THE VALUE OF INTRODUCING STRUCTURAL REFORM TO IMPROVE BOND MARKET LIQUIDITY: EXPERIENCE FROM THE U.K. GILT MARKET

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ABSTRACT

The importance of maintaining sufficient liquidity in financial markets is emphasised strongly in the academic literature. During the 1990s the United Kingdom monetary authorities introduced a number of structural reforms in the government bond market, aimed at improving secondary market liquidity. In this paper we examine the impact of the reforms by attempting to ascertain if liquidity levels improved in the post-reform period. We estimate the change in liquidity levels through the use of a proxy measure of liquidity, namely the benchmark bond theoretical versus market yield error. We examine the determinants of the proxy measure of market liquidity, and estimate which of the explanatory variables carries the greatest weight in influencing liquidity levels. We identify those factors that contributed most to maintaining secondary market liquidity and thereby draw conclusions of potential value to sovereign bond market monetary authorities.

JEL Codes: G11, G12, G32

I. INTRODUCTION

Investors and central monetary authorities are concerned that financial markets operate in an orderly manner and offer sufficient liquidity. The importance of having adequate levels of liquidity is emphasised strongly in the academic literature. Although there is more than one definition of liquidity, the general understanding of it is clear and breaks down into an ease of undertaking transactions in the secondary market. In the 1990s the United Kingdom (UK) central monetary authorities introduced a number of structural reforms designed to improve market liquidity. Our objective here is to determine if the reforms succeeded in this goal. We measure liquidity using two proxy measures. We also investigate the significance of the relationship

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between the proxy measures of liquidity and their explanatory variables. As a result of our study we draw conclusions for policy analysis that may be of value to sovereign debt agencies.

The work is motivated by the following factors: a desire to fill gaps in the existing literature with respect to sterling markets and UK government bonds; a response to an examination of gilt market liquidity by the sovereign issuing authority itself, which concluded with an observation that further research was required; to ascertain if results from earlier academic studies of the US Treasury market also hold in the UK market; and the wish to ascertain if the two proxy liquidity measures we selected were effective in their purpose.

We consider the UK gilt market during the period 1993–2002. This time period is dictated by the timing of the structural reforms themselves, implemented during 1996-1998, and takes into account the period immediately before and after the implementation of the reforms. The market reforms, which were designed to improve liquidity and accessibility of the UK gilt market, included the introduction of new products as well as technical changes to operating processes. The following reforms were introduced:[2]

- an open secured lending or "repo" market in gilts;
- a market in gilt zero-coupon bonds (strips);
- a regular auction issuance and benchmarking programme;
- changes to operating methods including a different accrued interest day-count basis, to bring gilts into line with practice in the US Treasury and euro-area sovereign bond markets.

To measure liquidity level we use a proxy measure, the theoretical price (yield) error. We consider the relationship between liquidity as measured by the yield error and a number of explanatory variables, to assess the size and significance of their effect on liquidity. We determine the significance of the selected determinants, and also observe if any significant change in the relationship has taken place during our observation period. At the conclusion of our examination we identified the significant determinants of the proxy measure of liquidity, as well as the suggestion that it was deemed to have increased in level of significance and size of coefficient during the observation period. Additional tests indicated likelihood that a structural break was evident in the time series data at two expected points in the period before and after the market reform implementation period.

Our study makes three contributions to the existing literature: it is the first such study using the named proxy indicators that looks specifically at the UK gilt market; secondly, it presents results of the interaction of various explanatory variables as drivers of liquidity, which will be of value to the sovereign monetary authority; and thirdly it suggests policy direction for other sovereign debt agencies that wish to improve liquidity levels in their

[2] For greater detail on the structural reforms that were undertaken during 1996-1998 see Bank of England (1995) and Debt Management Office (1998, 2000)

own markets. The implied success of the reforms suggests they may be implemented in other markets.

The paper is structured as follows. In Section 1 we review the literature and provide a discussion of market liquidity. This is followed by the background to empirical testing, the formulation and testing of the regression model for the theoretical price (yield) error, the tests of structural change, and discussion of the results. The final section presents our conclusions.

II. LITERATURE REVIEW

We consider first the definition of financial market liquidity, before presenting a review of the literature.

A. Market liquidity

There is no standard definition of financial market liquidity. That said, there is a general understanding of the nature of liquidity, and academics and practitioners use a number of commonly accepted definitions and measures. Essentially a liquid market can be defined as one where:

- it is possible for market participants to transact buy or sale transactions at any time (during opening hours) in size, at no extra cost, without this transaction causing prices to move;
- two-way markets are made available to market participants in wholesale market size, and where there is openness in determining asset fair value.

The first definition has been suggested by O'Hara (1995) and Fleming (2001) among others, while the second was described by Mackintosh (1995).

B. Literature

A general introduction into the structure of the gilt market and its trading mechanisms is given in Choudhry *et al* (2003). The academic literature on the gilt market is sparse. Steeley and Ahmad (2002) conducted an investigation on the behaviour of prices in the gilt market during the period 1993 to 2001. The period Steeley and Ahmad investigate takes in the time of the reforms to the gilt market, as well as periods of general market correction such as the Russian debt default in 1998 and the Long Term Capital Management (LTCM) hedge fund crisis of 1999. The authors consider the information and price action efficiency of gilts, specifically (i) the characteristics of the price movements during this period, testing the null hypothesis that price movements are random, and (ii) whether any non-random behaviour in prices could have been exploited. Their general conclusion is that the gilt market exhibited returns persistence during the crisis period, due to its safe-haven status.

Repo is a common feature in many government bond markets, both in developed and emerging economies, being a standard money market secured loan instrument. It was a key ingredient of the BoE market reforms. A basic coverage and definition of repo is given in Blake (1990). The Bank for International Settlements (BIS) study group (2000) investigated the part played by repo in the maintenance of an orderly secondary market and concluded that it was a vital tool for such purposes.

The academic literature reviews financial market liquidity in some depth. O'Hara (1995) defines liquidity as the ability to trade a security quickly and with little cost. Sundaresan (1997) defines liquidity as a market where investors can buy and sell large amounts of stock with ease, at a narrow bid-offer spread and without an adverse price reaction. Gravelle (1998) defines liquidity as being the ease with which large-size bond transactions can be effected without market prices being impacted. He also reports that the central authorities desire the maintenance of a liquid market. Borio (2000, p.38) describes a liquid market as one where "…transactions can take place rapidly and with little impact on price".

Previous research into liquidity measures has concentrated mainly on the liquidity of the US government bond market and US corporate markets; these included Fleming (2001) and Diaz and Skinner (2001). Other studies considered the US dollar interest-rate swap market: these included Amihud and Mendelson (1991a, 1991b), Alexander, Edwards and Ferry (2000), Hong and Warga (2000), Brown, In and Fang (2002) and Kalimipalli and Warga (2002).

A number of proxies for liquidity have been studied in the previous research. Yield spreads were investigated in Sarig and Warga (1989), Blume, Keim and Patel (1991), Warga (1992) and Crabbe and Turner (1995). Trading volume was investigated in Kamara (1994) and Alexander, Edwards and Ferri (2000). Nunn, Hill and Schneeweis (1986) used a combination of three proxies for liquidity, which were (i) the bond's age (ii) the bid-offer spread and (iii) the amount of bonds outstanding. Mackintosh (1995) proposed a liquidity score for a bond based on an aggregate liquidity rating. This rating was based on a combined measure of factors including issue size, the nature of the clearing (settlement) system, the number of market makers, the bid-offer spread and the geographical spread of holdings.

A number of studies have tested the hypothesis that larger size bond issues are more liquid. For example Hong and Warga (2000) observed that larger-size issues had smaller bid-offer spreads. They also observed a positive relationship between bid-offer spreads and the age of the bond, its yield, and time-to-maturity, and a negative relationship between price spread and bond credit rating. Alexander, Edwards and Ferri (2000) examined the determinants of trading volume for corporate bonds, and concluded that the larger-size issues were more liquid.

The importance of liquidity to the smooth functioning of financial markets is emphasised frequently in the literature. Datar, Naik and Radcliffe (1998) suggest that liquidity has an impact on asset returns. Amihud and Mendelson (1986) concluded that investors allow for lower liquidity by demanding a higher return premium, which is the trade-off required for bearing the higher cost of trading in illiquid markets. The same authors (1991) also found that the difference in bid-offer spread between US Treasury bills and Treasury securities had an impact of yield-to-maturity. Amihud, Mendelson and Lauterbach (1997) observed that asset values on the Israeli stock exchange underwent changes when the equities began to be traded on a more liquid electronic system.

McCauley and Remolona (2000) reported how a number of Organisation for Economic Cooperation and Development (OECD) governments continued to maintain gross issuance in an effort to preserve market liquidity, despite budget surpluses removing the need to issue debt. This reflects the importance of the government bond market to all market participants, including investors, traders and brokers. The authors emphasise the importance of a liquid market in government bonds.

Further proxies for liquidity include yield spreads, investigated in Sarig and Warga (1989), Blume, Keim and Patel (1991), Warga (1992) and Crabbe and Turner (1995). Trading volume was investigated in Kamara (1994) and Alexander, Edwards and Ferri (2000).

Blennerhassett and Bowman (1998) studied the impact of a move from a telephone dealership market to a screen-based order book on the New Zealand stock exchange; this produced evidence of a reduction in trading costs. They also found that the bid-offer spread became more sensitive to changes in trade size, and this effect may mean that larger-size dealers carry disproportionate costs. Naik *et al* (1999) studied the impact of the change from the dealership market to an order book market in the London Stock Exchange (LSE) and found that investors had benefited from the change as they now faced narrower bid-offer spreads.

Researchers have identified various factors that are determinants of liquidity. Alexander, Edwards and Ferri (2000) and Sarig and Warga (1989) found that corporate bonds that were issued more recently were more actively traded, implying age of bond as a liquidity factor. Among numerous studies that make this observation, Babbel *et al* (2001) showed that benchmark or "on-the-run" US Treasury securities were more actively traded than older Treasuries. Fleming and Remolona (1999) found that macroeconomic announcements had a significant impact on the bid-offer spread. Another factor is the outstanding amount in issue for a bond; one expects this to be of influence on liquidity and Fisher (1959) observed this in a very early study. Garman (1976), Stoll (1978), Amihud and Mendelsohn (1980), and Ho and Stoll (1981) found that the bid-offer spread increases with the bond price and the credit risk of the bond, and also decreased with higher levels of trading activity.

In credit-risky corporate bond markets credit ratings have an impact on bond liquidity, as shown by Fridson and Garman (1998). They analysed a sample of lower credit-quality bonds and found that the credit ratings of the bonds had the biggest impact on bid-offer spread at time of issue. The primary concern with looking at corporate bonds when measuring liquidity is that there are other issues, such as credit risk, that will influence the results and which make separation from liquidity more problematic. This viewpoint is supported by Kamara (1994), who concluded that looking only at Treasury bonds removes liquidity issues arising from credit risk, because all the bonds in the sample are credit-risk-free. The same applies to UK gilts; all bonds in a sample of gilts have uniform tax, trading and settlement issues, with zero credit risk.

C. Measuring liquidity: testing the theoretical price (yield) error

Market practitioners derive the zero-coupon interest rate yield curve from actual market prices. Bond prices obtained from the spot yield curve represent the correct theoretical price for those bonds.[3] The difference between the theoretical price of a bond and its actual price as observed in the secondary market is in effect a mis-pricing. Should a practitioner believe in the integrity of his yield curve model, such mis-pricing can be exploited for profit in the market. This logic is behind much arbitrage trading activity undertaken in the world's sovereign bond markets by investment bank proprietary trading desks.

Essentially, *ceteris paribus* the more liquid the market, the narrower the yield spread between the two yields because it implies greater market transparency and therefore less mis-pricing. In theory, a liquid market should have no, or only a small, spread between the theoretical bond yield and the market-observed bond yield. This has been suggested in Diaz and Skinner (2001) and Brown, In and Fang (2002) amongst others. Therefore a narrowing theoretical price error (yield spread) implies greater liquidity. We use our database of benchmark bond prices (yields) and compare these to the theoretical bond price (yield) for each week. The theoretical price (yield) is calculated from a fitted zero-coupon yield curve, which is in turn calculated from the yield-to-maturity yield curve for that week.[4] The difference between the two prices is the observed price error (OPE). A reduction in the OPE over the sample period may be considered to be an indicator of increased liquidity, as suggested in Fleming (2001) and Kalimipalli and Warga (2002). Therefore we wish to test for any improvement in liquidity suggested by a decreasing OPE, and we wish to examine the determinants of the OPE to identify the relationship between a set of dependent variables and overall level of liquidity.

[3] The correct theoretical price is obtained by deriving the zero-coupon (spot) yield curve from observed market prices. A yield curve model is used to derive the spot curve; this can be a linear interpolation model such as RATE, a cubic B-spline model such as YCF 2.0 or a single-factor stochastic yield curve model such as Vasicek (1977) or Cox, Ingersoll and Ross (1985).

[4] In other words, we carry out the following: our dataset contains benchmark bond prices and yields, as well as the gilt yield-to-maturity yield curve, for each week in the observation period (510 observations). We use the yield curve for each week to derive a zero-coupon yield curve for that week. This theoretical zero-coupon curve shows us the theoretical yield for each of the benchmark bonds. We then obtain the difference between the actual yield and the theoretical yield for each bond each week. This difference is the observed price error (OPE). Note that it is the difference between the theoretical *yield* of the bond and its actual yield observed in the market that is measured as the OPE. Bond price is synonymous with bond yield in this context.

We calculated OPE spreads for four benchmark bonds for each week of the period under study. These are market closing prices as at close of business each Friday, obtained from the Bloomberg trade system. The observation period is broken into three distinct periods:

- Period 1, the sample period before the implementation of the market structural reforms (Jan 1993 – Dec 1995);
- Period 2, the period during which reforms were introduced by the Bank of England (Jan 1996 – Jan 1998);
- Period 3, the sample period after the introduction of reforms (Feb 1998 – Dec 2002).

We found that the mean OPE had reduced during the sample period, with a mean lower in Period 3 compared to that in Period 1.

The regression results we obtained (see Table II) are significant with an adjusted R^2 above 50% for all maturities. The statistically significant determinants of the spread are bond maturity, market confidence and swap spread.

D Deriving the theoretical yield curve

To derive the theoretical yield curve, we estimate the zero-coupon discount function. The OPE is determined for each benchmark bond for each week of the sample period. Beim (1992), James and Webber (2000) and Martellini, Priaulet and Priaulet (2003) find that cubic spline yield curves perform at least as well as, if not better than, other techniques. This approach is commonly used in the market, and is often preferred over the dynamic or stochastic models because of the ease and quickness of its calculation, and its requirement for lower computing power. Hence we use the cubic spline interpolation method to derive the theoretical discount function, from which we plot the spot yield curve. We use two different packages, CUBED software and the YCF2.0 model run on Excel.[5]

We use the database of benchmark gilts, which holds the bid and offer prices for the two-, five- and 10-year benchmark gilts and the long-bond benchmark for each week in the sample period. Thus we have a total of 510 weeks of prices, with four benchmarks each week, a total of 2040 prices. We then compile the corresponding yield-to-maturity yield curve for each week in the sample period. This yield curve is taken from Bloomberg. This is one yield curve per week, a total of 510 different curves in the sample period.[6]

We then apply the cubic spline method to this data to estimate the gilt yield curve on a weekly basis from January 1993 through to December 2002. Both the CUBED and YCF applications automatically generate the equivalent discount function. We use this discount function to price each benchmark

[5] Both of these packages can be obtained for use in the market by finance practitioners, for example they can be downloaded from www.yieldcurve.com . A summary of the approach used in these packages is available from the author.

[6] We ignore the last week in each year, which is characterised by illiquid trading due to the extended Christmas and New Year holiday period.

bond each week, simultaneously calculating each bond's implied yield. This is the bond's theoretical yield. We then measure the difference between the observed market yield and the theoretical yield. This difference is the OPE.[7]

We accept that the extent of the OPE will vary depending on which yield curve fitting method is used to derive the theoretical spot curve. The extent of the actual difference in the OPE is, we feel, ultimately irrelevant; the object of this analysis is to determine the significance and impact (if any) of selected independent variables on the OPE itself. We recognise the existence of an OPE, and this is sufficient. That said, to determine this with any certainty, we derive an additional theoretical yield curve by applying the single-factor Vasicek model.[8] The results of this OPE calculation are available on request from the author.

III. DATA AND METHODOLOGY

We regress selected determinants to see what factors are driving the extent of the errors. The choice of independent variables is influenced by the academic literature; but we also add a new determinant not previously observed in the literature in the form of the swap spread. We take the absolute value of the OPE as the dependent variable in the regression. The independent variables are:

- issue size (*SIZE*), which was considered in our earlier regression analysis. A larger OPE may result for a bond with smaller issue size as this indicates lower liquidity, and vice-versa;
- bond maturity (*MATURITY*), in years; this has similar implications to issue size and was also considered in the earlier regression;
- overall market confidence (*CONFIDENCE*); following Eom, Subrahmanyam and Uno (2002), we wish to use an indicator of general market conditions, as this may influence liquidity and hence the OPE. We use the level of the United Kingdom equity market as the proxy for general market confidence, as measured by the FTSE-100 share index. Our general assumption is that a relatively higher level of confidence should provide for greater liquidity and hence a narrower OPE;

whether the bond price is above or below par, that is at a premium (*PREMIUM*) or discount (*DISCOUNT*); bonds trading significantly away from par are more likely to sit away from the theoretical yield curve, and hence this may influence a higher OPE;

- the swap spread (*SWAP*); this is the spread of the equivalent-maturity interest-rate swap rate over the market yield of the benchmark bond. The swap spread reflects the credit risk of the interbank market over the sovereign market, and in times of higher spread reflects lower market confidence and more credit-risky economic environment. Hence a higher

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[7] It is termed observed *price* error but in fact it is the difference in *yield* that is considered. The OPE is therefore the difference between the yield of the bond given by its actual market price and its implied price as given by the derived theoretical zero-coupon (spot) yield curve.

[8] See Vasicek (1977), and in accessible detail in James and Webber (2000).

spread should influence a higher OPE. Therefore we consider it as an explanatory variable.

The selection of the explanatory variables above, with the exception of the swap spread, is driven by the previous literature. The *SWAP* variable has not previously been considered in the research literature in testing on liquidity and its determinants. We adopt it here because it is a critical measure of market financial health, which can be expected to influence the OPE. A wide swap spread relative to the historical spread is an indicator of economic downturn. Note that the swap spread variable will be correlated with the market confidence variable, so it may exhibit multicollinearity. Following Greene (2000), we deem our sample size to be sufficiently large to negate any impact of this, hence a diagnostic test for multicollinearity is not required.

Our database is supplemented with the following additional data:

- the level of the FTSE-100 index; this is obtained from Bloomberg;
- the swap curve for each week in the sample period; this is recorded on Bloomberg. The required swap rates will be on the table of rates for the swap curve, reported on Bloomberg. We use the swap rates that correspond with the benchmark bond maturities, that is, two-, five-, 10-year swap rate and long-bond equivalent swap rate.

We estimate the following regression to explain the absolute values of the OPE:

$$Y_{OPEit} = \alpha + \beta_1 SIZE_{it} + \beta_2 MATURITY_{it} + \beta_3 CONFIDENCE_{it} + \beta_4 PREMIUM_{it} + \beta_5 DISCOUNT_{it} + \beta_6 SWAP_{it} + \varepsilon_{it}$$

(1)

where Y_{OPEit} is the OPE measured from the derived zero-coupon yield curve, for bond *i* at time *t* for the sample.

The model will analyse pooled cross-section time series data. There is precedent for this approach in the literature, most notably Diaz and Skinner (2001) and Moulton (2004). Diaz and Skinner test the yield spread error between an observed yield curve and a fitted yield curve, this being estimated from the selected yield curve model for bond *i* at time *t* for the sample at hand.

Table I shows where we expect the signs of the coefficients to lie. With regard to the variables price premium and price discount, we are uncertain what sign the coefficients should be, although excessive price premiums are sometimes associated with illiquidity and so this may result in a positive sign. This is suggested by Elton and Green (1998), who report that institutional investors sometimes prefer not to hold bonds that are significantly away from par in price for this reason.

Table I Predicted signs of explanatory variables

Explanatory Variable	Predicted Sign	Reasoning
Issue size	Negative	A larger issue size suggests greater liquidty and hence smaller spread
Term to maturity	Positive	Higher term to maturity increases interest-rate risk (modified duration), therefore wider spread
Market confidence	Negative	Higher level of market confidence suggests favourable economic conditions, hence greater liquidity and lower OPE
Price premium	Uncertain / Positive	Unable to suggest what sign to expect for price premium
Price discount	Uncertain / Positive	Unable to suggest what sign to expect for price discount
Swap spread	Positive	A wider swap spread suggests great market uncertainty with regard to credit risk, hence lower liquidity and hence greater OPE

We conduct an additional test on the timing of the structural reforms. A dummy variable D_2 is added to the model at (1). D_2 takes the value 0 for all regressions run prior to the end of reforms, and a value of 1 for the period thereafter. The cut-off point is January 1998. The test is run for the whole period, with D_2 taking the value of 0 for every week up to January 1998 and a value of 1 for every week thereafter.

IV. EMPIRICAL RESULTS

Table II reports the summary statistics of the spread OPEs. From the differences arising from the comparison of market prices to our theoretical cubic spline yield curve, we see that the lowest OPE is consistently shown by the two-year benchmark, over all three periods. The highest spread varies across periods between the 10-year bond and the long-bond. Overall, there is a steady reduction in the OPE from period 1 to period 3 for all four bonds, indicating *prima facie* an increasing level of market liquidity over time. The mean OPE has reduced at the end of the period, although it increased between period 1 and period 2. Of note is the reduction in the standard deviation in the time from period 1 to period 3, which gives support to a conclusion that OPE values have reduced during our observation period. The reduction in OPE does not suggest conclusively an increase in liquidity in this period, although we may infer this; rather, it suggests that price transparency has increased in this period. However we can conclude that greater liquidity has been a factor leading to narrower OPEs, on the grounds that a market experiencing a reduction in liquidity would have witnessed wider OPEs. The results in Table VIII also influence our view that it is unnecessary to run an autocorrelation regression. The aim of such a test would be to see if over time the OPE is going to reduce to a certain level; however we see from the table that the OPE fluctuates during the period with the minimum OPE narrowing by end of period 3.

Table II Summary statistics of OPE spread errors: theoretical yields calculated using cubic spline method

Period 1 (1993-95)

Bond	2-year	5-year	10-year	Long-bond
Mean	0.018343	0.019642	0.023421	0.099594
Median	0.015631	0.0185752	0.026124	0.091243
Maximum	0.0281791	0.0334629	0.0341254	0.1347196
Minimum	-0.0241684	-0.0312579	-0.0351654	-0.0392152
Standard Deviation	0.047695	0.042574	0.085322	0.117675
Kurtosis	28.2975	25.1571	15.1695	33.5258

Period 2 (1996-98)

Bond	2-year	5-year	10-year	Long-bond
Mean	0.021025	0.029124	0.039178	0.0442174
Median	0.022624	0.029170	0.040012	0.0450092
Maximum	0.0293135	0.0365582	0.0441225	0.0420158
Minimum	-0.0235781	-0.0373135	-0.0396853	-0.0409613
Standard Deviation	0.05857	0.043123	0.106012	0.100178
Kurtosis	33.2514	24.7585	44.5215	41.4516

Period 3 (1998-2002)

Bond	2-year	5-year	10-year	Long-bond
Mean	0.009785	0.0093527	0.020186	0.069594
Median	0.009254	0.013561	0.020784	0.071243
Maximum	0.0243614	0.0319851	0.0316794	0.0917187
Minimum	-0.0210059	-0.0287542	-0.0329761	-0.032166
Standard Deviation	0.031325	0.041018	0.074792	0.072514
Kurtosis	21.0803	25.7895	14.9233	22.6174

Errors are the difference between the market observed yield and the yield implied by the derived yield curve, calculated using the cubic spline method
Errors given in percentage (x100 to obtain basis points)

From Table II we note two technical observations, namely that one standard deviation in period 3 is a very low 3 to 8 basis points, and that the distribution of the data exhibits positive kurtosis. A low standard deviation suggests we can attach greater value to the mean value itself. Positive kurtosis suggests stability in the results, as well as a fatter tail (see, for instance Jones, Sulkin and Larsen [2002]).

The OPE data are pooled cross section time-series data and in common with most financial time series can be expected to exhibit autocorrelation and heteroscedasticity. In fact there is no presumption of autocorrelation in this case as the *DW* test statistics lie between d_U and $(4 – d_U)$. We apply the Newey-West technique to estimate a consistent estimate of (1). The results of the regression, carried out separately for periods 1, 2 and 3, are shown at Table III.

We repeat the exercise as carried out earlier for the bid-offer spread and also run a pure time series test for the bonds individually, for Periods 1 and 3. The results are shown as Panels B and C in Table III.

Table III Observed price error (OPE) test regression results; dependent variable is observed theoretical price error

Panel A

Variable Coefficient	Period 1 (1993-95)	Period 2 (1996-98)	Period 3 (1998-2002)	Full period (1993-2002)
Intercept α	0.0615[b] (3.51)	0.0509[b] (3.01)	0.0632[b] (3.48)	0.05392[b] (3.69)
Size β_1	-0.023 (-0.86)	-0.014 (-0.97)	-0.002 (-1.36)	-0.009 (-1.92)
Term to maturity β_2	0.0214[a] (8.19)	0.0344[a] (7.26)	0.0321[a] (7.57)	0.0368[a] (7.14)
Confidence β_3	-0.000632[b] (-3.37)	-0.000347[b] (-3.65)	-0.001455[b] (-3.43)	-0.001864[b] (-3.83)
Premium β_4	0.00159 (1.71)	0.00295 (2.001)	0.00065 (0.618)	0.00094 (1.045)
Discount β_5	-0.0046 (-1.89)	-0.0089 (-1.54)	-0.0021 (-1.35)	-0.0010 (-1.58)
Swap β_6	0.0517[a] (9.76)	0.0667[a] (4.13)	0.0633[a] (8.21)	0.0684[a] (7.71)
Dummy β_7	0.000001 (0.17)	0.000001 (0.31)	0.03001[a] (4.16)	0.248[b] (3.59)
Adjusted R^2	0.38	0.39	0.43	0.48
D-W statistic	2.080612	2.096825	2.064758	2.069514
F-statistic	4.901074	4.886713	4.674718	4.72415
N	153	106	251	510

t-statistic in brackets, using Newey-West standard errors
[a] Significant at 1% level
[b] Significant at 5% level

Panel B Period 1 (1993-95): Time series
Dependent variable is observed weekly price (yield) error for benchmark bonds

Variable Coefficient		Two-year	Five-year	10-year	Long-bond
Intercept	α	0.0234[b] (3.69)	0.0515[b] (3.92)	0.0679[b] (3.87)	0.04718[a] (3.99)
Size	β_1	-0.019 (-0.92)	-0.018 (-1.18)	-0.0001 (-2.46)	-0.00009 (-1.02)
Term to maturity	β_2	0.00161[a] (6.23)	0.0301[b] (3.35)	0.0367[a] (6.86)	0.0421[a] (6.43)
Confidence	β_3	-0.0016[b] (-3.45)	-0.000167[a] (-3.97)	-0.000437[b] (-3.39)	-0.000244[b] (-3.82)
Premium	β_4	0.00352 (1.88)	0.00264 (2.72)	0.00104 (1.27)	0.0010 (1.41)
Discount	β_5	-0.0106 (-2.06)	-0.0090 (-1.85)	-0.015 (-1.62)	-0.0118 (-2.08)
Swap	β_6	0.00409[a] (8.28)	0.0646[a] (5.29)	0.0651[a] (7.99)	0.0702[a] (7.05)
Adjusted R^2		0.39	0.4	0.42	0.44

t -statistic in brackets, using Newey-West standard errors
[a] Significant at 1% level
[b] Significant at 5% level

Panel C Period 3 (1998-2002): Time series
Dependent variable is observed weekly price (yield) error for benchmark bonds

Variable Coefficient		Two-year	Five-year	10-year	Long-bond
Intercept	α	0.0215[b] (3.84)	0.0517[b] (3.31)	0.05932[b] (3.88)	0.04091[b] (3.33)
Size	β_1	-0.021 (-0.97)	-0.008 (-1.76)	-0.0001 (-2.64)	-0.011 (-2.03)
Term to maturity	β_2	0.00267[a] (8.43)	0.0418[a] (6.31)	0.0471[a] (8.03)	0.0399[a] (7.78)
Confidence	β_3	-0.001064[b] (-3.52)	-0.000109 (-3.04)	-0.000832[a] (-3.99)	-0.0001742[b] (-3.01)
Premium	β_4	0.00098 (1.85)	0.00233 (1.99)	0.00121 (1.019)	0.00089 (1.95)
Discount	β_5	-0.0044 (-1.99)	-0.0084 (-1.63)	-0.0011 (-1.58)	-0.0029 (-1.96)
Swap	β_6	0.00533[a] (8.89)	0.0596[a] (4.39)	0.0684[a] (7.76)	0.0669[a] (6.47)
Adjusted R^2		0.4	0.4	0.44	0.43

t -statistic in brackets, using Newey-West standard errors
[a] Significant at 1% level
[b] Significant at 5% level

V. EVALUATION OF RESULTS

The results for both sign and magnitude of coefficients generally are in line with expectation.

The intercept predicts an OPE of just over 0.5 of a basis point if the impact of all other explanatory variables is removed, and the results are statistically significant at the 5% level. This implies that the methodology we used to fit the theoretical zero-coupon yield curve is an efficient and accurate one.

SIZE is the correct sign but is not statistically significant. We posit that this reflects that benchmark bonds invariably are all of large issue size in any case, therefore this factor carries little explanatory influence. *MATURITY* is the expected sign and also statistically significant at the 5% level.

CONFIDENCE is the correct sign, and is of statistical significance. However it is not of *practical* significance and has negligible impact on the OPE. This is perhaps surprising, but we infer that the transparency and efficiency of the market is sufficiently highly developed such that market yields reflect true fair value and are not influenced by market sentiment. This backs up the earlier result obtained using Hasbrouck's "market quality" indicator.

The price variables, *PREMIUM* and *DISCOUNT,* do not provide any significant results. They have no practical or statistical significance. The premium variable is the expected positive sign however. This is different to the result reported by Diaz and Skinner (2001), who obtained a negative value for both premium and discount proxies.

Finally, the *SWAP* variable is the expected sign and also significant at the 5% level. In terms of magnitude of the coefficient, it has the greatest influence on the OPE. The results suggest that a higher relative swap spread will cause the market yield of bonds to reflect greater uncertainty in fair-value yields and hence a greater spread away from the theoretical yield.

The result for the additional test with the dummy variable D_2 is encouraging as the sign of the coefficient is positive and statistically significant at the 5% level for the whole period. The magnitude of the relationship is large, and we may infer that the reforms were associated with an improvement in market transparency such that observed yields became more reflective of fair value.

An examination of Panels B and C shows how the impact of the statistically significant explanatory variables differs with bond maturity. The *MATURITY* and *SWAP* variables have the greatest impact on the longer-dated bonds, while the *CONFIDENCE* variable has largest impact on the short-dated bond. There is a reduction in the intercept value in Period 3 compared to Period 1, from which we infer that the "fair value" OPE has reduced. This implies an improvement in liquidity.

The adjusted R^2 values are below 50% and therefore do not explain the majority of the spread error; however they are relatively large as they lie between 38% and 48%. Taking our initial premise that a lower OPE is a reflection of a liquid market, our test results show that the explanatory variables are significant determinants of the OPE, in itself a proxy for liquidity. Monitoring these variables and understanding the relationship between them will assist in the maintenance of an orderly, liquid market.

VI. THE OBSERVED PRICE ERROR: TESTS OF STRUCTURAL CHANGE

Observation of the results suggests a change in the OPE. We wish to test if the OPE function estimated above has undergone a structural change at any point during the entire observation period. The tests undertaken to test for structural change in the relationships are the Chow test, the Wald test, the Quandt test and the CUSUM squares test.

A Chow test: results and evaluation

The application of the *F*-test in tests of structural change is common in the financial economics literature, as suggested in Greene (2001). In this context it is named the Chow test after Chow (1960) for tests at a known or suspected known break date. The model we test is the one shown at equation (1). We split the sample period 1993-2002 into two sub-sample periods, which are sub-sample 1 for 1993-1997 and sub-sample 2 for 1998-2002.

We obtain three estimated regressions, shown in Table IV below. The first regression is that shown already for the complete period in Table III Panel A. We apply a pooled cross-section analysis to incorporate all four benchmark bonds.

The Chow *F*-statistic obtained is $F = 2.0247$.

If the constant in (1) is fixed at the 5% level, the critical value $F_{7,\,496}$ is 2.01. The Chow test statistic only just exceeds this value, so we may reject the null hypothesis that the OPE function in both sub-sample periods is the same (albeit with much less certainty than we were able to before). Taken formally, this means we can infer that there has been a structural change in the relationship between the variables, and the coefficients are indeed different in the two periods. Note that the test statistic does *not* exceed the 1% critical value $F_{7,\,496}$ which is 2.64. Therefore we are not able to state with certainty that the structural break is due to changes in both the intercept value and the variable coefficients.

Table IV OPE regression equation: Chow test sub-sample periods and Wald statistic

Variable Coefficient	Full period (1993-2002)	Sub-sample period 1 (1993-1997)	Sub-sample period 2 (1998-2002)
Intercept α	0.05392	0.0612	0.0501
Size β_1	-0.009	-0.0126	-0.017
Term to maturity β_2	0.0368	0.0379	0.0371
Confidence β_3	-0.001864	-0.00989	-0.00114
Premium β_4	0.00094	0.00167	0.001601
Discount β_5	-0.0010	-0.0099	-0.001
Swap β_6	0.0684	651	0.0692
Dummy β_7	0.248	0.295	0.262
Adjusted R^2	0.48	0.42	0.44
Sum of squares	34.011	15.062	9.281
Wald statistic	5.071	-	-
N	510		
N_1		255	
N_2			255
k	7	7	7

B Wald test

We test for possibility of a "Type I" error using the Wald test for unequal variances, valid with large sample sizes.

The test statistic for the regression is shown in Table IV and is a value of 5.071. The χ-squared 5% critical value for 7 degrees of freedom is 14.07. Thus under the Wald test we are unable to reject the null hypothesis that the same coefficients apply in both sub-sample periods 1 and 2. This renders the Chow test results less effective with regard to what inferences can be drawn. Nevertheless as the *F*-test measures the increase in the sum of squared residuals when variables are dropped from the model, and the Wald test is essentially an *F*-test of the unrestricted model, we must infer that we cannot conclude that the relationship between the dependent and independent variables has changed during the entire period.

C. The QLR test for break at an unknown date

When conducting the Chow test we selected the date at which to split the dataset into two as the point at which implementation of the market reforms was complete. This pre-supposes that this was the date at which the structural break occurred. More realistically, the date of the possible break could lie at any point during the period the reforms were being undertaken – a time frame of 25 months – or on a point shortly after the reform process was completed. Therefore we apply a modified Chow test known as the Quandt likelihood ratio (QLR) statistic.

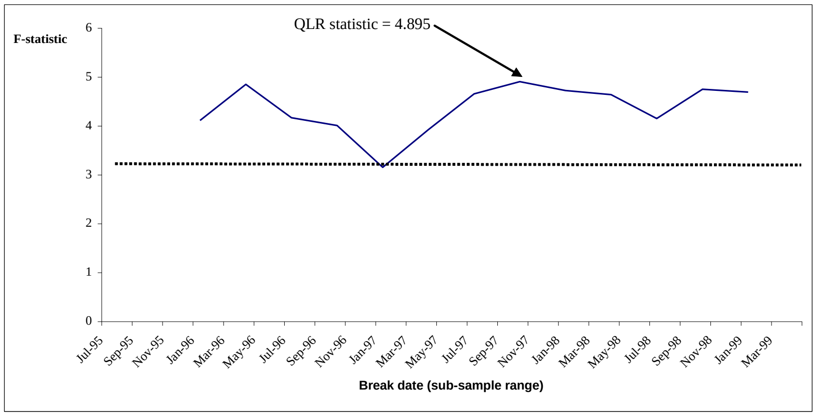
Our supposition is that the break lies during the period from the start of the reforms through to a point up to 12 months following their conclusion. We therefore apply the QLR test for breaks at all possible dates from January 1996 [t_1] to January 1999 [t_2] which is a sub-sample range within the full range t_0 to T of January 1993-December 2002.

Results are shown in Table V.

We observe that at the largest of the *F*-values on October 1997 we exceed the 5% critical value, suggesting that this is an estimator of the break date. This is a different date compared to that observed for the bid-offer spread test (which was April 1998), and technically it is *inside* the period of reforms. Note also that the test statistic exceeds the critical value for all but one of the dates during the entire period. It is therefore not certain that the break occurred at the time point implied by the test results. We may still conclude however that at least one of the coefficients in (5) has changed *at some point* during this sub-sample period.

Table V QLR test for break in equation (1) during sub-sample period January 1996-January 1999 (*F*-statistics)

Date t_n	F-statistic
Jul-95	
Oct-95	
Jan-96	4.103
Apr-96	4.842
Jul-96	4.156
Oct-96	3.998
Jan-97	3.144
Apr-97	3.916
Jul-97	4.647
Oct-97	4.895
Jan-98	4.714
Apr-98	4.629
Jul-98	4.143
Oct-98	4.739
Jan-99	4.681
Apr-99	



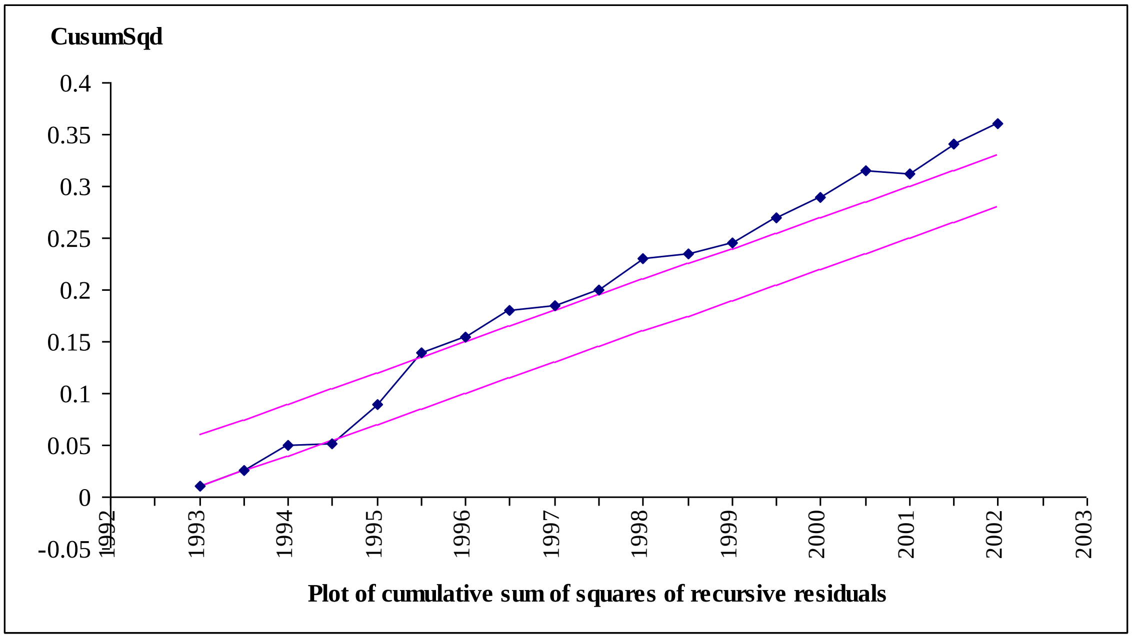
F-statistic tests H_0 of a break in one or more of the coefficients or the intercept in Equation (7.9)
QLR statistic is the largest of the results obtained
The 5% critical value with 7 restrictions is 3.15

D CUSUM of squares (CUSUMQ) test

A further test of model stability is the CUSUM test suggested by Brown, Durbin and Evans (1975). We apply the similar but alternative test CUMUM of squares (CUMUMQ) based on the cumulative sum of squared residuals. Under this technique we run the regression with no pre-determined break point, adding one period at a time, to see if the results indicate a coefficient change.

We calculate the CUSUMQ test statistic and plot this and the upper and lower confidence bounds (at the 5% significance level, with k equal to 7) against time t. The results are shown at Figure 1. We observe that the test result moves outside the critical range from the middle of 1995 onwards, and stays outside the critical range for the remainder of the observation period. In other words, the evidence of structural change in the relationship starts in Period 2 (the period during which reforms were being implemented). As with the previous tests, this makes inference of the exact time of the break harder to draw.

Figure 1 CUMSUM of Squares test



The regression test results are generally consistent with evidence of a structural break in the time series data, and a change in the coefficients at *some point* or *points* during the observation period. The results of the CUSUMQ test are consistent with the previous results. Figure 1 indicates that the model experiences instability at a number of points during the observation period, where the test statistic moves outside the confidence limits. This indicates model instability, and that we should reject the null hypothesis of parameter stability.

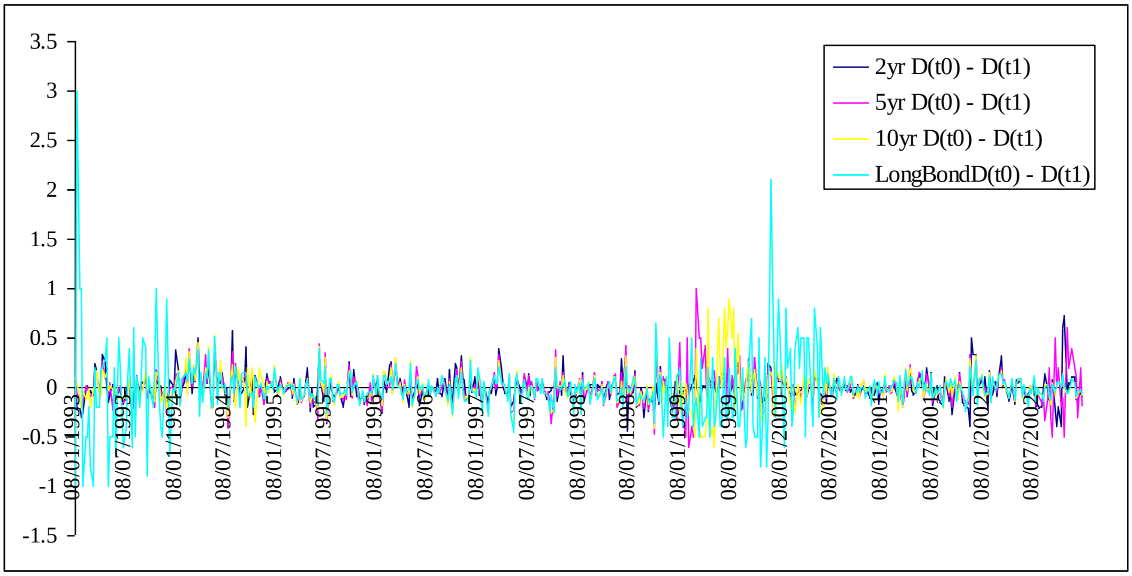
All the tests indicate an element of structural break in the model, but not necessarily at the same point in time. Again, we suggest that this reflects other factors at work influencing market liquidity and the magnitude of the observed price (yield) error, which are not specified in our model. In addition, while we have used a market-convention observed yield curve (the one recorded on Bloomberg L.P.), we have noted how there can be more than one fitted (theoretical) yield curve, and although the differences between the theoretical curves will be minor, nevertheless they influence the magnitude of the OPE.

VII. THE OBSERVED PRICE ERROR: TESTS FOR STATIONARITY

The econometric analysis we apply here can be relied on to give valid results if the time series data is stationary. In practice, time series that have linear and stochastic trends and are I(1) are often observed to move together. This suggests that their difference is I(0) or stationary; for example see Hayashi (2000). We test now for this property in our OPE spread time series dataset.

Gujarati (1995), Hatanaka (1996) and Stock and Watson (2003) suggest that visual observation of a plot of the time series is a valid initial test of cointegration. Figure 2 shows the first-differenced benchmark bond OPE data; we note that the differenced data does not exhibit any trend.

Figure 2 First differences of OPE



Because the original OPE spread time series is non-stationary, we conduct the Johansen test for cointegration in a multivariate environment. We have six variables in the system (see Table III); that is, g = 6. Therefore there can be at most 5 linearly independent cointegrating vectors, so that $r \leq 5$. We use the trace statistic formula shown in Brooks (2002).

Results are shown in Table VI. The test statistic is larger than the critical value for the first two rows, so we may reject the null hypothesis for r = 0, r = 1 and $r = 2$ at the 5% level, although for $r = 2$ the test statistic only narrowly exceeds the critical value. The null cannot be rejected for higher r. Hence we may conclude that there are at least two cointegrating vectors in the series. This supports the conclusions reached in the previous section.

The evidence that there are linear combinations of the time series of explanatory variables that are stationary, and thus an element of error correction representation, implies that we may place a measure of reliance on the main regression results presented earlier.

Table VI Results of Johansen test for cointegration between OPE explanatory variables

r	Test statistic	5% critical value
0	44.1	38.6
1	25.6	23.8
2	12.8	12.1
3	2.8	4.2
4	1.4	3.4
5	0.08	3.2

V. SUMMARY AND CONCLUSIONS

In this paper we report the findings of econometric testing of the explanatory variables behind a proxy measure of liquidity, in order to determine (i) if these variables are significant, (ii) whether the relationships have changed over the time of the observation period, and (iii) whether the implied level of liquidity has increased during the time period under observation.

We tested the determinants of a common proxy measure of liquidity, namely the theoretical price error. We observed that the theoretical price error (OPE) for benchmark gilts had reduced during the time from period 1 to period 3. This implied an increase in market liquidity in this period, on our reasoning that we would not expect to see a reduction in the OPE in illiquid trading conditions. This reduction in OPE was observed again when we used the Vasicek model to derive the theoretical yields. Hence we concluded that the actual methodology used to calculate the theoretical zero-coupon yield curve is not responsible for this reduction in OPE. Because we calculated the OPE for the entire time period using (consistently) first the cubic spline method and then the Vasicek model, both showing the same direction in results, we conclude that there has indeed been a reduction in OPE from Period 1 to Period 3.

This result suggests with a high degree of certainty an increase in liquidity level during the period under observation.

The theoretical price error is influenced by:

- longer time to maturity (interest-rate risk), leading to higher OPE spread;
- a higher swap spread, leading to higher OPE spread.

However these two variables explain less than 50% of the theoretical price error.

The regression test results are generally consistent with evidence of a structural break in the OPE time series data, and a change in the coefficients during the observation period. The results of the cumulative sum of residual squares test are consistent with the previous results.

While we are not able to determine the *direct* relationship between an improvement in liquidity and the introduction of the specific market reforms, we can conclude that the market structural reforms themselves are associated with an improved level of liquidity in the time period following their introduction.

One further conclusion we draw from the results is that they suggest how market liquidity can be maintained through most trading conditions. For example, we see that a narrowing OPE, implying a liquid market, is influenced by the level of the swap spread, market volatility, benchmark bond issuance and other factors. In times of market correction or instability, the central and regulatory authorities may wish to consider these factors when addressing market policy. In addition the value of an open repo market in government bonds to improving liquidity is implied. Therefore sovereign debt agencies may consider introducing this reform as an aid to increasing and maintaining liquidity.

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