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How to measure Corporate Bond Liquidity?

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How To Measure Corporate Bond Liquidity?

We consider eight different measures (issued amount, coupon, listed, age, missing prices, price volatility, number of contributors and yield dispersion) to approximate corporate bond liquidity and use a five-variable model to control for maturity, credit and currency differences between bonds. The null hypothesis that liquidity risk is not priced in our data set of euro corporate bonds is rejected for seven out of eight liquidity measures. We find significant liquidity premia, ranging from 9 to 24 basis points. A comparison test between liquidity measures shows that some ways to measure liquidity are better than others.

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1 Introduction

The effect of liquidity on bond yields has been frequently studied in the recent finance literature. Since liquidity is a rather subjective concept, a lot of measures have been proposed to approximate the extent to which a bond is liquid or illiquid. For corporate bonds, where most transactions occur on the over-the-counter market, direct liquidity measures (based on transaction data) are often not reliable and difficult to obtain. Therefore, researchers resorted to indirect measures that are based on bond characteristics and/or end-of-day prices. This paper makes a number of contributions to this literature on corporate bond liquidity. First, we pay great attention to control for other sources of risk to properly identify the premium associated with liquidity risk. As far as we know, this is the first paper in this strand of literature to use the well-known Fama and French (1993) two-factor bond-market model to control for interest rate and credit risk and to augment it with individual bond characteristics, as recommended by Gebhardt, Hvidkjaer and Swaminathan (2001). Second, we do not make a subjective choice of which indirect liquidity measures to work with, but implement as much of the measures proposed in the literature as possible on our data set. We evaluate the relative performance of all measures, employing a method recently applied by Goldreich, Hanke and Nathy (2002) on treasury bonds. Third, the vast majority of empirical papers on sovereign and corporate bond liquidity have studied data from the United States and relatively little is known about the extent to which these results apply to the euro market. Although euro corporate bond data were also studied by other authors, including Annaert and De Ceuster (1999), Dimson and Hanke (2001), McGinty (2001) and Díaz and Navarro (2002), none of them analyzed the euro corporate bond market using data on individual bonds over a substantial time period.

To properly identify a security's premium for the liquidity risk it imposes on its bearer, researchers have to control for other sources of risk that affect the security's expected return too. Fortunately, theory (like the standard discounted cash flow equation for default-free bonds and the reduced form credit risk models following Jarrow and Turnbull (1995) for defaultable bonds) nominates two risk factors: (*i*) interest rate risk and (*ii*) credit risk. Gebhardt et al. (2001) found that both the Fama and French (1993) 'term' and 'default' factors and the individual bond characteristics duration and rating are important to properly capture the impact of interest rate and credit risk on bond yields. We augment these four variables with a fifth variable, a bond's denomination currency, to get our final set of variables. We test the presence of liquidity effects after correcting for the effects of these five variables.

In this paper, we use the Brennan and Subrahmanyam (1996) methodology to test whether liquidity is priced in the euro-denominated corporate bond market. We use eight indirect measures of bond liquidity: issued amount, coupon, listed, age, missing prices, price volatility, number of contributors and yield dispersion (see Section 3.5 for a detailed description). For each liquidity measure, we construct P, mutually exclusive portfolios by sorting all bonds on their value of the liquidity measure and assigning the first $100/P$ % of the bonds to portfolio 1, the next $100/P$ % to portfolio 2, and so on, until the last $100/P$ % of the bonds are assigned to portfolio P. The P time series of portfolio yields are subsequently used in two regression models.

In the first model, the regression equation for each portfolio has its own intercept and under the null hypothesis that liquidity does not affect bond yields, these intercepts should be jointly zero. In the second model, all portfolios share a common intercept, but a portfolio-specific liquidity variable is added to the regression equation. Here, the null hypothesis is that the intercept and the coefficient of the liquidity variable are jointly equal to zero. Further, to determine the effectiveness of the different liquidity measures relative to each other, we run a series of regressions with pairwise combinations of the liquidity measures, as proposed by Goldreich et al. (2002). By running the regressions for all possible combinations, we can count the number of times a measure adds power to another measure, and vice versa, the number of times a measure subsumes another measure. This allows us to rank the different liquidity measures we consider.

We use a detailed data set consisting of daily yields of individual corporate bonds denominated in euros or in one of the currencies of the euro-participating countries ('legacy' currencies). The results for the first regression model indicate that the five-variable model should be rejected for seven out of eight liquidity measures. The premium between liquid and illiquid portfolios ranges from 9 to 24 basis points and is the largest for the measures *age* and *yield dispersion*. For the second model the null hypothesis of no liquidity effects is even always rejected. Finally, the pairwise comparison tests point out that the measures *price volatility* and *number of contributors* add power to most other measures, and that most other measures are subsumed by them.

The content of this paper is as follows. Section 2 gives an overview of the theoretical and empirical liquidity literature. In Section 3, the Brennan and Subrahmanyam (1996) approach of testing the compensation for liquidity in equity returns and the Fama and French (1993) model are explained and our modifications to both approaches are given. This section also describes the portfolio construction and the eight liquidity measures that are used in this construction. Next, in Section 4, the data that are used to test the hypotheses of corporate bond liquidity are described. In Section 5, the results from the model implementation are shown. Finally, Section 6 summarizes.

2 Literature

Both theoretical and empirical evidence demonstrate that liquidity risk is priced in security markets. The market microstructure models of Amihud and Mendelson (1986), Boudoukh and Whitelaw (1993) and Vayanos (1998) show that transaction costs cause liquidity differences between securities, and that illiquid securities have higher expected rates of return than liquid securities. Empirical evidence on priced liquidity risk in equity markets is provided by, e.g., Amihud and Mendelson (1986), Brennan and Subrahmanyam (1996), Haugen and Baker (1996), Brennan, Chordia and Subrahmanyam (1998), Chordia, Roll and Subrahmanyam (2001) and Chordia, Subrahmanyam and Anshuman (2001). These studies on equity markets had to cope with an important drawback: they resorted to approximating expected returns by realized returns, which are, by definition, realizations of a stochastic process instead of expectations. For bonds, on the other hand, the yield-to-maturity can be used as expected return measure. It may be for this reason, that bond liquidity has been the topic of numerous papers. A substantial part of these studies analyzed data from US Treasury markets, including Sarig and Warga (1989), Amihud and Mendelson (1991), Warga (1992), Daves and Ehrhardt (1993), Kamara (1994), Elton and Green (1998), Fleming (2001), Strebulaev (2001), Fleming (2002), Goldreich et al. (2002) and Krishnamurthy (2002). Markets for other countries' government bonds were studied by Boudoukh and Whitelaw (1991, 1993, Japan), Kempf and Uhrig-Homburg (2000, Germany) and Jankowitsch, Mösenbacher and Pichler (2002, six EMU countries).

Research on corporate bonds has also been predominantly conducted on US data; references include Cornell (1992, high yield mutual funds), Gehr and Martell (1992, investment grade bonds), Shulman, Bayless and Price (1993, high yield bonds), Crabbe and Turner (1995, new issues), Fridson and Jónsson (1995, high yield indices), Chakravarty and Sarkar (1999, corporate, municipal and Treasury bonds), Alexander, Edwards and Ferri (2000, high yield bonds), Hong and Warga (2000), Collin-Dufresne, Goldstein and Martin (2001, corporate bonds), Ericsson and Renault (2001, zero-coupon bonds), Elton, Gruber, Agrawal and Mann (2002, corporate bonds) and Mullineaux and Roten (2002, corporate bonds). Non-US corporate bond data were used by Annaert and De Ceuster (1999, euro bond indices), Dimson and Hanke (2001, UK equity index-linked bonds), McGinty (2001, euro-denominated corporate bonds; data for only one month) and Díaz and Navarro (2002, Spanish corporate bonds). So, although there are numerous empirical papers on bond liquidity, none of them studied the euro corporate bond market using individual bond data over a substantial time period.

3 Methodology

We use the Brennan and Subrahmanyam (1996) approach to test whether liquidity risk is priced in the euro-denominated corporate bond market. Therefore, we first describe their framework in Section 3.1, followed by our modifications in Section 3.2. Our implementation of the framework is detailed in 3.3. The Goldreich et al. (2002) method to compare different liquidity measures is presented in Section 3.4. Our liquidity measures are discussed in Section 3.5.

3.1 Brennan-Subrahmanyam Approach

Brennan and Subrahmanyam's (1996) portfolio construction made use of two variables. First, the stocks were sorted on their market capitalization and divided into size quintiles. Next, within each size quintile, the stocks were sorted on their estimated Kyle (1985) liquidity measure of market depth and assigned to one of five portfolios. In this way, Brennan and Subrahmanyam (1996) evenly divided the total sample of stocks into 25 portfolios depending on the firm's size and liquidity. Finally, they tested whether the constructed portfolios had significantly different returns. To control for other sources of risk, Brennan and Subrahmanyam (1996) used the Fama and French (1993) equity-market model.

Fama and French (1993) found three common factors that explained the return of an equity portfolio: an overall market factor, a size factor and a book-to-market factor. To test their model, Fama and French (1993) subdivided the stocks in their sample in portfolios based on several other criteria, and regressed the portfolios' excess returns over the default-free interest rate on the three factors. The intercept coefficients from these regressions were almost never statistically significant, indicating the validity of their model on their data set.

Similarly, Brennan and Subrahmanyam (1996) regressed the realized excess returns of their portfolios on the Fama-French equity market factors. For each portfolio, they ran a Fama-French regression model augmented with an intercept term. Under the null hypotheses that liquidity has no additional power in explaining excess equity returns, the intercepts of these regressions should not be jointly significantly different from zero. This null hypothesis was also tested by an alternative regression model. Again the portfolios' excess returns were used as dependent variables. However, the portfolio-specific intercepts were replaced by a common intercept for all portfolios, and a portfolio-specific liquidity variable was added to the regression equation. For both regression models, the null hypothesis had to be rejected, implying that liquidity was an additional source of risk, beyond the Fama-French risk factors, that was priced by financial market participants.

3.2 Modifications

We use Brennan and Subrahmanyam's (1996) methodology to test whether liquidity is priced in the euro-denominated corporate bond market. We make three modifications to their method. First, we use a bond's yield-to-maturity instead of its realized return to proxy for its expected return. Amihud and Mendelson (1991) provided the following argument why the yield of a bond should contain a compensation for liquidity. Suppose an investor wants to buy an illiquid bond. Since the bond is illiquid, he faces higher transaction costs when he wants to unwind his position before the bond's maturity, due to a larger bid-ask spread and/or order processing costs, than for a comparable, liquid bond. In order to persuade him to buy the illiquid bond, the investor should be compensated by a lower price. The yield of the illiquid bond should thus be higher than that of the liquid bond. In other words, the investor is willing to accept a lower yield on a liquid bond, because of the option to liquidate his position before maturity at lower costs.

The advantage of yields over realized returns is twofold. First, yields really represent the market's expectation of a bond's expected return to maturity; realized returns, on the other hand, are, by definition, realizations of a stochastic process rather than expectations. The second advantage of yields over realized returns can be understood by considering the hypothetical case where the prices of a liquid and an illiquid bond always have a fixed ratio to each other; the realized returns of these bonds will be exactly equal, but their yields will differ. So, to the extent that there is a fixed percentage price discount for illiquidity, realized returns are unsuited to determine whether liquidity is a determinant of security prices.

The second modification to the Brennan-Subrahmanyam framework is that we replace the three-factor Fama and French (1993) equity-market model by their two-factor bond-market model, augmented with bond characteristics as recommended by Gebhardt et al. (2001). Fama and French (1993) found two common risk factors in the returns on bonds. These two bond-market factors explained the excess returns of seven bond portfolios: two government bond portfolios with average maturities of 1 to 5 years and 6 to 10 years, and five corporate bond portfolios with average, Moody's ratings of Aaa, Aa, A, Baa and below Baa. The excess return was defined as the portfolio return minus the one-month Treasury rate. Fama and French (1993) defined the first bond-market factor as the difference between the long-term government bond return and the one-month Treasury rate at the end of the previous month. Thus, this *slope factor* should explain variations in excess bond returns by changes in the slope of the Treasury yield curve. The second factor was defined as the difference between the long-term corporate bond return and the long-term Treasury return. This *credit factor* was therefore related to the likelihood of credit events in the corporate bond portfolio. These two factors did a very good job in explaining the excess returns of the seven bond portfolios, see Fama and French (1993, Table 3): all estimated parameters were statistically significant with t-values ranging from 8 to 140 and the R^2-values were also high, with values ranging from 79% to 98%. Moreover, the intercepts of all five corporate bond portfolios were statistically not significant.

In their analysis, Fama and French (1993) used the government curve to calculate the excess returns and the two bond-market factors. In contrast, we use the swap curve. Recently, fixed income investors have moved away from using government securities to extract default-free interest rates and started using interest rate swap rates instead. Golub and Tilman (2000) and Kocić, Quintos and Yared (2000) mentioned the diminishing amounts of US and European government debts, the credit and liquidity crises of 1998, and the introduction of the euro in 1999 as primary catalyzing factors for this development. Empirical research by Houweling and Vorst (2002), on the same market and over the same time period as our data set, indicated that the swap curve was a better proxy for the default-free curve than its government counterpart.

Gebhardt et al. (2001) looked at the validity of the Fama-French bond market model by analyzing whether individual bond characteristics could rival the two Fama-French factors. Three characteristics were considered: rating, duration and Altman's (1968) Z-scores. Using bivariately sorted portfolios and multivariate regressions, Gebhardt et al. (2001) concluded that both factor loadings and characteristics were important in explaining bond yields and recommended a model containing four variables: the Fama-French slope and credit factors, rating and duration. In Section 5.2, we show that for our data set three characteristics are relevant: rating, maturity and an indicator variable that equals 1 if a bond is denominated in euros, and 0 otherwise. Therefore, our null model consists of five variables: two Fama-French factors and three characteristics, see Section 3.3. Clearly, all our conclusions about the relation between liquidity and bond yields are based on the assumption that our five-variable pricing model is well-specified (see also Dimson and Hanke (2001)).

The third difference with the Brennan-Subrahmanyam framework is that we do not use the Kyle (1985) direct liquidity measure. Instead, we consider eight indirect liquidity measures, which are detailed in Section 3.5.

3.3 Implementation

For each liquidity measure, we construct P time series of portfolio yields as follows (the choice for P will be discussed shortly). Every two weeks, we order all bonds in the sample by the value of that liquidity measure; only bonds that have already been issued and have not yet matured or been redeemed on that date are used in the ordering. Then, $100/P$ % of the bonds gets assigned to each of the P portfolios. We do this in such a way that for each liquidity measure portfolio 1 contains the most liquid bonds and portfolio P the most illiquid bonds. Every day we calculate the portfolio yield as the unweighted average of the yields of the bonds that make up the portfolio. The bond yield is calculated as follows: if a bond is not quoted, we disregard it for that day; if it is quoted by one pricing source, we use that yield; if it is quoted by more than one pricing source, we use the average quote.

Like Brennan and Subrahmanyam (1996), we consider two regression models. For measure i, model 1 is

$$\begin{aligned} Y_{pt}^{i} &= \alpha_{p}^{i} + \sum_{j=1}^{2} \beta_{jp}^{i} F_{jt} + \sum_{j=1}^{3} \gamma_{j}^{i} C_{jpt}^{i} + \varepsilon_{pt}^{i}, \qquad (1) \\ E\left[\varepsilon_{pt}^{i}\right] &= 0, \\ E\left[\varepsilon_{pt}^{i}\varepsilon_{qs}^{i}\right] &= \sigma_{pq}^{i}, \text{ if } t = s, \text{ and 0 otherwise,} \end{aligned}$$

where Y_{pt}^{i} is the excess yield of the p^{th} measure-i portfolio on day t, and F_{1t} and F_{2t} are the two Fama-French factors and C_{1pt}^{i}, C_{2pt}^{i} and C_{3pt}^{i} are the three portfolio characteristics. The disturbance terms are allowed to be heteroscedastically distributed and to be cross-sectionally correlated, but we do assume that they are uncorrelated across time. For measure i, we estimate all $3P+3$ coefficients $\left(\alpha_{1}^{i}, \ldots, \alpha_{P}^{i}, \beta_{11}^{i}, \ldots, \beta_{1P}^{i}, \beta_{21}^{i}, \ldots, \beta_{2P}^{i}, \gamma_{1}^{i}, \gamma_{2}^{i}, \gamma_{3}^{i}\right)$ for all P portfolios simultaneously with Feasible Generalized Least Squares (FGLS) as a system of seemingly unrelated regressions (SUR, see, e.g., Greene (2000, Chapter 15)). To correct for possible autocorrelations in the disturbances, we apply the Newey and West (1987) estimator for the covariance matrix. To test the null hypothesis that liquidity has no additional power in explaining bond yields beyond the two Fama-French factors and the three portfolio characteristics, we use a Wald test to determine the joint significance of the intercepts: H_0: $\alpha_{1}^{i} = 0 \wedge \ldots \wedge \alpha_{P}^{i} = 0$. The test statistic is asymptotically χ^2-distributed with P degrees of freedom. Further, to test the null hypothesis that all intercepts are equal, we use a Wald test for H_0: $\alpha_{1}^{i} = \ldots = \alpha_{P}^{i}$. This test statistic is asymptotically χ^2-distributed with $P-1$ degrees of freedom.

Regression model 2 reads

$$Y_{pt}^{i} = \alpha^{i} + \sum_{j=1}^{2} \beta_{jp}^{i} F_{jt} + \sum_{j=1}^{3} \gamma_{j}^{i} C_{jpt}^{i} + \delta^{i} L_{pt}^{i} + \varepsilon_{pt}^{i}, \qquad (2)$$

where the assumptions on the disturbances are equal to those in (1) and L_{pt}^{i} is the value of the liquidity measure of the p^{th} measure-i portfolio on day t in deviation from its daily average; so, if l^i_{pt} denotes the value of the liquidity measure, and $\bar{l}^i_t$ is its daily average, i.e.

$$\bar{l}^i_t = \frac{1}{P}\sum_{p=1}^{P} l^i_{pt},$$

then L^i_{pt} is calculated as

$$L^i_{pt} = l^i_{pt} - \bar{l}^i_t.$$

In Equation (2), the portfolio-specific intercepts of Equation (1) have been replaced by a single intercept and an additional regressor has been introduced that contains a proxy for portfolio p's liquidity. Therefore, the constant liquidity premium of α^i_p in regression model 1 has been replaced by a time-varying premium $\alpha^i + \delta^i L^i_{pt}$, where δ^i gives the effect of the deviation of a liquidity measure from its mean. In this model, the null hypothesis of no liquidity premiums is tested with a Wald test on the joint significance of α^i and δ^i, H_0: $\alpha^i = 0 \wedge \delta^i = 0$. The test statistic is asymptotically χ^2-distributed with 2 degrees of freedom.

For both model 1 and 2, there is the problem that if we want to test whether a particular measure i is a good liquidity measure that we are actually testing a joint hypothesis (see also Kempf and Uhrig-Homburg (2000) and Jankowitsch et al. (2002)): illiquidity leads to yield increases and i is a proxy for liquidity. If we reject this joint hypothesis, then either i is a not a good liquidity measure or illiquidity does not lead to yield increases (or both). Given the strong empirical evidence mentioned in Section 2, we feel confident that a rejection of the joint hypothesis can in fact be traced to i being an inadequate liquidity measure.

We now discuss the choice for the number of portfolios P for both models. For model 1, we create two portfolios for each of the liquidity measures. This gives an intuitive interpretation of portfolio 1 as the 'liquid portfolio' and portfolio 2 as the 'illiquid portfolio'. Moreover, the difference $\alpha^i_2 - \alpha^i_1$ between the two intercepts can be interpreted as the yield premium investors get for bearing liquidity risk caused by measure i. In model 2, we have to estimate the slope coefficient δ^i, i.e. the relation between a portfolio's value for liquidity measure i and its excess yield. Clearly, two portfolios would be insufficient to estimate a slope. However, using 'too much' portfolios diminishes the power of the Wald test, see Lys and Sabino (1992). From their Figure 1, it follows that if the portfolios contain approximately 25% of the bonds the power of the test of no relation between the liquidity measure and the excess yield is maximized. Therefore, we use 4 portfolios for model 2.

Lo and MacKinlay (1990) showed that serious biases can arise in the test statistics when portfolios are used to test the efficient market hypothesis. The portfolios are constructed by sorting securities on empirical characteristics, which typically follow either from own research on a data base or from results of other papers that have analyzed the same database. If the statistical tests are carried out on exactly the same data base, significant biases in the tests can occur. Lo and MacKinlay (1990) called this *data-snooping*. In our analysis, data-snooping is probably limited, since our liquidity measures originate from two sources. First, some of our measures follow from theoretical models. Second, the remaining measures have been taken from empirical research on *other* bond data bases, so that no data mining has been applied to our data base.

3.4 Comparison

Given the large number of liquidity measures that have been proposed in the literature, a natural question to ask is if all measures are equally suited to proxy bond liquidity or if some measures work better than others. One way to test this is to extend model 2 from the previous section with additional regressors for all other measures

$$Y_{pt}^i = \alpha^i + \sum_{j=1}^{2} \beta_{jp}^i F_{jt} + \sum_{j=1}^{3} \gamma_j^i C_{jpt}^i + \delta^i L_{pt}^i + \sum_{j=1, j \neq i}^{8} \delta^{ij} L_{pt}^{ij} + \varepsilon_{pt}^i,$$

where L_{pt}^{ij} is value of liquidity measure j for the p^{th} measure-i portfolio in deviation of its daily average; the assumptions on the disturbances are equal to those in Equation (1). The problem with such an approach, however, is that the liquidity measures are strongly correlated. This may lead to multicollinearity problems between the regressors.

Instead we follow Goldreich et al. (2002) by running a series of regressions with pairwise combinations of the liquidity measures. For each combination (i, k) of measures, we estimate a regression like Equation (2) for measure i, augmented with measure k

$$Y_{pt}^i = \alpha^i + \sum_{j=1}^{2} \beta_{jp}^i F_{jt} + \sum_{j=1}^{3} \gamma_j^i C_{jpt}^i + \delta^i L_{pt}^i + \delta^{ik} L_{pt}^{ik} + \varepsilon_{pt}^{ik}, \tag{3}$$

where the disturbances behave as in Equation (1) . In this regression equation[1], we test for the significance of δ^{ik}. If it is significant, we say that 'k adds explanatory power to i', and otherwise we say that 'k is subsumed by i' (this follows the terminology in Goldreich et al. (2002)). By repeating this procedure for all possible combinations, we can count the number of times a measure adds power to another measure, and the number of times a measure subsumes another measure. This is allows us to rank the different liquidity measures we consider.

3.5 Liquidity Measures

Empirical papers that examined liquidity in bond or equity markets, used both direct and indirect measures of liquidity. Examples of *direct* liquidity measures are quoted and effective bid-ask spreads, quote and trade sizes, quote and trade frequencies and trading volume. For corporate bonds, where most transactions occur on the over-the-counter market, these direct measures are often not reliable and difficult to obtain. Therefore, we collected eight *indirect*

[1] Note that Goldreich et al. (2002) first orthogonalized the values of measure k relative to measure i and used the orthogonalized values in Equation (3) instead of L_{pt}^{ik}. This is not necessary, since, by the Frisch-Waugh theorem (see, e.g. Greene (2000, Section 6.4.3)), the regression already 'automatically' does this for us.

liquidity measures from the empirical literature on sovereign and corporate bond liquidity.

The measures *issued amount, coupon* and *listed* are static, as they are fixed characteristics of a bond or its issuer. The *age* measure changes gradually over time. The other measures are dynamic and depend on market information; the measures *missing prices* and *price volatility* use daily price information, whilst the measures *number of contributors* and *yield dispersion* also consider quote composition information. Table 1 shows which papers used which measures and the effects they found; *missing prices* and *yield dispersion* are not mentioned in this table, because they were not used in previous papers. We will now discuss each measure in more detail.

[insert Table 1 around here]

Issued Amount

The *issued amount* of a bond is often assumed to give an indication of its liquidity. Most investment banks use it as liquidity criterion in building their bond indices; for example, Lehman Brothers use this criterion for their Euro-Aggregate Corporate Bond index. Its use was first proposed by Fisher (1959), who claimed that large issues should trade more often, so that the indirect measure *issued amount* is actually a proxy for the direct liquidity measure trading volume. Since Fisher, several alternative hypotheses have been put forward that also predict a positive effect of *issued amount* on liquidity (and thus on bond prices). In market microstructure models, like Smidt (1971) and Garman (1976), transaction costs arise, because dealers hold inventories. Further, dealers's inventory costs are higher if it is more difficult to obtain information about a security and if the expected holding time is longer. Crabbe and Turner (1995) subsequently reasoned that large issues may have lower information costs, since more investors own them or have analyzed its features; similarly, information about small issues may be less broadly disseminated among investors. Therefore, small issues will have a higher yield due to an illiquidity premium. Another frequently heard argument, for instance in Sarig and Warga (1989) and Amihud and Mendelson (1991), is that bonds with smaller issued amounts tend to get locked in buy-and-hold portfolios more easily, reducing the tradeable amount and thus their liquidity. To summarize, we hypothesize a negative effect of *issued amount* on yields.

Table 1 shows that many empirical papers considered *issued amount* as liquidity measure. The papers on Treasury securities found negative and mostly significant effects, so that larger Treasury issues have lower yields, as expected. Empirical research on corporate bonds is inconclusive, though: both negative and positive coefficients are observed. McGinty (2001) confirmed this by showing that most large issues in his corporate bond sample were liquid, but some large issues were also illiquid and some small issues were liquid.

Coupon

Amihud and Mendelson (1991) argued that financial institutions that are constrained to distribute only coupon income on their investments may prefer bonds with higher coupon percentages. This higher demand for high-coupon bonds implies lower yields. On the other hand, *coupon* is also frequently seen as a proxy for tax effects, see, e.g., Shiller and Modigliani (1979): if coupon income is taxed, then bonds with higher coupons will have higher before-tax yields. In addition, lower-rated companies will typically issue higher-coupon bonds, so that higher coupons are again associated with higher yields. The predicted sign of the measure *coupon* is thus ambiguous.

Few empirical papers employed measure *coupon*, see Table 1. Two papers found an insignificant, positive coefficient, whereas one paper, Amihud and Mendelson (1991), found a significant negative effect.

Listed

Alexander et al. (2000) reasoned that companies whose equity is listed on a stock exchange must disclose more information than privately held companies. According to the market microstructure models mentioned above, the costs of making a market in bonds of listed firms should thus be smaller. Therefore, we hypothesize that the measure *listed* is associated with higher liquidity and lower yields.

Since Alexander et al. (2000) were the only authors to use the liquidity measure *listed*, the empirical evidence is limited to their results. Contrary to their expectations, they found that issues of private firms trade more actively and thus are more liquid than issues of listed firms. Their explanation of this result was that for private firms debt is the only investment vehicle, while for public firms both debt and equity are traded; therefore, debt of private firms might trade more and have higher liquidity.

Age

The *age* of a bond is a popular measure of its liquidity. Sarig and Warga (1989) observed that as a bond gets older, an increasing percentage of its issued amount is absorbed in investors' buy-and-hold portfolios. Thus, the older a bond gets, the less trading takes place, and the less liquid it becomes. Moreover, once a bond becomes illiquid, its stays illiquid until it matures. McGinty (2001) and Schultz (2001) also noted that new issues trade more than old issues. McGinty mentioned lead managers' commitment to making market in the newly issued bond. Schultz pointed out that new issues are typically underpriced, so that traders buy bonds after the offering and sell them shortly thereafter. Following these arguments, we hypothesize a positive relation between *age* and yield.

Empirical research strongly confirms the positive effect of *age* on yields, see Table 1. This finding holds for corporate and sovereign bonds and for US and European data sets. Moreover, Schultz (2001) found evidence for Sarig and Warga's (1989) argument, since in his sample most bonds were bought and not sold; in other words, the bonds were put in buy-and-hold portfolios.

Market practitioners often use a threshold value to determine if a bond is 'old' or 'young': for some T, they mark all bonds with an age smaller than T as 'young' and an age larger than T as 'old'. Some academic papers also use such a dichotomous approach for the liquidity measure *age*. For instance, Alexander et al. (2000) set $T =$ 2 years, Ericsson and Renault (2001) used $T = 3$ months, and Elton et al. (2002) employed a threshold value of 1 year. To determine which threshold values give useful divisions of bonds, we estimate model 1 on two portfolios, where portfolio 1 contains all bonds younger than T months and portfolio 2 older than T months, for $T = 2, 4, \ldots, 30$. The difference $\alpha_2 - \alpha_1$ between the portfolio intercepts, i.e. the liquidity premium between old and young bonds, and the significance of the Wald test on H_0: $\alpha_2 - \alpha_1 = 0$ are displayed in Figure 1. Thresholds from 4 to 24 months give rise to a significant liquidity premium, while the 2-month threshold and thresholds larger than 24 months do not. All thresholds, except for the smallest of 2 months, yield a significant premium of at least 10 bps. The division between young and old bonds seems to be the strongest for a threshold of 14 months, where the premium equals 36 bps. For the remainder of the paper, we arbitrarily use a threshold of 1 year for the measure *age*, although any other value between 0 and 2 years could also be used.

[insert Figure 1 around here]

Missing Prices

The occurrence of 'price runs' and missing values is our first liquidity measure that uses market information. Sarig and Warga (1989) argued that if the liquidity of a bond is sufficiently low, it may happen that on some business day there is virtually no trading in that bond. In their data set, this was recorded as a 'price run': two consecutive prices for a bond were identical. We extend their notion of illiquidity by considering not only the occurrence of a price run, but also the occurrence of a missing value, since in both cases there is no activity in that bond on that day. We will jointly refer to these events as the measure *missing prices*. We hypothesize a positive relation between *missing prices* and yield.

Price Volatility

The measure *price volatility* is a measure of price uncertainty. In the market microstructure models discussed above, dealers' inventory costs are higher if information uncertainty is higher. An important source of uncertainty is related to the predictability of future price movements. Therefore, we hypothesize that a higher *price volatility* leads to higher bid-ask spreads, and thus to lower liquidity and higher yields.

The empirical evidence for price uncertainty as liquidity measure is mixed, see Table 1. Shulman et al. (1993) used *price volatility* as proxy for price uncertainty and found a significantly positive effect on bond spreads. Hong and Warga (2000) proxied uncertainty with squared price return and estimated a positive and significant coefficient in a regression using bid-ask spread as dependent variable; this also implies a positive effect of uncertainty on bond yields. Alexander et al. (2000) approximated uncertainty as the average of absolute price returns; in their regressions, they found a significant, positive effect on trading volume, implying a negative relation between uncertainty and yields.

Number of Contributors

The *number of contributors* is our following measure of a bond's liquidity, and the first that uses quote composition information. In Ericsson and Renault (2001), a larger number of active traders competing for the same bond leads to a smaller price discount for illiquidity and thus a smaller yield premium. Alternatively, Gehr and Martell (1992) and Jankowitsch et al. (2002) argued that a larger number of market participants makes it easier to trade a bond, because it is easier to find a counterparty for a transaction and large orders can be split up into smaller parts without affecting the market price. Either way, we hypothesize a positive relation between the measure *number of contributors* and liquidity and therefore expect a negative effect of this measure on bond yields.

Direct empirical evidence on the *number of contributors* liquidity measure is limited. Jankowitsch et al. (2002) found that bonds with more contributors have lower yields for all but one of the six European countries they analyzed. Indirect evidence is provided by Schultz (2001), who showed that there was a positive relation between the number of trades in a bond and the number of dealers as counterparties. Further, Gehr and Martell's (1992) results showed a negative, though insignificant effect of the number of dealers on the bid-ask spread.

Yield Dispersion

Our final liquidity measure, *yield dispersion*, reflects the extent to which market participants agree on the value of a bond. Tychon and Vannetelbosch (2002) derived a model that predicts that if investors have more heterogeneous beliefs, the liquidity premium is larger. The inventory costs argument, mentioned above, applies here as well, since dealers face more uncertainty if prices show a larger diffusion among contributors. Either way, we hypothesize a positive relation between scatter and bond yields.

We proxy this notion of liquidity with a *yield dispersion* statistic, which has not been used before in the literature, as far as we know. We define the yield dispersion of bond i on day t as the standard deviation of percentage yield differences relative to the mean

$$\text{Dispersion}_{it} = \sqrt{\frac{1}{n_{it}-1}\sum_{j=1}^{n_{it}}\left(\frac{y_{itj}-\bar{y}_{it}}{\bar{y}_{it}}\right)^2}, \tag{4}$$

where y_{itj} is the yield quoted by pricing source j, $\bar{y}_{it}$ is the average yield and n_{it} is the number of contributors. This measure can only be calculated if we have at least two quotes for a bond on a particular day, i.e. if $n_{it} > 1$.

Application

Table 2 gives details on the calculation of each liquidity measure. It also shows the expected sign of the measure. To get the l^i_{pt} variable of Section 3.3, we multiply measures with a negative expected sign by -1. This makes sure all δ^i coefficients in model 2 are expected to be positive.

Finally, the table shows the order in which bonds are put in the portfolios: the first portfolio always contains the bonds that are hypothesized to be most liquid, the last portfolio contains bonds that we expect to be most illiquid.

[insert Table 2 around here]

As described in Section 3.3, every two weeks the portfolios for each liquidity measure are rebalanced according to each bond's value for that measure. For the measures *issued amount, coupon, listed* and *age*, we use the value of the liquidity measure on the rebalancing date. For the measures *missing prices, number of contributors* and *yield dispersion,* we use the average value over the two weeks prior the rebalancing date. For the measure *price volatility*, we calculate the standard deviation of the observed prices over the two weeks prior to the rebalancing date. If for a particular bond it is not possible to calculate the value of a liquidity measure on the rebalancing date, that bond is ignored for that measure until the next rebalancing date.

4 Data

The data are downloaded from three different sources. Lehman Brothers provides the International Securities Identification Numbers (ISINs) of the members of their Euro-Aggregate Corporate Bond index. From Bloomberg the required characteristics of these corporate bonds are downloaded. Reuters 3000 EXtra provides daily bid yields of each bond quoted by different pricing sources. The download period starts on 1 January 1999 and ends on 31 May 2001. The ISINs are obtained for 31 May 2000. The total number of bonds on this date equalled 1190. All bonds that are issued in euros directly after the currency's introduction are included in this analysis. Moreover, the yield time series of each corporate bond has at least twelve months history.

4.1 Lehman Brothers

Lehman Brothers provides the ISINs of the corporate bonds in their Euro-Aggregate Corporate Bond index. This index serves as a proxy of the investment-grade euro-denominated, corporate bond market. Lehman Brothers imposes a number of criteria before the corporate bonds can enter its index. All bonds must be denominated in euros or in one of the legacy currencies. Further, all bonds are investment grade, have a fixed-rate coupon, at least one-year to maturity and an issued amount of at least 150 million euro. The country of issuance and the country of the issuer are no index criteria. The credit ratings of all corporate bonds are also provided by Lehman Brothers. All ratings are downloaded for 31 May 2000. Due to data limitations, we have kept these ratings unchanged during the whole sample period. Finally, their Euro-Aggregate Corporate Bond BBB sub index is used to construct the Fama-French credit factor.

4.2 Bloomberg

Bloomberg provides the required bond characteristics. Using the ISINs that are given by Lehman Brothers these characteristics are downloaded. In case an ISIN code is not recognized by Bloomberg, the bond data are obtained from Lehman Brothers' PC Product system. From the initial 1190 ISINs, three are not available in the Bloomberg database. The downloaded corporate bond characteristics are: issued amount, issue date, maturity date, currency, call dates, put dates and sinking fund dates. Euro-denominated par swap data, which are used to calculate the two Fama-French factors and the portfolio excess yields, are also downloaded from Bloomberg.

4.3 Reuters

Reuters 3000 EXtra provides the bid yields of the selected corporate bonds. Most corporate bond yields in the Lehman Brothers Euro-Aggregate index are bid yields; only newly issued corporate bonds have ask yields during their first month in the index (see Lehman Brothers (1999)). Therefore, we download bid yields from Reuters. For each corporate bond, all pricing sources (also called contributors) are downloaded. We exclude two Reuters pricing sources, the clearing agency ISMA and two anonymous pricing sources from the list of contributors, since they are averages of other pricing sources. The total number of different pricing sources thus obtained equals 74.

From the original 1190 ISINs in the Lehman Brothers Euro-Aggregate Corporate Bond index, 191 bonds cannot be analyzed, because it either has no Reuters Identification Code (RIC) that matches its ISIN or it does have a RIC but no contributor. For the remaining 999 bonds, all bid yields from all pricing sources are downloaded. This means that a number of time series, equal to the number of pricing sources, shows the yield development of each bond. Most bonds are quoted by more than one pricing source.

5 Results

We first present the results of applying the Fama-French bond-market model to the entire sample in Section 5.1 and show the extension of this model with portfolio characteristics in Section 5.2. Next, the regression results for models 1 and 2 are given in Sections 5.3 and 5.4. Finally, the performance of the liquidity measures is compared in Section 5.5.

5.1 Entire Sample

To test whether the euro-dominated corporate bond market can, on average, be described by the two-factor Fama-French model, we first run their model on a portfolio consisting of all bonds in our sample, i.e.

$$Y_t = \alpha + \sum_{j=1}^{2} \beta_j F_{jt} + \varepsilon_t, \ \varepsilon_t \sim i.i.d.\left(0, \sigma^2\right), \tag{5}$$

where the excess yield Y_t is the average bond yield, calculated over all bonds in the sample, minus the one-year euro swap rate, the slope factor F_{1t} is defined as the ten-year swap rate minus the one-year swap rate of the previous day and the credit factor F_{2t} is calculated as the Lehman Brothers Euro-Aggregate Corporate Bond BBB sub index minus the ten-year euro swap rate.

The first row of Table 3 shows the R^2 and the estimated coefficients along with their t-values. The R^2 value is high and comparable to the values reported by Fama and French (1993). The estimated slope and credit coefficients have the expected positive sign and are strongly statistically significant. The intercept is not statistically significant, so that the Fama-French model cannot be rejected for the entire sample.

To test our choice for approximating default-free interest rates with swap rates, regression model (5) is estimated again, but with the swap rates replaced by the government rates. So, the excess yields and the slope and credit factors are now calculated with government yields. Our proxy for euro government rates is the Lehman Brothers Euro-Aggregate Treasury index. The second row of Table 3 shows the regression results. Both the R^2 and the t-values of the slope and credit factors have decreased compared to the model with swap rates. Moreover, the intercept is now significantly different from zero. Therefore, the Fama-French model should be rejected in case government rates are used as default-free rates. This empirically confirms our choice for using swap rates as proxy for default-free interest rates instead of treasury rates.

[insert Table 3 around here]

5.2 Characteristics

As recommended by Gebhardt et al. (2001), we analyze the added value of incorporating characteristics into the model. We consider three characteristics:

- *Rating:* rating of the bond's issuer at 31 May 2000: AAA, AA, A or BBB.
- *Maturity:* the remaining time to maturity of a bond, measured in years.
- *Euro:* whether a bond is denominated in euros or in one of the legacy currencies. This variable was not used in Gebhardt et al. (2001), who studied US data, but we nevertheless consider it to be relevant for our data set. The motivation is that the market generally sees legacy bonds as less liquid, because these bonds are relatively old, not well known to investors and more difficult to trade due to the legacy currency.

To determine whether a characteristic is important for explaining excess bond yields, we follow the same procedure as for our liquidity measures, as described in Section 3.3, except that the null model is now the Fama-French model of the previous section. For each characteristic i, we create portfolios and estimate the following regression model

$$Y_{pt}^{i}=\alpha_{p}^{i}+\sum_{j=1}^{2}\beta_{jp}^{i}F_{jt}+\varepsilon_{pt}^{i},$$

where the assumptions on the disturbances are equal to those in Equation (1). For the characteristic *rating*, we create four portfolios: portfolio 1 contains the AAA-rated bonds, portfolio 2 the AAs, portfolio 3 the As, and portfolio 4 the BBBs. For the characteristic *maturity,* two portfolios are constructed: portfolio 1 consists of the 50% shortest bonds, and portfolio 2 of the 50% longest bonds.[2] Finally, for the characteristic *euro*, two portfolios are created as well: portfolio 1 contains the euro-denominated bonds and portfolio 2 the legacy bonds.

The regression results are reported in Table 4. For *rating*, we find that the intercepts are larger for lower ratings, although the step from AA to A is very small. The Fama-French factor loadings are all significant. The Wald test indicates that the four intercepts are jointly highly significant. For *maturity,* the intercepts of the portfolios reveal that short-maturity bonds have smaller yields than long-maturity bonds. The null hypothesis that the two intercepts are jointly equal to zero is easily rejected. Finally, for *euro*, the results imply that euro-denominated bonds have smaller yields than legacy bonds, with an average spread of 21 bps between them. Again, the Wald statistic is significantly different from zero.

[insert Table 4 around here]

From these results, we conclude that the *rating*, *maturity* and *euro* characteristics are important determinants of excess yield in the euro corporate bond market. To make the characteristics operational, we have to transform them to a numerical scale:

- *Rating:* the letters are mapped to a linear scale as follows: AAA=1, AA=2, A=3 and BBB=4. Although this linearity assumption is somewhat crude, it is not uncommon in the literature. Moreover, since our bonds are all investment grade, and the non-linearities in S&P's and Moody's rating scales are especially apparent for speculative grade ratings, we believe that the linear scale is a reasonable approximation.
- *Maturity:* this is already a continuous variable, and thus needs no transformation.
- *Euro:* this characteristic is represented by an indicator variable that takes the value 1 if the bond is denominated in euros, and 0 if it is denominated in one of the legacy currencies.

The value of characteristic j for the p^{th} measure-i portfolio on day t, denoted C_{jpt}^{i} in Section 3.3, is calculated analogously to the liquidity variable L_{pt}^{i} below Equation (2). For instance, for the characteristic *maturity*, it is the average maturity of all quoted bonds in that portfolio on that day, in deviation from the average maturity of all quoted bonds on that day.

[2] These portfolios are updated every two weeks, just like in Section 3.3.

5.3 Model 1

For the first regression model, Equation (1), we create two portfolios for all eight liquidity measures. Table 5 contains some summary statistics for these 16 portfolios, averaged over the full sample period of 602 trading days. We observe that the average yields of portfolio 1 (containing the hypothesized liquid bonds) and portfolio 2 (illiquid bonds) are quite different. The deviations range from 0 bps (for *coupon*) to 59 bps (for *price volatility*). We also see that the average values of the liquidity measures differ substantially. Except for the measures *price volatility* and *number of contributors*, we could prematurely conclude that the liquidity premium is negative, since portfolio 1 has a higher average yield than portfolio 2. However, it is not correct to fully attribute the yield differences to differences in liquidity, since the average maturity and the average credit worthiness also strongly vary. Therefore, this table illustrates the necessity of using the Fama-French factors and the portfolio characteristics to correct for differences in maturity and credit rating.

[insert Table 5 around here]

Table 6 displays the results of estimating model 1 for all liquidity measures. All Fama-French factor loadings are statistically significant and have the expected positive sign. The same holds for the coefficients of the *rating* and *maturity* characteristics (with one exception: the rating coefficient for *issued amount* is insignificant). The coefficient for the *euro* characteristic is mostly insignificant, though it does have the expected negative sign for seven out of eight cases. All R^2-values are around 98%.

Except for the liquidity measure *listed*, all intercept pairs are jointly statistically different from zero at a 95% significance level, as evidenced by the p-values of the Wald statistics. This indicates that the remaining seven measures are indeed able to separate the bonds in our data set into two mutually exclusive portfolios that have statistically different yields, after controlling for differences in maturity, rating and currency. Next we look at the portfolio intercepts themselves. If our hypotheses on the sign of the liquidity effects are correct, the intercept of portfolio 1 should be smaller than that of portfolio 2 for all liquidity measures. We see that this holds for six out of eight cases; for *listed* and *price volatility* the order is reversed. For *listed,* this poses no problem, since the Wald test already indicated that for this measure the null model cannot be rejected. For *price volatility*, the intercepts are inconsistent with our expectations, since the low-volatility portfolio has a higher yield than the high-volatility portfolio. Further, for the measure *coupon*, the results show that low coupon bonds have lower yields than high coupon bonds; this contradicts the liquidity hypothesis of Amihud and Mendelson (1991), but instead supports the alternative interpretation of *coupon* as tax and/or credit risk proxy.

Another way of looking at the intercepts, is to calculate their differences $\alpha_2^i - \alpha_1^i$, which we interpret as the liquidity premium for measure i. The last column of Table 6 shows that the premiums for measures *yield dispersion* and *age* are the largest with 24 bps and 20 bps, respectively, while the premia for the other measures are between 9 and 13 bps. All premiums are statistically significant at the 95% confidence level.

[insert Table 6 around here]

5.4 Model 2

For model 2, we create four portfolios since it maximizes the power of the test for the presence of liquidity effects, see Section 3.3. Unfortunately, this means we cannot conduct the test for measures *listed* and *age,* since they are both binary variables ('listed' versus 'not listed', and 'young' versus 'old'). The average yields and the average liquidity values for the other six measures are shown in Table 7.[3] Clearly, the differences between the portfolios are now larger than in Table 5, since we have assigned the bonds to four size percentiles instead of two.

[insert Table 7 around here]

The regression results are displayed in Table 8.[4] The Wald statistic that tests for the joint significance of the intercept and the coefficient of the liquidity measure is statistically significant for all six measures. So, also using model 2, we find statistical evidence of the presence of liquidity effects in our data set, after controlling for maturity, rating and currency differences between the portfolios. The signs of all liquidity coefficients are positive, as hypothesized.

[insert Table 8 around here]

5.5 Comparison

Table 9 summarizes the results of conducting the pairwise comparisons between the liquidity measures, as described in Section 3.4. For each measure i, we count the number of times it adds power to a model that already contains measure j. We also count the number of times a measure j is subsumed if it is added to the model of measure i. Looking at the sum of both counts, we see that measures *number of contributors* and especially *price volatility* outperform the other four measures.

[insert Table 9 around here]

6 Summary

We use the Brennan and Subrahmanyam (1996) methodology to test which measures can be used to approximate liquidity in the euro-denominated corporate bond market. Eight indirect measures of liquidity are employed: issued amount, coupon, listed, age, missing prices, price volatility, number of contributors and yield dispersion. For each liquidity measure, we construct

[3] The average maturities and ratings are omitted from Table 7 for space considerations. They are available from the authors on request.

[4] The Fama-French factor loadings and the coefficients for the portfolio characteristic are omitted from Table 8 for space considerations. They are available from the authors on request.

mutually exclusive portfolios. The time series of portfolio yields are subsequently used in two Fama and French (1993) regression models, augmented with portfolio characteristics as recommended by Gebhardt et al. (2001), to control for differences in maturity, credit worthiness and currency. We also conduct pairwise comparisons between the liquidity measures, as proposed by Goldreich et al. (2002).

The results indicate that the augmented Fama-French model should be rejected for seven out of eight liquidity measures. The premium between liquid and illiquid portfolios depends on the liquidity measure and ranges from 9 to 24 basis points. The highest premiums are found for the measures *age* and *yield dispersion*. The comparison tests show that the measures *price volatility* and *number of contributors* most often have added value over other measures or that other measures are subsumed by them.

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Authors	Data	Liquidity measures					
		issued amount	coupon	listed	age	price volatility	number of contributors
Corporate bonds							
AEF00	US	–*		–*	+*	–*	
CT95	US	~					
EGAM02	US	~			+*		
ER01	US				+*		
GM92	US	+~,–~	+~				–~
HW00	US	–*			+*	+*	
M01	EMU	~			~		
MR02	US	+~,–~					
S01	US				+		
SBP93	US	~				+*	
Treasury bonds							
AM91	US		–*				
EG98	US				+*		
F02	US	~					
JMP02	EMU [1)]	–*					–*
K02	US	–*					
KU00 [2)]	Germany	–*					
SW89	US	–			+*		
W92	US	–~	+~		+*		
Corporate & treasury bonds							
DN02	Spain	+*,–*			+*		
Corporate, municipal & treasury bonds							
CS99	US				+*		

Table 1. Literature overview.

Overview of liquidity measures from the empirical bond liquidity literature and their effects on the bond yield.

Authors: AEF00=Alexander, Edwards and Ferri (2000), AM91=Amihud and Mendelson (1991), CS99=Chakravarty and Sarkar (1999), CT95=Crabbe and Turner (1995), DN02=Díaz and Navarro (2002), EG98=Elton and Green (1998), EGAM02=Elton, Gruber, Agrawal and Mann (2002), ER01=Ericsson and Renault (2001), F02=Fleming (2002), GM92=Gehr and Martell (1992), HW00=Hong and Warga (2000), JMP02=Jankowitsch, Mösenbacher and Pichler (2002), K02=Krishnamurthy (2002), KU00=Kempf and Uhrig-Homburg (2000), M01=McGinty (2001), MR02=Mullineaux and Roten (2002), S01=Schultz (2001), SBP93=Shulman, Bayless and Price (1993), SW89=Sarig and Warga (1989), W92=Warga (1992).

Data: EMU=European Monetary Union, US=United States.

Legend: – negative; + positive; * significant; ~ insignificant.

Notes: [1)] JMP02 considered the following EMU countries: Austria, France, Germany, Italy, Spain and The Netherlands. [2)] The price discounts in Kempf & Uhrig-Homburg (2000, Table 2) can be used to calculate the impact of maturity on yields.

Liquidity measure	**Details**	**Sign**	**Portfolio** first	last
Issued amount	total notional in billions of euros	−	largest	smallest
Coupon	coupon rate	?	smallest	largest
Listed	whether a firm's equity is publicly traded, or not	−	yes	no
Age	time between issue date and quote date in years	+	young	old
Missing prices	1 if price is missing or equal to previous price, 0 if not	+	least	most
Price volatility	standard deviation of prices since previous rebalancing	+	lowest	highest
Number of contributors	number of market participants quoting the bond	−	largest	smallest
Yield dispersion	see Equation (4)	+	smallest	largest

Table 2. Liquidity measures.
Overview of the liquidity measures, their expected signs and the portfolio order. The *sign* column contains the expected signs of the relationship between the measures and bond yields. The *portfolio* columns show the order in which the ranked bonds are assigned to the first (most liquid) portfolio and the last (most illiquid) portfolio.

	Intercept	**Slope**	**Credit**	R^2
Swap rates	0.0371	0.785	0.173	97.9%
	(1.01)	(36.5)	(6.66)	
Government rates	0.419	0.540	0.273	95.0%
	(12.4)	(31.4)	(5.46)	

Table 3. Results for the entire sample.
Regression results for the Fama-French model estimated on the entire sample with either swap rates or government rates as default-free interest rates (t-values between parentheses).

	Intercept	Slope	Credit	Wald	R^2
RATING					
AAA	−0.220	0.736	0.0838	946	97.2%
	(8.30)	(46.8)	(4.40)	(0.00)	
AA	0.120	0.732	0.0310		
	(5.60)	(55.8)	(2.04)		
A	0.122	0.856	0.295		
	(4.95)	(59.4)	(15.8)		
BBB	0.453	0.824	0.435		
	(8.28)	(24.4)	(10.6)		
MATURITY					
short	−0.135	0.635	0.165	474	98.8%
	(3.09)	(25.0)	(5.36)	(0.00)	
long	0.247	0.944	0.138		
	(13.6)	(82.0)	(10.6)		
EURO					
euro	−0.066	0.888	0.291	112	97.8%
	(1.85)	(42.1)	(11.2)	(0.00)	
legacy	0.139	0.682	0.0242		
	(5.53)	(45.7)	(1.35)		

Table 4. Results for the characteristics portfolios.
Regression results for the Fama-French model estimated for portfolios based on the rating, maturity and euro characteristics (t-values between parentheses). The *Wald* column shows the test on the joint significance of the intercepts (p-value between parentheses).

	Yield		Maturity		Rating		Liquidity	
	1	2	1	2	1	2	1	2
Issued amount	5.33	5.09	6.47	4.64	0.22	0.35	0.65	0.20
Coupon	5.21	5.21	6.05	5.04	0.25	0.32	4.29	6.91
Listed	5.26	5.01	5.68	5.11	0.27	0.33	1.00	0.00
Age	5.44	5.16	6.91	5.31	0.17	0.30	0.64	3.80
Missing prices	5.28	5.07	6.09	4.57	0.19	0.46	0.19	0.46
Price volatility	4.91	5.50	3.81	7.24	0.31	0.26	0.21	0.45
Number of contributors	5.19	5.27	5.58	5.56	0.22	0.42	2.31	0.76
Yield dispersion	5.40	5.14	7.42	4.91	0.09	0.14	0.47	1.50

Table 5. Portfolio statistics.
Summary statistics of the two constructed portfolios using the eight liquidity indicators. Portfolio 1 (respectively 2) contains the bonds that are hypothesized to be most liquid (respectively most illiquid). *Yield* is the average portfolio yield. *Maturity* is the average time to maturity in years. *Rating* is the average credit worthiness, measured on the following scale: AAA=1, AA=2, A=3, BBB=4. *Liquidity* is the average value of the liquidity measure.

		Factors		Characteristics					
	Intercept	Slope	Credit	Rating	Maturity	Euro	**Wald**	**Premium**	R^2
ISSUED AMOUNT									
large	−0.0320	0.866	0.211	0.0720	0.121	−0.263	6.90	12.4	98.0%
	(0.880)	(51.5)	(10.4)	(1.56)	(8.24)	(2.84)	(0.03)	(0.01)	
small	0.0924	0.712	0.130						
	(2.30)	(36.9)	(5.53)						
COUPON									
small	−0.0187	0.786	0.174	0.304	0.121	−0.0348	21.7	11.0	97.7%
	(0.671)	(51.9)	(9.54)	(6.62)	(8.04)	(0.515)	(0.00)	(0.00)	
large	0.0918	0.783	0.179						
	(2.67)	(37.2)	(7.13)						
LISTED									
yes	0.0153	0.783	0.165	0.143	0.109	−0.0581	1.72	−4.46	98.0%
	(0.476)	(45.0)	(7.95)	(2.37)	(7.64)	(0.667)	(0.42)	(0.19)	
no	−0.0293	0.748	0.143						
	(0.842)	(42.4)	(6.71)						
AGE									
<1y	−0.0365	0.912	0.252	0.224	0.115	−0.0520	54.9	19.6	98.1%
	(1.35)	(53.6)	(11.8)	(5.51)	(11.7)	(0.909)	(0.00)	(0.00)	
>1y	0.159	0.741	0.180						
	(5.25)	(36.4)	(7.40)						
MISSING PRICES									
few	−0.0315	0.798	0.148	0.189	0.164	−0.0351	27.8	12.8	97.6%
	(1.01)	(44.9)	(6.95)	(5.47)	(23.1)	(0.890)	(0.00)	(0.00)	
many	0.0969	0.732	0.177						
	(2.85)	(35.6)	(6.78)						
PRICE VOLATILITY									
small	0.121	0.630	0.168	0.314	0.0965	−0.169	24.8	−13.3	98.5%
	(3.32)	(28.6)	(6.34)	(6.42)	(22.2)	(2.22)	(0.00)	(0.00)	
large	−0.0123	0.903	0.157						
	(0.454)	(54.9)	(8.45)						
NUMBER OF CONTRIBUTORS									
large	0.0165	0.786	0.164	0.205	0.140	0.0169	52.5	9.15	97.6%
	(0.544)	(44.2)	(7.38)	(6.89)	(26.9)	(0.608)	(0.00)	(0.00)	
small	0.108	0.747	0.108						
	(5.02)	(40.1)	(4.82)						
YIELD DISPERSION									
small	−0.0331	0.893	0.169	0.323	0.0925	−0.107	64.4	24.1	98.4%
	(1.13)	(50.7)	(8.18)	(8.32)	(16.7)	(1.52)	(0.00)	(0.00)	
large	0.208	0.698	0.113						
	(7.03)	(36.9)	(5.18)						

Table 6. Results for model 1.
Regression results for the Fama-French model augmented with portfolio characteristics (see Equation (1)) estimated for two portfolios based on one of the eight liquidity measures (t-values between parentheses). The *Wald* column shows the test on the joint significance of the intercepts (p-value between parentheses). The *Premium* column contains the difference between the portfolio intercepts in basis points (p-value between parentheses).

	Yield				Liquidity			
	1	2	3	4	1	2	3	4
Issued amount	5.38	5.28	5.08	5.10	0.88	0.38	0.24	0.16
Coupon	5.16	5.27	5.31	5.11	3.48	5.17	5.99	7.85
Missing prices	5.35	5.21	5.07	5.12	0.05	0.34	0.45	0.53
Price volatility	4.77	5.02	5.38	5.63	0.15	0.25	0.37	0.54
Number of contributors	5.27	5.10	5.25	5.32	3.48	1.13	0.80	0.57
Yield dispersion	5.43	5.37	5.19	5.07	0.35	0.60	0.92	2.15

Table 7. Portfolio statistics.
Summary statistics of the four constructed portfolios using six liquidity indicators. Portfolio 1 (respectively 4) contains the bonds that are hypothesized to be most liquid (respectively most illiquid). *Yield* is the average portfolio yield. *Liquidity* is the average value of the liquidity measure. The portfolios' average maturities and ratings are omitted for space considerations.

	Intercept	Liquidity	Wald	R^2
Issued amount	0.0316	0.338	147	97.9%
	(1.32)	(11.9)	(0.00)	
Coupon	0.0405	0.0569	65.3	97.6%
	(1.71)	(8.07)	(0.00)	
Missing prices	0.0894	0.357	66.2	96.3%
	(3.23)	(7.92)	(0.00)	
Price volatility	0.0637	0.0295	8.22	98.3%
	(2.75)	(0.922)	(0.02)	
Number of contributors	0.102	0.00100	15.9	96.2%
	(3.99)	(0.173)	(0.00)	
Yield dispersion	0.0855	0.0335	28.9	97.8%
	(4.26)	(3.15)	(0.00)	

Table 8. Results for model 2.
Regression results for the Fama-French model augmented with portfolio characteristics and a liquidity variable (see Equation (2)) estimated for four portfolios based on one of the six liquidity measures (t-values between parentheses). The coefficients and t-values of the two Fama-French factors and the three characteristics are omitted for space considerations. The *Wald* column shows the test on the joint significance of the intercept and the coefficient of the liquidity variable (p-value between parentheses).

	Adds explanatory power	Subsumes other measure	Total
Issued amount	3	1	4
Coupon	3	1	4
Missing prices	2	1	3
Price volatility	4	4	8
Number of contributors	4	2	6
Yield dispersion	3	1	4

Table 9. Results of the comparison tests.
Results of the pairwise comparisons of six liquidity measures (see Equation (3)). The table displays the number of times a measure *adds explanatory power* to another measure, as well as the number of times a measure *subsumes another measure*. The *total* column contains the sum of both counts.

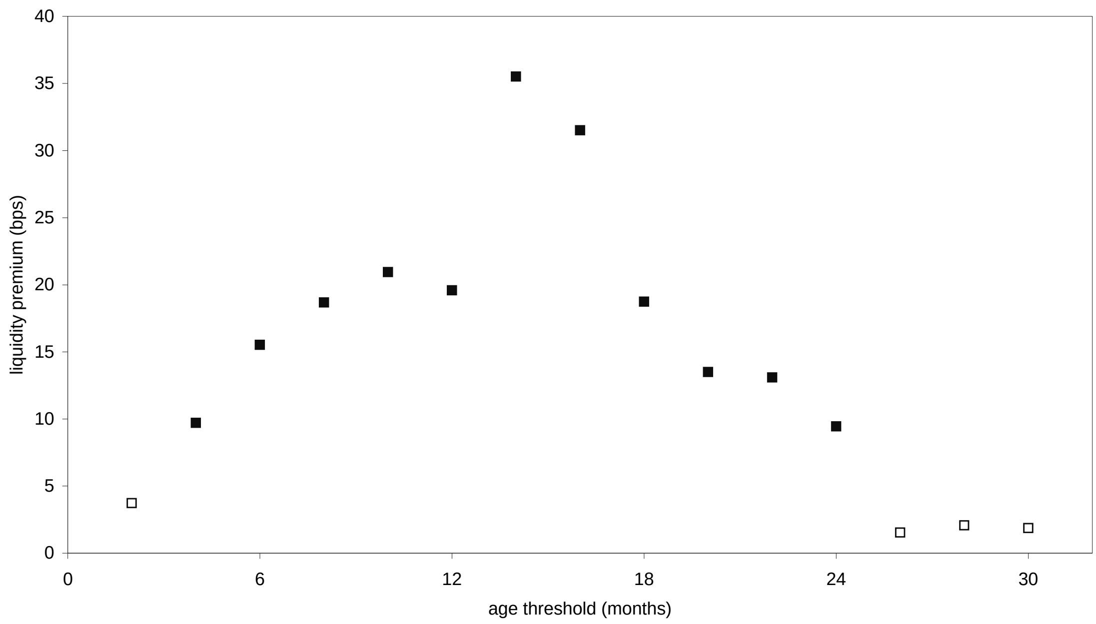

Figure 1. Selecting an age threshold.
Liquidity premium between two portfolios created for different age thresholds. A solid square denotes significance of the Wald test on the joint significance of the two intercepts (p-value < 0.05).