0.04
Swap									1.00	0.29	0.74	-0.46
g										1.00	0.19	-0.02
ABS											1.00	-0.16
UB												1.00

Table 3: Description of Variables and Data Sources Used

Variable	Definitions	Source	Dataset Code
SI	3-month or 90 day UK LIBOR	OECD	
LI	10-year government bond yields	OECD	
UB	All bands of UK bond clean prices index edited by International City/ County Manager Association	DATASTREAM	ISMSTAL
ABS	US spreads of asset-backed-securities	IMF	GISR 04/2010
PV	Asset price volatility	IMF	GISR 04/2010
Swap	Euro area swaps spreads	IMF	GISR 04/2010
LQ	Market liquidity index	IMF	GISR 04/2010
Repo	Spreads between yield on a 3-month gilt repo and on a 3-month UK treasury bill	BOE	
\$/£	British pounds against US dollars exchange rate	IFS	AH.ZF
€/£	British pounds against Euros exchange rate	IFS	ED.ZF
π	Inflation rate	IFS	64 ..XZF
g	Real GDP growth rate	IFS	99BPXZF

Table 4: Exposure Model Results

Bank Name	UK banks	Barclays	RBS	Lloyds	HSBC	NatWst	Nationwide
Intercept	0.14**	0.39***	1.16	0.11	0.25***	-0.21	0.017
	(0.056)	(0.110)	(0.71)	(0.148)	(0.062)	(0.195)	(0.026)
SI	0.26***		2.49***	0.38**	0.33***	1.5****	0.14****
	(0.054)		(0.656)	(0.151)	(0.083)	(0.288)	(0.022)
LI				-1.32***		-1.74***	-0.26***
				(0.284)		(0.429)	(0.059)
UB	2.59*						-1.31*
	(1.338)						(0.661)
PV	-0.36***	-0.87***					
	(0.082)	(0.178)					
Swap		3.36**	-21.62***				
		(1.10)	(6.362)				
Repo	-2.03*		-25.99**		-2.78**	-12.11***	
	(0.982)		(9.413)		(1.114)	(2.9)	
\$/£							
€/£		4.62**		4.3*			
		(1.426)		(1.91)			
π		0.88**	-3.78***		0.38**		0.15***
		(0.199)	(1.093)		(0.123)		(0.037)
g				0.84****	-0.15***	-0.6****	
				(0.072)	(0.044)	(0.107)	
R^2	0.911	0.891	0.896	0.976	0.73	0.833	0.909
Ad R^2	0.867	0.837	0.844	0.965	0.595	0.749	0.863
P(normal)	0.419	0.168	0.225	0.428	0.742	0.353	0.535
P(non-auto)	0.646	0.447	0.301	0.692	0.311	0.162	0.137
standard error	0.186	0.382	2.28	0.464	0.199	0.610	0.078

Note: Coefficients show average cash flow changes in billions of British pounds from one-unit increases in the independent variables. In order to keep enough degrees of freedom, we use the best estimation results with a maximum of 4 explanatory variables in each model. '$*$' indicates significance at the 90% confidence level, '$**$' at the 95% confidence level, '$***$' at the 99% confidence level, and '$****$' at the 99.9% confidence level.

Table 5: Exposure-Based CFaR Estimates for 2011 (£bn)

	Mean Cash Flow (A)	CFaR at 5% confidence level (B)	CFaR in percent $(\lvert A-B\rvert/A)\times 100$
Barclays	6.54	-0.34	109%
RBS	9.97	-40.29	504%
HSBC	5.40	0.67	88%
Lloyds TSB	0.14	-4.90	3600%
Natwest	1.45	-10.38	816%
Nationwide	0.93	-0.72	177%

Figure 1: UK Banks' Simulated Cash Flow Distributions

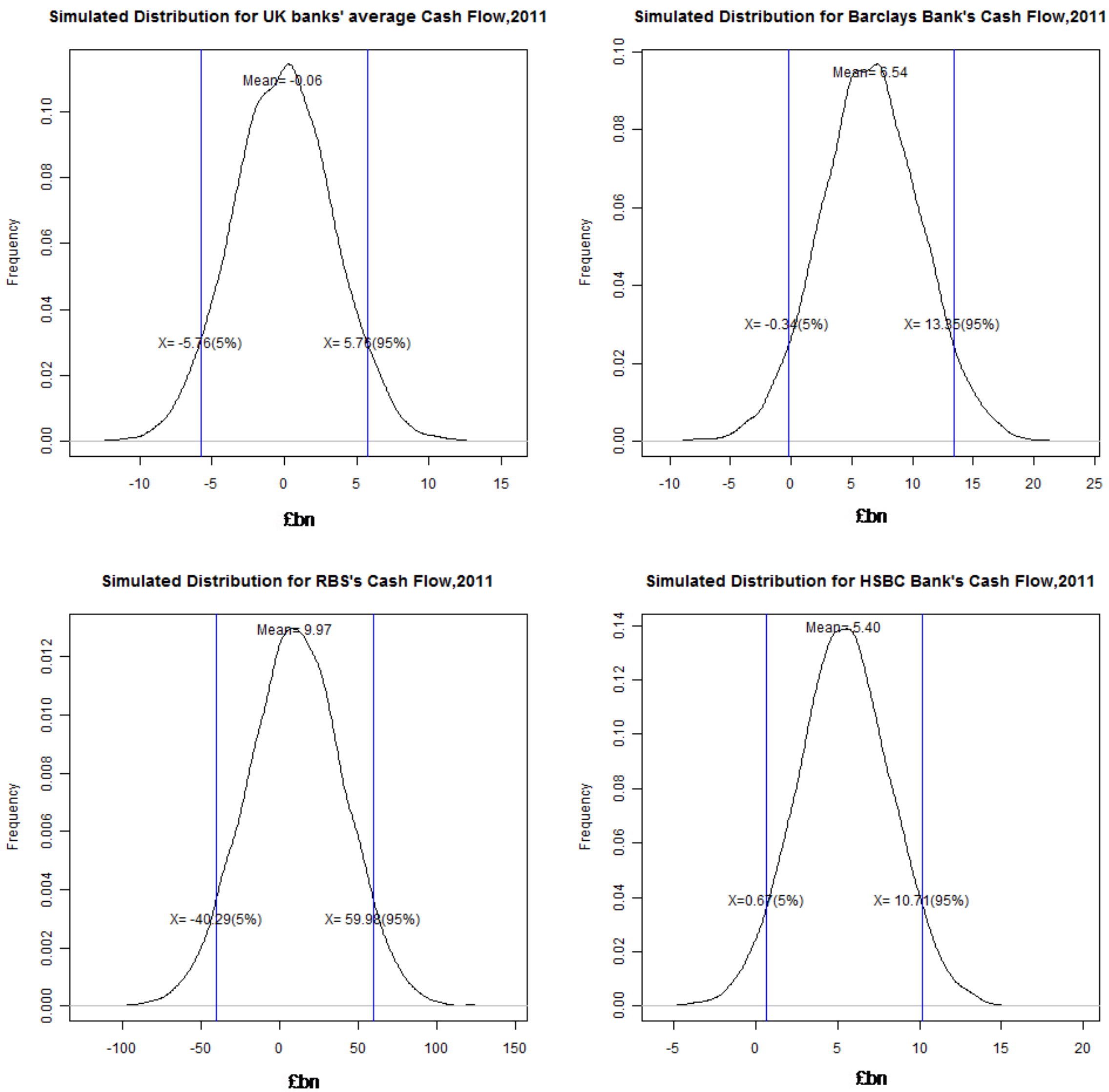

Figure 2: UK Banks' Simulated Cash Flow Distributions ($cont^d$)

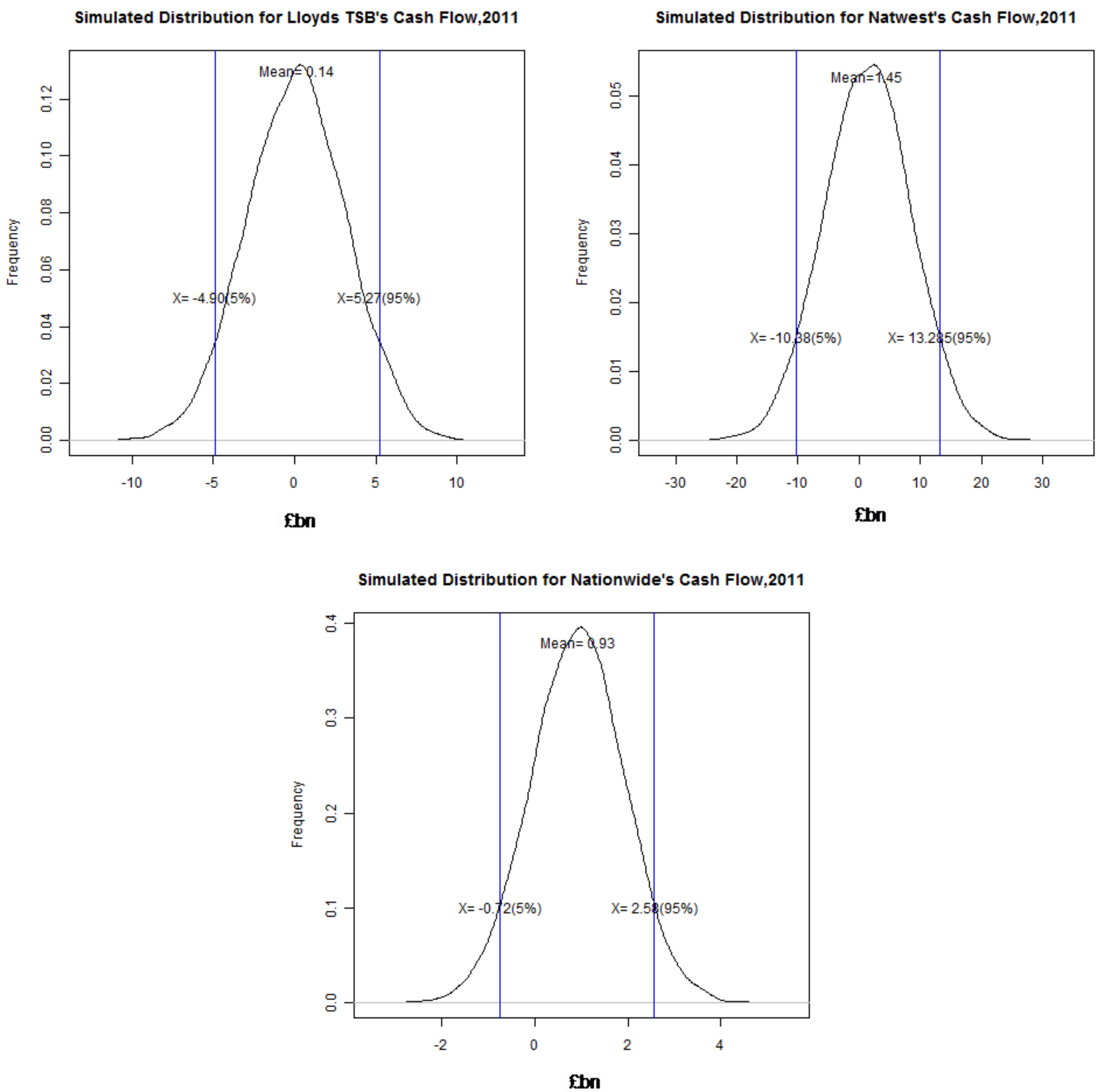

Figure 3: UK Banks' Simulated Cash Flow Distributions: A Comparison