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Spanish Treasury bond market liquidity and volatility pre- and post-European Monetary Union ☆

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Abstract

Spain enacted a number of important debt management initiatives in 1997 to prepare its Treasury bond market for European Monetary Union. We interpret the impacts of these changes through shifts in a bond liquidity "life cycle" function. Furthermore, we highlight the importance of expected average future liquidity in explaining Spanish bond liquidity premiums. We also uncover pricing biases that support the Spanish Treasury's tactical decision to target high-coupon, premium bonds in its pre-EMU debt exchanges. Finally, we show that EMU has been associated with both a decrease in bond yield volatility and an increase in pricing efficiency.

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1. Introduction

This paper examines liquidity and volatility in the Spanish Treasury bond market within the context of debt policy shifts engineered by the Spanish government in preparation for entrance into European Monetary Union.[1] The Treasury's mid-1997 debt management innovations were designed to make Spanish debt more attractive to the new class of Pan-European government bond investors created under European Monetary Union. These measures included (1) increases in the size of new issues, (2) increases in the time between bond issuance tranches, (3) development of a strips market and (4) institution of a new aggressive exchange policy to replace certain seasoned issues. A key purpose of this paper is to investigate the impact of Spain's debt management initiatives on both trading activity and valuation in its debt market. As it happens, Spain's concerns over properly preparing its markets for dramatic shifts in the relevant investor class under EMU turned out to be quite prescient. The share of Spanish government debt held by non-resident investors climbed from 25% in 1996 to 47% by February 2003.[2]

Analysis of Spain's actions and experiences during these special circumstances provides a number of specific insights on market structure and policy impacts of interest to both policymakers and academic researchers. To facilitate these insights, we estimate a model that relates individual Treasury issue market share of overall trading volume to a bond's age (the time since its initial auction) in a fashion best described as a liquidity life cycle. We then test for shifts in this liquidity life cycle function as a result of the Treasury's debt policy innovations. We also estimate the structure of liquidity premiums in the different maturity sectors within the Spanish bond market and quantify the impacts of Spain's EMU-related debt management policy shifts on Spanish Treasury bond valuation. We conclude by examining the impacts of European Monetary Union on volatility and pricing efficiency in the Spanish Treasury market.

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[1] In general, prudent debt management by any sovereign requires attention to market structure and trading costs. Indeed, one of the three debt management goals espoused by the US Treasury is to "promote efficient markets" (see the US Treasury website). Likewise, the joint International Monetary Fund-World Bank guidelines for developing country debt management list an entire menu of regulatory and market infrastructure conditions designed to enhance debt market efficiency (see Box 5, "Relevant Conditions for Developing an Efficient Government Securities Market", in International Monetary Fund/World Bank (2001)).

[2] *Source:* Spanish Treasury (*Tesoro Público*). In contrast, during the transition to EMU, trading volume in the MEFF's (Mercado Español de Futuros Financieros) Spanish 10-year government bond future contract withered away.

1.1. Bond market liquidity proxies and model specification

Liquidity is the somewhat amorphous financial market concept that embodies the ease with which a security can be traded within a short period of time without causing significant impacts on prices. Liquidity is valuable because of the associated savings of both trading costs and trading time. Theoretically, investors should require lower returns on assets with relatively high degrees of liquidity. The difference between the required return on liquid versus less liquid assets is called a liquidity premium. Issuers whose securities trade in liquid secondary markets should benefit through lower costs of capital. This effect should hold for both debt and equity securities and for both private and sovereign issuers.[3]

Operationally, analysis of potential liquidity effects in the cash bond markets involves choosing both a specific observable proxy for liquidity and a security valuation model. In this paper, we feature issue-specific trading volume market share and "auction status" proxies for liquidity. We test for the importance of liquidity effects by using these liquidity proxies to explain the valuation residuals from a standard term structure model. Our auction status approach attempts to follow the lead of the empirical literature for the US Treasury market, where the most recently auctioned or "on-the-run" issue in each maturity sector is distinguished from all other "off-the-run" issues. However, due to the special issuance system employed by the Spanish Treasury, we propose the need for *three* different status stages: "pre-benchmark", "benchmark" and "seasoned".[4] Furthermore, following Goldreich et al. (2005), our empirical specifications stress the importance of distinguishing between current and expected *future* liquidity. As it happens, this distinction is critically important for understanding liquidity in the Spanish market. In particular, the pre-benchmark Spanish Treasury bond has a low share of overall trading volume at issue, but carries an expectation of a sharply increasing future market share. In contrast, the current benchmark bond has a high current share of market trading volume, but carries an expectation of a decreasing future share of market trading volume.

Our main results regarding the impacts of Spain's debt policy changes concern both the liquidity *life cycle* of the typical bond and the *value* of liquidity. First, we show that a specific continuous, highly non-linear function of bond age explains the typical bond's changing market share of trading volume quite well. Moreover, we confirm that important structural changes took place in the Spanish market during the approach to monetary union. In particular, shifts in the liquidity life cycle model's key parameters after 1997 show that Spanish debt market trading activity became more concentrated in benchmark bonds and reveal that the benchmark status period lengthened.

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[3] Sarig and Warga (1989), Amihud and Mendelson (1991), Warga (1992), Kamara (1994), Carayannopoulos (1996), Duffee (1998), Elton and Green (1998), Fleming (2001), Strebulaev (2001), Krishnamurthy (2002) and Goldreich et al. (2005) analyze liquidity in the US government debt markets. The liquidity of Spanish government debt has been studied by Alonso et al. (2004), who apply the Elton and Green (1998) methodology, and by Díaz and Navarro (2002).

[4] Alonso et al. (2004) propose similar stages for Spanish bonds.

We also present a number of interesting results concerning liquidity value in the Spanish bond market. We show that our explicit life cycle function adds significant explanatory power to the literature's standard bond auction status dummy variable approach. In particular, we use our estimated market share life cycle functions to project each issue's future liquidity. This allows us to test for an empirical relation between bond values and liquidity, while specifically distinguishing between the impacts of current versus expected future liquidity. Our results reveal that expected future liquidity is much more important than current liquidity for explaining relative Spanish Treasury bond values.

In addition, we examine the valuation impacts of bond-specific characteristics such as the coupon rate and price premiums and discounts versus par. Our results for the 1993–1997 sample period detect statistically significant valuation biases confirming that Spanish investors favored discount bonds over premium bonds. These results lend support to the Spanish Treasury's tactical decision to target high-coupon, premium bonds in its debt exchanges. Interestingly, we find that the impact of such bond-specific characteristics on value in the Spanish market decreased after European Monetary Union.

Finally, we examine the impacts of European Monetary Union on the volatility of yields in the Spanish Treasury market. As anticipated by its early proponents, European Monetary Union led to dramatic falls in both yield levels and yield volatility for "Club Med" members such as Spain and Italy. For these countries, European Monetary Union membership decreased the relevant currency translation risks as well as the perceived bond default probabilities. Formal tests here based on the first-differences of yields strongly reject the null hypothesis of equal yield variances in our pre- and post-EMU periods. Such an impact on volatility is generally acknowledged (see Codogno et al., 2003). It is less widely recognized that European Monetary Union has also led to more efficient *relative* pricing in the Spanish Treasury bond market. Our results reveal that the residual variance of our liquidity and bond characteristic-augmented yield regressions fell sharply between our pre-EMU and post-EMU samples. Such improved pricing efficiency may be attributed to an important byproduct of European Monetary Union: the creation of a much larger universe of euro-based fixed income investors willing to focus attention on trading opportunities in any member market without the hindrance of currency risk.

2. Institutional features of the Spanish Treasury debt markets

With total domestic Treasury debt of approximately €315 billion as of year-end 2002, Spain is the fourth largest euro zone sovereign debt market, trailing only Italy (€1061 billion), Germany (€745 billion) and France (€732 billion) in total par amount outstanding.[5] Spanish Treasury debt consists of both bills and coupon-

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[5] *Source:* Security statistics, Bank for International Settlements, September 2003.

bearing notes and bonds. *Letras del Tesoro* (Treasury bills) are issued at discount with 6-, 12- and 18-month maturities. *Bonos* and *Obligaciones del Estado* (Treasury bonds and notes) bear annual coupon payments and have been issued for 3-, 5-, 10-, 15- and 30-year maturities. *Letras del Tesoro* and, since 1999, *Bonos* and *Obligaciones* have been traded free of withholding tax for non-residents and institutional investors.

All Spanish Treasury debt is issued via competitive auction. However, the Spanish Treasury traditionally has built up the total par amount of each new security by keeping the same issue open over several (at least three) consecutive auctions. The securities issued through each tranche were fully fungible since they shared the same nominal coupon, interest payment and redemption dates, and security code. When the total nominal amount issued reached the appropriate target size, the corresponding security code was closed, and any further issuance took place using a new security. The secondary market for Spanish Treasury debt is known as *Mercado de Deuda Pública Anotada* or MDPA.[6]

Current practices in the Spanish market are the result of changes made by Spain as it prepared for entry into European Monetary Union. Under EMU, the Spanish Treasury recognized that it would have to compete directly with other euro zone sovereign debt issuers. Thus, beginning in mid-1997, the Spanish Treasury "prioritized the achievement of a more liquid and efficient public debt market".[7] In practical terms, this meant undertaking a set of initiatives aimed to attract investor savings within the new single capital market. Among these initiatives, we highlight the following measures designed to increase the depth and liquidity of the market:

1. Reform of the Treasury market makers regime adapting it to the EMU rules and modifying the rights and obligations of public debt market makers and recognized dealers;
2. Enlargement of Spanish public debt trading platforms through "the advance in the blind segment of the Spanish market centred on the roll-out of a fully electronic trading system supporting automatic posting of public debt prices";
3. A change of the tax regime of the public debt;
4. An increase in the size of bond issues to total par amounts in the €11 billion to €12 billion range;
5. Organization of a Treasury strips market;
6. An increase in the range of issued Treasury maturities to include a 30-year bond;

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[6] The MDPA conducts trading through three systems. The first two are reserved for market members, while the third is for transactions between market members and their clients. The first member system is a "blind market" electronic trading system conducted without knowledge of the counterparty's identity, while the second system channels all the remaining transactions between market members. The structure of the Spanish market is quite similar to the US Treasury market (see Fleming and Remolona, 1999 for details about the US Treasury market).

[7] See "Memoria 2000" of Tesoro Público (http://www.mineco.es/tesoro/htm/deuda/Memorias/indice_i.htm).

7. A new government debt exchange policy designed to replace certain seasoned, low liquidity, high-coupon issues with new strippable, close-to-market coupon rate bonds.

The debt exchanges provided a crucial mechanism through which to build par amount size in new issues with current market coupon levels that would be priced near 100% of par. This shift was designed to increase market liquidity and depth through two channels. First, the exchange policy ensured an adequate tradable supply of bonds priced near par (at the expense of premium bonds that some classes of investors avoid). Second, the debt exchanges produced the larger outstanding amounts of strippable bonds that were critical in supporting bond dealer stripping and reconstitution operations in the new strips market.[8]

3. Liquidity in the Spanish public debt market

In this section, we first describe our database and discuss alternative proxies for liquidity in the Spanish Treasury bond market. We then analyze the impact of the new EMU-related debt management policy shifts on bond trading activity and bond liquidity.

3.1. The data

The original database consists of 65,135 observations derived from actual transactions in all Spanish Treasury bills and bonds traded in MDPA (obtained from annual files made available by the Banco de España) over the period from January 1993 to December 2002. For each issue, the Banco de España database reports daily information on the number of transactions and both the nominal and effective trading volumes. The database also reports the maximum price, the minimum price and the average price for each issue computed from all MDPA transactions over each day in the sample. We match this information with each issue's coupon rate, maturity date, issue date and remaining coupon payment dates. We also track the par amount outstanding of each issue at the end of each month. Table 1 gives a brief overview of the average trading volume and par amounts outstanding where bonds are grouped by original issuance date term-to-maturity. The 10-year sector is the most actively traded maturity sector and accounts for about 41% of overall Treasury market trading. In this paper, we focus on trading activity in the three most active sectors: 10-, 5- and 3-years.

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[8] Government debt exchanges were conducted via competitive auction, in which the Treasury reserved the right to decide the cut-off price. (Also, in 2001 and 2002, exchange transactions were substituted by direct repurchases of the targeted high-coupon issues using the Treasury's cash surpluses.)

Table 1
Spanish Treasury market database summary for the 1993–1997 and 1998–2002 sample periods

	Bills	3-year bonds	5-year bonds	10-year bonds	15-year bonds	30-year bonds
1993–1997						
Daily data						
Average volume per traded issue[a]	26.84	94.26	77.22	99.50	24.94	–
Average volume per sector	184.99	440.49	504.29	708.73	34.05	–
# Traded issues per day	6.9	4.7	6.5	7.1	1.4	–
# Observations	8539	5809	8117	8837	1301	–
Monthly data						
% Days traded per issue	22.9%	74.6%	78.5%	95.2%	87.0%	–
Average amount outstanding per issue	1548	4265	4490	5022	5695	–
Average market share per issue	0.2%	3.7%	3.2%	5.1%	1.0%	–
Average market share per sector	10.1%	23.5%	27.1%	38.0%	1.3%	–
Average # outstanding issues	38.12	6.3	8.3	7.5	1.5	–
Global information						
Total # issues in subsample	255	16	12	10	3	–
1998–2002						
Daily information						
Average volume per traded issue[a]	18.33	136.23	126.38	136.76	37.63	61.71
Average volume per sector	97.53	485.81	641.86	542.14	93.64	84.47
# Traded issues per day	5.3	3.6	5.1	8.1	2.5	1.4
# Observations	6604	4511	6430	10,256	3113	1677
Monthly information						
% Days traded per issue	14.5%	71.3%	77.7%	63.7%	61.6%	95.1%
Average amount outstanding per issue	1194	6986	7409	6737	6262	6714
Average market share per issue	0.1%	4.0%	3.9%	3.4%	1.0%	2.2%
Average market share per sector	4.6%	20.1%	25.4%	43.2%	3.8%	3.0%
Average # outstanding issues	43.2	5.0	6.6	12.7	4.0	1.4
Global information						
Total # issues in subsample	203	9	13	15	5	2

Average volume and amounts outstanding expressed in million € of par value. Issues are sorted by maturity sector of original issue.

[a] Average calculated after excluding sample points for issues with zero volume on the given day.

3.2. Empirical liquidity proxies in the previous literature

The literature recognizes a wide range of market condition variables and security-specific characteristics related to bond liquidity. In the US Treasury market, a common liquidity proxy is a bond's bid–ask spread.[9] Elton and Green (1998) suggest that the best proxy for liquidity is trading volume, though Fleming (2001) finds improved

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[9] See, for example, Shen and Starr (1998), Chakravarty and Sarkar (1999), Hong and Warga (2000), Chen and Wei (2001), Fleming, 2001), Gwilym et al. (2002) and Goldreich et al. (2005).

performance using the number of trades instead.[10] The literature also promotes bond age, auction status and issue size as relevant explanatory variables.[11] For example, Fisher (1959) uses the amount of bonds outstanding on the basis of the potential correlation between the existing stock of a particular bond and the flow of trade in the bond. Sarig and Warga (1989) and Warga (1992) suggest that younger bonds are usually traded more frequently. Warga (1992) uses an auction status dummy variable that indicates whether or not an issue is "on-the-run" (i.e., the most recently issued security of a particular maturity). Amihud and Mendelson (1991) observe that bonds approaching maturity are significantly less liquid since they are "locked away" in investors' portfolios. Importantly, Goldreich et al. (2005) emphasize expected liquidity over the full life of the issue – not just the current level of any liquidity measure – as the most relevant theoretical constructs for *valuing* bond liquidity.

Here, we analyze the evolution of Spanish Treasury bond liquidity with respect to auction status and bond age. We argue that the two-stage (on-the-run/off-the-run) division traditionally used for US Treasury debt is not the most suitable choice for Spanish Treasury assets over our sample period since the Spanish Treasury built up its issues through a series of issuance tranches. Thus, the most recently issued security (the on-the-run) might have been only one-fourth or one-third of the size of the first off-the-run issue. This important relative issue size difference suggests that the on-the-run issue need *not* have the highest *current* liquidity.[12] Moreover, detailed analysis of the data motivates a more sophisticated approach to modeling the evolution of a typical bond's trading activity over its life cycle. As it happens, this approach also allows us to build appropriate measures of expected average future liquidity to maturity for any issue on any trading date. Thus, this approach is particularly convenient for distinguishing between the values of current and future liquidity for Spanish Treasury bonds in the spirit of Goldreich et al. (2005).

We use individual issue market share of total trading activity as the measurable proxy for relative liquidity.[13] Many previous studies of bond market liquidity analyze raw trading volume (see, for example, Elton and Green, 1998; Fleming, 2001). We prefer the market share measure to raw volume measure since Spanish Treasury bond trading volumes trended higher over the 1993 to 2002 sample period. Scaling these individual issue volumes by total market volume both detrends these data and controls for week-to-week volume fluctuations that are unrelated to relative liquidity. Let the market share measure MS_{it} for security i during week t be calculated as the ratio of the par value traded in bond i to the total par value traded

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[10] Shulman et al. (1993) uses trading frequency and Houweling et al. (2002) use the number and dispersion of quotes per day.

[11] Other variables that have been used include the volatility of interest rates (Kamara, 1994) and the percentage growth of mutual funds (Fridson and Jónsson, 1995).

[12] As it happens, in mid-2002 (near the end of our sample) Spain ultimately became confident enough to approach the market with large enough initial tranches such that new issues immediately become benchmarks.

[13] We choose among volume-based measures since the Banco de España database does not include bid–ask quotes.

by all outstanding issues. The MS_{it} variable allows us to compare the degree of liquidity among issues and to monitor the evolution of the liquidity of a given issue throughout its life.

We divide the life of a Spanish Treasury bond issue into *three* status stages. We term the first stage to be the "pre-benchmark" period – beginning at the issue of a new bond's initial tranche (the bond is also by definition the "on-the-run" issue at this time). This pre-benchmark period covers the time during which the issue's market share increases with age, but still lies below the market share of the former on-the-run bond. The second stage is the "benchmark" period. This stage corresponds to the period during which the issue has the highest market share among all outstanding issues of the same original maturity. The last stage is the "seasoned" (post-benchmark) period. The seasoned stage corresponds to the period beginning the week that the particular bond's market share is eclipsed (by a newer and now sufficiently liquid issue) and ends at the bond's maturity.

3.3. The impact of EMU preparations on liquidity

Spain's debt management policy changes generated important shifts in issuance tranches, outstanding issue sizes and the evolution of bond auction status stages. Panel A of Table 2 reports two sets of summary statistics on issue par amounts for both individual tranches and total issue sizes for each of the three main bond maturity sectors: 10-, 5- and 3-years. The 1993–1997 and 1998–2002 sample splits were chosen to reflect the two different Spanish issuance policy regimes. The latter subsample begins after the 1997 shift toward larger issue sizes. Note that tranche sizes were reasonably similar across the two regimes. However, the number of tranches increased so that the par amounts outstanding after the last tranche essentially doubled across board. The shifts in issuance policy also had an important effect on bond status. Panel B of Table 2 presents summary statistics on the evolution of the lengths of the crucial pre-benchmark and benchmark stages in a bond's life cycle. The average length of the pre-benchmark stage is similar across issuance regimes, but the length of the benchmark stage is considerably larger during the post-1997 period.

3.4. Modeling the market share function

So far, we have classified bond liquidity using three discrete status categories. However, individual bond market shares of trading may be more generally modeled as smooth, non-linear functions of bond age. Here, we posit a parsimonious function to describe the behavior of individual bond market share (MS_{it}) as a function of bond age (Age_{it}):[14]

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[14] Eq. (1) is inspired by forms arising from actuarial research on human mortality (see Heligman and Pollard, 1980). That literature uses this function's "hump" to capture the impact of traffic accidents on mortality rates of 15–25-year-olds within a general mortality-versus-age relationship.

Table 2
Effects of Spanish debt management changes on issuance and bond benchmark status

	Years to maturity in each tranche			Average amount per auction (million €)	Amount outstanding after the first tranche	Amount outstanding after the last tranche
	Minimum	Maximum	Average			
Panel A: Evolution of the issuance tranches and amounts outstanding (million € par value) by sector						
1993–1997						
3-year bond	2.21	3.54	3.09	900	1075	5385
5-year bond	4.21	5.54	5.00	934	1285	6076
10-year bond	9.42	10.54	10.01	890	1198	5830
15-year bond	12.71	15.63	14.20	245	676	4171
30-year bond	–	–	–	–	–	–
1998–2002						
3-year bond	2.22	3.98	3.14	824	1350	10,769
5-year bond	4.29	5.98	5.12	881	1686	11,152
10-year bond	8.96	11.06	10.21	1031	2371	13,737
15-year bond	12.64	15.65	14.65	575	1691	10,599
30-year bond	28.24	31.54	30.06	620	2128	7532

	Number of new issues	Weeks between adjacent auctions			Weeks that a bond keeps pre-benchmark status			Weeks that a bond keeps benchmark status		
		Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average
Panel B: Evolution of bond auction status by sector										
1993–1997										
10-year bond	8	13	43	33	3	28	16	12	49	33
5-year bond	8	6	82	30	5	81	27	2	87	41
3-year bond	9	6	69	26	1	67	17	4	92	37
1998–2002										
10-year bond	5	38	71	50	3	34	16	31	58	40
5-year bond	5	31	74	54	0	21	16	32	75	53
3-year bond	4	4	56	38	0	27	17	32	68	53

$$\mathrm{MS}_{it} = \beta_1 \exp[-\beta_2(\mathrm{Age}_{it} - \beta_3)^2] + \beta_4 \cdot \beta_5^{\mathrm{Age}_{it}} + u_{it}. \tag{1}$$

The first term allows for a hump in the liquidity profile during the first few years of bond life. The second term is a decreasing exponential function that describes the declining trading activity of the bond as it approaches maturity. The third term is a random error.

The parameters in Eq. (1), with expected signs given in parentheses, can be interpreted as follows:

1. β_1 measures the degree of concentration of trading activity in the benchmark bond, i.e., the size of the hump ($\beta_1 > 0$);
2. β_2 is inversely related to the length of the period over which a bond keeps the benchmark status, i.e., the width of the hump ($\beta_2 > 0$);
3. β_3 is the bond age at which the function's first term (the liquidity hump) has the highest amplitude ($\beta_3 > 0$);
4. β_4 is the initial value for the exponential function component ($\beta_4 > 0$);
5. β_5 relates to the speed at which a seasoned bond's trading activity changes with time ($1 \geqslant \beta_5 > 0$).

For positive values of all parameters, the MS(·) function is also positive.

We apply equation (1) to weekly data on individual bond issue shares of trading volume for all original-issue 10-, 5- and 3-year bonds in our database.[15] Table 3 presents the parameter estimates for Eq. (1) for the two subsamples suggested by the changes in Spanish Treasury issuance policy. All reported individual *t*-statistics embody the Newey–West correction. Consider first the estimates for 10-year bonds over the 1993–1997 period presented in Panel A. The regression's adjusted *R*-square of 71.2% reveals that, through the functional form given by Eq. (1), bond age does a very good job of explaining market share in the 10-year sector. As expected, all five coefficient estimates are positive in sign and significantly different from zero (all individual coefficient *t*-statistics have *p*-values of 0.00). The most interesting individual estimates are $\hat{\beta}_3 = 0.67$ and $\hat{\beta}_1 = 18.47$. The $\hat{\beta}_3$ estimate reveals that the peak in a typical 10-year bond's market share occurs two-thirds of a year after its first issue date. The estimate for $\hat{\beta}_1$ implies that the shift in the 10-year bond's market share versus its baseline value at this peak point is about 18.5%.[16]

The 10-year sector's results for the 1998–2002 period are qualitatively similar. However, the key coefficients exhibit very interesting quantitative shifts. The new estimate for β_1 implies that the peak shift in the 10-year bond's market share is now 23.5% (about 5% higher versus the earlier period) indicating that trading

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[15] While we prefer the market share measure, the results from using raw volume as the dependent variable were qualitatively similar. However, see Footnote 16 below.

[16] Some experimentation showed that the reported parameter estimates are robust to the choice of specific starting values in the non-linear least squares estimation procedure. Ironically, the estimates generated when using raw volume as the dependent variable are highly sensitive to the initial set of parameters.

Table 3
Estimates of the market share life cycle function

	Sample period: 1993–1997		Sample period: 1998–2002	
	Coefficients	*t*-Statistics	Coefficients	*t*-Statistics
Panel A: 10-year bonds				
β_1	18.47	(34.11)	23.50	(24.88)
β_2	4.16	(12.00)	2.43	(8.75)
β_3	0.67	(37.96)	0.83	(35.68)
β_4	2.16	(6.80)	4.85	(4.03)
β_5	0.89	(22.95)	0.69	(16.65)
Adjusted R^2 (%)	71.2		76.3	
# Observations	1686		3193	
Panel B: 5-year bonds				
β_1	5.95	(3.64)	10.43	(15.74)
β_2	0.56	(2.52)	3.00	(5.85)
β_3	0.64	(3.75)	0.89	(32.27)
β_4	1.76	(0.81)	4.69	(5.46)
β_5	0.86	(3.14)	0.75	(20.54)
Adjusted R^2 (%)	36.2		63.6	
# Observations	2020		1700	
Panel C: 3-year bonds				
β_1	7.87	(5.53)	11.11	(18.75)
β_2	0.67	(2.78)	1.83	(6.84)
β_3	0.53	(6.39)	0.88	(32.65)
β_4	0.16	(0.10)	1.06	(1.43)
β_5	1.15	(0.31)	1.10	(4.35)
Adjusted R^2 (%)	38.9		60.5	
# Observations	1502		1102	

Non-linear least squares regressions of the market share (MS_{it}) of the bond i during week t on Age_{it} of the bond for two sample periods: 1993–1997 and 1998–2002. MS_{it} is the trading volume of bond i during week t divided by total trading volume of all Treasuries during week t. The regression equation is

$$\mathrm{MS}_{it} = \beta_1 \exp[-\beta_2(\mathrm{Age}_{it} - \beta_3)^2] + \beta_4 \cdot \beta_5^{\mathrm{Age}_{it}} + u_{it}.$$

Newey–West adjusted t-statistics are in parenthesis.

activity became more concentrated in the benchmark bond in this later period. Moreover, the market share peak in the later period comes later (0.83 years versus 0.67 years). Furthermore, $\hat{\beta}_2$ is shorter in the second period, suggesting that the benchmark bond tends to keep this status longer. Finally, $\hat{\beta}_5$ is lower in the second period, indicating that the liquidity of seasoned bonds decays even faster than in the earlier period.

Panels B and C of Table 3 present corresponding results for the original-issue 5-year and original-issue 3-year bond sectors, respectively. The adjusted R-square for each of the regressions reveals that bond age also provides important explanatory power for market share in these maturity sectors. The explanatory power is much larger in the later 1998–2002 sample. Moreover, as in the 10-year sector, the estimates for β_1 imply that trading activity for both the 5- and 3-year sectors became more concentrated in the benchmark bond in the later period. Moreover, in the later period, the market share peaks appear later in bond life as well. However, the estimates for β_1 show that the magnitudes of the benchmark effects for 5- and 3-year bonds in both periods are less than one-half of the corresponding values for 10-year bonds.[17]

The point estimates presented in Table 3 suggest increases in both the height and width of the liquidity function's "hump" in each sector in the later period. To examine whether the issuance policy shifts in mid-1997 had any effect on the structure of Spanish Treasury bond liquidity, we apply the Chow test for structural change to the coefficients in Eq. (1) after December 1997. The p-values for the Chow test statistics are 0.00 in all three sectors. Schmidt and Sickles (1977) argue that the Chow statistic may overstate the true test size in the presence of heteroscedastic residuals. Thus, we also review the results for the individual equation coefficient estimates β_1 through β_5 and their reported Newey–West corrected estimated coefficient standard errors. For each sector and subsample, consider the two standard error bounds around the estimated equation coefficients. For each sector there is at least one β estimate for which the two standard error bounds do not overlap across subsamples.[18] Taken together, these results are consistent with the hypothesis that the mid-1997 changes in issuance policy induced significant shifts in the liquidity structure of the Spanish Treasury market.

4. Liquidity premiums and the impact of EMU

In the search for liquidity premiums in bond pricing, care must be taken to control for other determinants of bond value. Previous researchers have used a variety of methods to isolate the value impacts of liquidity on bond pricing. For US bond markets, Amihud and Mendelson (1991), Kamara (1994) and Strebulaev (2001) have used the yield spread between a bill and a bond with similar term to maturity as the appropriate variable to be explained. Warga (1992) uses the mean return difference between a portfolio of seasoned bonds and a portfolio of the most recently issued securities with similar duration. Goldreich et al. (2005) study on-the-run versus off-the-run yield spreads adjusted for coupon and yield curve effects. Díaz and Skinner (2001) use the differences between the yield-to-maturity of a bond and its theoretical yield as given by an explicit term structure model. Fleming (2001) also examines a yield spread calculated as the difference between the observed yield of

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[17] The point estimate of β_5 for the 3-year note sector is greater than 1.0 in each subsample. Given the other parameter estimates, this value implies that a 3-year bond's market share would be greater than 100% if bond age were extrapolated over horizons greater than 4 years. Of course, original issue 3-year bonds would be "dead" by this time. Moreover, in either subsample, the hypothesis that $\beta_5 = 1.0$ cannot be rejected at standard significance levels and, if we impose the constraint that $\beta_5 = 1.0$, the re-estimated values of β_1 through β_4 are very close to the original values.

[18] Specifically, the two standard error bounds do not overlap in four of five parameter cases for the 10-year; one of five for the 5-year; and two of five for the 3-year.

the on-the-run security and that predicted by a term structure model estimated with off-the-run bond prices. He finds that this yield differential is consistently correlated with a number of other liquidity proxies widely used in the literature.

We begin our study of the yield impact of liquidity by estimating a daily term structure of interest rates using actual mean daily MDPA Treasury transactions prices. We include all the spot transactions that took place with Treasury bills and bonds during the day for all issues with a daily trading volume of at least than €3 million (500 million pesetas) and terms to maturity between 15 days and 15 years. We also include the one-week general collateral repo market interest rate to provide a liquid point at the very front of yield curve. We employ Nelson and Siegel's (1987) exponential model to fit the daily term structures. These daily term structure estimates do not incorporate any specific liquidity effects. Thus, the theoretical values for all bonds generated from these estimations are those produced by discounting coupon and principal payments according to fitted term structures that reflect an average liquidity level. The differences between actual bond yields and the theoretical ones can be understood as a liquidity effect plus an error term due to other factors.

4.1. Liquidity value versus current and expected future market share and auction status

As recently emphasized by Goldreich et al. (2005), the price of a security depends on the flow of liquidity services generated over its entire life. Lifetime liquidity involves not only a security's current of liquidity, but also the expected *future* path of liquidity. We continue to use a bond's share of trading volume as the relevant index of liquidity. Conveniently, the liquidity function of the previous section relates a bond's market share of trading volume to bond age, a deterministic variable. Thus, at any point in time, this function can be used to project the future path of liquidity of any individual bond. In turn, this approach permits identification of both current and expected future lifetime liquidity, and subsequently allows analysis of their separate impacts on bond valuation.

Specifically, we define $E_t[\mathrm{MS}_{i,t+j}]$ as the week t conditional expectation of the market share of bond i during some future week $t+j$. Using Eq. (1), $E_t[\mathrm{MS}_{i,t+j}]$ can be expressed as

$$E_t[\mathrm{MS}_{i,t+j}] = \hat{\beta}_1 \exp\lfloor -\hat{\beta}_2(\mathrm{Age}_{i,t+j} - \hat{\beta}_3)^2 \rfloor + \hat{\beta}_4 \cdot \hat{\beta}_5^{\mathrm{Age}_{i,t+j}}. \tag{2}$$

Furthermore, we define $\overline{\mathrm{MS}}_{i,t,t+m_{it}}$ as the average lifetime expected market share for bond i from week $t+1$ through maturity week $t+m_{it}$

$$\overline{\mathrm{MS}}_{i,t,t+m_{it}} = \frac{1}{m_{it}} \sum_{j=1}^{m_{it}} E_t\left[\mathrm{MS}_{i,t+j}\right], \tag{3}$$

where m_{it} is the number of weeks remaining until maturity for bond i as of the current week t.

We invoke rational expectations on the part of investors and interpret equation (3) to incorporate the expected future market share function (2). Furthermore, based

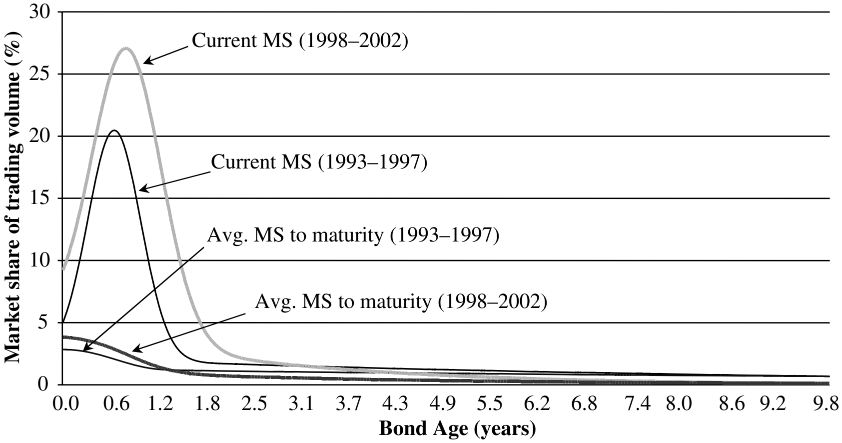

Fig. 1. Average expected market share to maturity versus current market share for 10-years bonds based upon parameter estimates for the market share equations reported in Table 3.

on the evidence of a regime shift in 1997, we match the appropriate set of parameters for the market share function from each subsample presented in Table 3 to generate the corresponding $\overline{\mathrm{MS}}_{i,t,t+m_{it}}$ for that same subsample for use in our valuation equations below. In the spirit of a rational expectations model, this choice presumes that investors understood the nature and consequences of the shifts in Spain's debt management policies at the time they were publicly announced in 1997. Fig. 1 provides some insight into the $\overline{\mathrm{MS}}_{i,t,t+m_{it}}$ variable for a newly issued 10-year-to-maturity bond. Fig. 1 plots two fitted series from the market share regressions for Eq. (1) generated using the parameter estimates for both the 1993–1997 and 1998–2002 sample periods. These series correspond to $E_t[\mathrm{MS}_{i,t+j}]$ of Eq. (2) for each subsample. Fig. 1 also plots the expected market share to maturity variable (i.e., $\overline{\mathrm{MS}}_{i,t,t+m_{it}}$) generated for each subsample by Eq. (3) using the corresponding $E_t[\mathrm{MS}_{i,t+j}]$ profile. For each subsample, note the clearly defined differences between a 10-year bond's current market share and its average expected future market share to maturity, especially over the first year after initial issuance.

Table 4 presents estimates of the following regressions for weekly data in both of our subsamples for 10-year sector issues with at least one year still remaining until maturity:

$$Y^{\mathrm{d}}_{it} = \phi_0 + \gamma_1 \mathrm{OTRD}^{\mathrm{o}}_{it} + \phi_1 \mathrm{MS}^{\mathrm{o}}_{it} + \phi_2 \overline{\mathrm{MS}}_{i,t,t+m_{it}} + v_{it}, \tag{4}$$

$$Y^{\mathrm{d}}_{it} = \phi_0 + \gamma_2 \mathrm{PreBD}^{\mathrm{o}}_{it} + \gamma_3 \mathrm{BD}^{\mathrm{o}}_{it} + \phi_1 \mathrm{MS}^{\mathrm{o}}_{it} + \phi_2 \overline{\mathrm{MS}}_{i,t,t+m_{it}} + v_{it}, \tag{5}$$

$$Y^{\mathrm{d}}_{it} = \phi_0 + \phi_1 \mathrm{MS}^{\mathrm{o}}_{it} + \phi_2 \overline{\mathrm{MS}}_{i,t,t+m_{it}} + v_{it}, \tag{6}$$

where Y^{d}_{it} is the weekly average of daily differences between the actual and theoretical yields to maturity of bond i during week t; $\overline{\mathrm{MS}}_{i,t,t+m_{it}}$ is defined as above; $\mathrm{MS}^{\mathrm{o}}_{it}$ is an

Table 4
Liquidity value impacts of current 10-year bond market share (MS^{o}_{it}) and expected average future market share ($\overline{MS}_{i,t,t+m_{it}}$) with and without on-the-run auction status ($OTRD^{o}_{it}$), pre-benchmark status ($PreBD^{o}_{it}$) and benchmark status (BD^{o}_{it}) dummy variables

	Sample period: 1993–1997			Sample period: 1998–2002		
	Coefficients	*t*-Statistics	Adjusted R^2 (%)	Coefficients	*t*-Statistics	Adjusted R^2 (%)
Constant	3.08	(15.90)	20.43	3.12	(30.29)	24.94
$OTRD_{it}$	−6.77	(−12.33)		−0.18	(−0.50)	
MS_{it}	0.00	(−0.10)		−0.06	(−7.22)	
$\overline{MS}_{i,t,t+m_{it}}$	−1.86	(−12.24)		−2.30	(−25.87)	
Constant	3.08	(16.45)	18.76	3.12	(30.36)	25.42
$PreBD_{it}$	−8.39	(−9.66)		−1.79	(−2.50)	
BD_{it}	−5.81	(−7.60)		0.87	(1.69)	
MS_{it}	0.00	(−0.09)		−0.06	(−6.81)	
$\overline{MS}_{i,t,t+m_{it}}$	−1.86	(−12.22)		−2.30	(−26.21)	
Constant	3.08	(13.89)	9.71	3.12	(30.28)	24.96
MS_{it}	0.00	(−0.09)		−0.06	(−7.17)	
$\overline{MS}_{i,t,t+m_{it}}$	−1.86	(−11.01)		−2.30	(−25.80)	

OLS regressions of the week *t* average difference between the actual and Nelson–Siegel theoretical yields to maturity for bond *i* (Y^{d}_{it}) on the various defined variables for two sample periods: 1993–1997 and 1998–2002. The regression equations are

$$Y^{d}_{it} = \phi_0 + \gamma_1 OTRD^{o}_{it} + \phi_1 MS^{o}_{it} + \phi_2 \overline{MS}_{i,t,t+m_{it}} + v_{it}, \tag{4}$$

$$Y^{d}_{it} = \phi_0 + \gamma_2 PreBD^{o}_{it} + \gamma_3 BD^{o}_{it} + \phi_1 MS^{o}_{it} + \phi_2 \overline{MS}_{i,t,t+m_{it}} + v_{it}, \tag{5}$$

$$Y^{d}_{it} = \phi_0 + \phi_1 MS^{o}_{it} + \phi_2 \overline{MS}_{i,t,t+m_{it}} + v_{it}. \tag{6}$$

Newey–West adjusted *t*-statistics are in parentheses and ° superscript indicates an orthogonalized variable.

orthogonalized version of MS_{it};[19] $OTRD^{o}_{it}$ is an orthogonalized version of a dummy variable set equal to 1.0 if bond *i* is the current on-the-run issue and zero otherwise; $PreBD^{o}_{it}$, is an orthogonalized version of dummy variable set equal to 1.0 if bond *i* is currently in its pre-benchmark stage and zero otherwise; and BD^{o}_{it} is an orthogonalized version of dummy variable set equal to 1.0 if bond *i* is currently in its benchmark stage and zero otherwise.[20] These regressions explicitly distinguish between the contributions of the current versus expected future market share variables for relative bond value and permit tests of the marginal contributions of these market share variables to both 2-stage and 3-stage auction status dummy variables. Orthogonalized variables are used to control for the correlation among the candidate explanatory

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[19] Thus, MS^{o}_{it} in (4) through (6) is the residual ε_{it} from the regression $MS_{it} = a_0 + a_1 + \overline{MS}_{i,t,t+m_{it}} + \varepsilon_{it}$.

[20] The $OTRD^{0}_{it}$ variable is the residual $\varepsilon_{OTRD_{it}}$ from the regression $OTRD_{it} = b_1 + b_2 MS_{it} + b_3 \overline{MS}_{i,t,t+m_{it}} + \varepsilon_{OTRD_{it}}$; and the other two orthogonalized dummy variables are defined in analogous fashion.

variables. We expect the signs of ϕ_1 and ϕ_2 to be negative: the larger a bond's market share, the higher its liquidity, and so the lower its yield.

Table 4 reports estimates of regressions (4) through (6) for original issue 10-year bonds. Here, incorporating the full explicit life cycle function adds significant explanatory power to the bond status dummies for most cases. Our results also reveal that *expected future* liquidity is much more important – in both magnitude and statistical significance – than *current* liquidity for explaining Spanish Treasury bond values. These patterns are most easily seen in regression (6), where only the market share variables appear. The explanatory power of Eq. (6) is quite high even though it excludes both forms of status dummy variables. However, note that in regressions (4) and (5), the new market share variables do not completely eliminate the contribution of the status dummy variables to overall explanatory power. Nevertheless, the contributions of the dummy variables are inconsistent across subsamples in sign and/or significance. In contrast, the key $\overline{\mathrm{MS}}_{i,t,t+m_{it}}$ variable's coefficient estimates are always properly signed and highly significant.[21]

4.2. Impacts of other bond-specific characteristics

As discussed in Section 2, a key component of the Spanish Treasury's preparations for European Monetary Union was a series of exchange auctions designed to help quickly build large-sized benchmark issues. These exchange auctions replaced seasoned premium, high-coupon issues with new market-coupon bonds. Targeting premium, high-coupon issues as candidates for these exchanges would have been a sensible choice if such bonds traded cheaply in the market because of tax or other reasons. Here we investigate whether discounts and premiums from par had discernable impacts on Spanish Treasury bond pricing. We use $D_{it} = \mathrm{Max}(0, 100 - V_{it})$ and $P_{it} = \mathrm{Max}(0, V_{it} - 100)$ to measure bond discounts and premiums, respectively, where V_{it} is the "clean" price of the ith bond. We also use C^{o}_{it}, an orthogonalized measure of the coupon rate (CR_{it}) of the ith bond, to pick up any coupon-related

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[21] For original issue 5-year bonds (results not shown here for space reasons), the explanatory power of Eq. (6) is reasonably high even though it excludes both forms of status dummy variables. Again, expected future market share has a significantly more powerful impact on liquidity value than does current market share. In fact, in the first subsample, the current market share variable is wrongly signed and not significantly different from zero. Again, the results for regressions (4) and (5) suggest that the new market share variables do not completely eliminate the contribution of the status dummy variables to overall explanatory power. For original issue 3-year bonds (not shown here), term structure deviations are harder to explain using our set of liquidity proxies. At least for the 1993–1997, the impact of $\overline{\mathrm{MS}}_{i,t,t+m_{it}}$ is properly signed and highly significant. (However, the coefficient for current market share is perversely signed and significant.) The results for the 1998–2002 subsample are disappointing since the overall explanatory power is low and the coefficient on $\overline{\mathrm{MS}}_{i,t,t+m_{it}}$ in all three specifications is wrongly signed, though not statistically different from zero. The puzzles for the 3-year sector are not confined to the market share variables. The traditional status dummy approach also leads to wrongly signed and insignificant coefficients in the 1998–2002 subsample.

Table 5
Value impacts of bond characteristics on 10-year bonds: price discount versus par (D_{it}); price premium versus par (P_{it}); coupon rate (C^{o}_{it}); and strippable issue dummy variable (S^{o}_{it})

	Sample period: 1993–1997			Sample period: 1998–2002		
	Coefficients	*t*-Statistics	Adjusted R^2 (%)	Coefficients	*t*-Statistics	Adjusted R^2 (%)
Constant	3.28	(10.77)	34.24	1.71	(12.79)	31.02
OTRD$_{it}$	−6.30	(−11.97)		−0.36	(−0.85)	
MS$_{it}$	−0.01	(−0.38)		−0.02	(−2.45)	
$\overline{\text{MS}}_{i,t,t+m_{it}}$	−0.99	(−4.68)		−1.52	(−19.02)	
Coupon$_i$ (C^{o}_{it})	1.04	(9.80)		0.18	(2.47)	
Discount$_{it}$ (D_{it})	−0.29	(−12.37)		−0.27	(−11.61)	
Premium$_{it}$ (P_{it})	−0.05	(−3.90)		0.08	(10.66)	
Strippable$_{it}$(S^{o}_{it})				−0.04	(−0.19)	
Constant	3.47	(10.57)	29.59	1.68	(12.72)	31.26
PreBD$_{it}$	−6.30	(−6.52)		−2.17	(−3.17)	
BD$_{it}$	−3.47	(−4.84)		−0.82	(−1.69)	
MS$_{it}$	0.00	(−0.13)		−0.02	(−2.41)	
$\overline{\text{MS}}_{i,t,t+m_{it}}$	−1.14	(−5.35)		−1.50	(−19.18)	
Coupon$_i$ (C^{o}_{it})	0.88	(9.20)		0.22	(3.04)	
Discount$_{it}$ (D_{it})	−0.29	(−9.09)		−0.26	(−11.43)	
Premium$_{it}$ (P_{it})	−0.05	(−3.85)		0.08	(10.59)	
Strippable$_{it}$ (S^{o}_{it})				0.01	(0.02)	
Constant	3.89	(11.79)	25.68	1.73	(13.69)	31.03
MS$_{it}$	0.00	(0.24)		−0.02	(−2.50)	
$\overline{\text{MS}}_{i,t,t+m_{it}}$	−1.18	(−5.63)		−1.53	(−19.77)	
Coupon$_i$ (C^{o}_{it})	0.84	(8.79)		0.17	(2.51)	
Discount$_{it}$ (D_{it})	−0.37	(−12.36)		−0.27	(−12.88)	
Premium$_{it}$ (P_{it})	−0.07	(−5.72)		0.08	(10.70)	
Strippable$_{it}$ (S^{o}_{it})				−0.02	(−0.10)	

OLS regressions of the week t average difference between the actual and Nelson–Siegel theoretical yields to maturity for bond i (Y^{d}_{it}) on the various defined variables for two sample periods: 1993–1997 and 1998–2002. The regression equations are

$$Y^{\text{d}}_{it} = \phi_0 + \gamma_1 \text{OTRD}^{\text{o}}_{it} + \phi_1 \text{MS}^{\text{o}}_{it} + \phi_2 \overline{\text{MS}}_{i,t,t+m_{it}} + \psi_1 C^{\text{o}}_{it} + \psi_2 D_{it} + \psi_3 P_{it} + \psi_4 S^{\text{o}}_{it} + v_{it},$$

$$Y^{\text{d}}_{it} = \phi_0 + \gamma_2 \text{PreBD}^{\text{o}}_{it} + \gamma_3 \text{BD}^{\text{o}}_{it} + \phi_1 \text{MS}^{\text{o}}_{it} + \phi_2 \overline{\text{MS}}_{i,t,t+m_{it}} + \psi_1 C^{\text{o}}_{it} + \psi_2 D_{it} + \psi_3 P_{it} + \psi_4 S^{\text{o}}_{it} + v_{it},$$

$$Y^{\text{d}}_{it} = \phi_0 + \phi_1 \text{MS}^{\text{o}}_{it} + \phi_2 \overline{\text{MS}}_{i,t,t+m_{it}} + \psi_1 C^{\text{o}}_{it} + \psi_2 D_{it} + \psi_3 P_{it} + \psi_4 S^{\text{o}}_{it} + v_{it}.$$

Newey–West adjusted t-statistics are in parentheses. The $^{\text{o}}$ superscript indicates an orthogonalized variable. (See notes to Table 4 for additional variable definitions.)

effects not captured by D_{it} and P_{it}.[22] Finally, the introduction of the Spanish strips market in January 1998 may have caused strippable bonds to trade at higher values than non-strippable issues. To investigate whether strip-related effects on value exist, we define the dummy variable S_{it} equal to +1 if the ith bond is strip market eligible

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[22] Thus, C^{o}_{it} is the residual $\varepsilon_{C_{it}}$ from the regression $CR_{it} = c_0 + c_1 D_{it} + c_2 P_{it} + \varepsilon_{C_{it}}$.

and zero otherwise. We include S^{o}_{it}, an orthogonalized measure of the strip eligibility dummy variable for the *i*th bond, in the 1998–2002 sample period regressions.[23]

Table 5 reports estimates of the following regressions for 10-year sector bonds in each of our subsamples:

$$Y^{\mathrm{d}}_{it} = \phi_0 + \gamma_1 \mathrm{OTRD}^{\mathrm{o}}_{it} + \phi_1 \mathrm{MS}^{\mathrm{o}}_{it} + \phi_2 \overline{\mathrm{MS}}_{i,t,t+m_{it}} + \psi_1 C^{\mathrm{o}}_{it} + \psi_2 D_{it} + \psi_3 P_{it} + \psi_4 S^{\mathrm{o}}_{it} + v_{it}, \tag{7}$$

$$Y^{\mathrm{d}}_{it} = \phi_0 + \gamma_2 \mathrm{PreBD}^{\mathrm{o}}_{it} + \gamma_3 \mathrm{BD}^{\mathrm{o}}_{it} + \phi_1 \mathrm{MS}^{\mathrm{o}}_{it} + \phi_2 \overline{\mathrm{MS}}_{i,t,t+m_{it}} + \psi_1 C^{\mathrm{o}}_{it} + \psi_2 D_{it} + \psi_3 P_{it} + \psi_4 S^{\mathrm{o}}_{it} + v_{it}, \tag{8}$$

$$Y^{\mathrm{d}}_{it} = \phi_0 + \phi_1 \mathrm{MS}^{\mathrm{o}}_{it} + \phi_2 \overline{\mathrm{MS}}_{i,t,t+m_{it}} + \psi_1 C^{\mathrm{o}}_{it} + \psi_2 D_{it} + \psi_3 P_{it} + \psi_4 S^{\mathrm{o}}_{it} + v_{it}. \tag{9}$$

Generally, the results point to statistically significant differences in the valuation of discount versus premium bonds. Note especially the results for the 1993–1997 sample period that reflect the recent experience observed by the Spanish Treasury at the time of its exchange auction decision-making. The D_{it} variable is highly significant and indicates that investors favored bonds priced below par. Surprisingly, the coefficient for P_{it} is negative and significantly different from zero; but it is small in magnitude (about one-sixth the size of the coefficient on D_{it}). The coefficient on C^{o}_{it} is positive and highly significant, indicating an additional pricing bias against high-coupon bonds. These results confirm that discount bonds were favored over high-coupon, premium bonds.[24] Thus, the estimates lend support to the Spanish Treasury's decision to target high-coupon, premium bonds in its debt exchanges. Moreover, some changes in the magnitude, sign and significance of the D_{it}, P_{it} and C^{o}_{it} variables from the 1993–1997 sample to the 1998–2002 sample are quite interesting. For the 10-year bonds, both the magnitude and significance of the C^{o}_{it} fall precipitously, and the impact of P_{it}, while turning positive, remains small in magnitude.[25] These patterns may indicate that market impacts of such bond-specific characteristics on value in the Spanish market have decreased since European Monetary Union ushered in a broader class of euro-based fixed income investors.[26]

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[23] Thus, S^{o}_{it} is the residual $\varepsilon_{S_{it}}$ from the regression $S_{it} = d_0 + d_1 D_{it} + d_2 P_{it} + \varepsilon_{S_{it}}$.

[24] The results for the 5-year bond sector for this same 1993–1997 sample period reveal investor biases favoring discount bonds over high-coupon, premium bonds. Here, the estimated coefficients on the D_{it} and C^{o}_{it} variables are each statistically significant. The P_{it} variable is statistically insignificant. In the 1993–1997 sample, the results for the 3-year bond sector show that investors favored discount bonds (i.e., a statistically significant negative impact for D_{it} on bond yields) versus high-coupon, premium bonds (both C^{o}_{it} and P_{it} have statistically significant positive slope coefficients).

[25] For the 5-year bonds, the coefficients on the D_{it}, and C^{o}_{it} variables switch signs and lose some significance. For 3-year bonds, the D_{it} variable's effect switches sign. Finally, for 3-year bonds, the estimated coefficient on S^{o}_{it} is both negatively signed and statistically significant, indicating a value premium for the strip feature. Evidence on the impact of the strip feature in the other sectors is mixed. The S^{o}_{it} variable is marginally significant for 5-year bonds and statistically insignificant for 10-year bonds.

[26] Recall from Section 2 that bond trades for non-residents and institutional investors have been settled free of withholding tax for since 1999.

4.3. The impact of EMU on Spanish bond market volatility

Table 6 presents an expanded analysis of European Monetary Union's effects on Spanish bond market pricing along two distinct dimensions regarding market volatility. We first quantify the impact of European Monetary Union on Spanish bond market yield volatility. Clearly, one major projected benefit for Spain under EMU was to be a dampening of market yield volatility in light of the elimination of currency crisis risk from bond pricing. Our sample of daily fitted term structures provides a particularly clean way in which to measure the volatility impact of EMU at different points along the zero coupon yield curve. Specifically, we create a daily time series of fitted zero coupon bond yields for annual maturities between 2 and 10 years. We then compute subsample means and standard deviations of these yield series and test for equality of yield variances across the two subsamples. While European Monetary Union actually officially began on January 1, 1999, market participants are widely viewed to have priced this merger as a *fait accomplie* before this date. We have kept the same two sample splits used before, interpreting that the market had fully priced in Spain's entry into EMU 1 year ahead of schedule.[27]

Panel A of Table 6 presents our yield volatility results based upon daily data for the 1993–1997 and 1998–2002 sample periods. The columns report estimated sample means and standard deviations of both yield levels (expressed in percentage points) and first-differences in yields. A profound downward shift in average yield levels and standard deviations across the zero coupon yield curve can be observed in the latter periods. Formal tests based upon the first-differenced data confirm that the hypothesis of equal variances in the 1993–1997 and 1998–2002 periods is easily rejected for all terms to maturity.[28] For example, the standard deviation of yield first-differences for 5-year zero coupon bonds nearly halved. Clearly, as was anticipated by the plan's early proponents, European Monetary Union has led to a dramatic fall in Spanish bond market yield volatility.

Our second volatility investigation examines whether European Monetary Union has led to more efficient relative pricing. We gauge relative pricing efficiency through the residual variance of the Spanish bond yield regression equation (8). In particular, we examine the residuals from the estimated Y_{it}^{d} regressions (8) of Table 5 and test for equality of residual variances across the two subsamples. The null hypothesis is that the residual variances from the Y_{it}^{d} regressions (8) in the 1993–1997 and 1998–2002 subsamples are equal. We interpret this null hypothesis to mean that European Mon-

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[27] On March 25, 1998, the European Commission had recommended that 11 countries – Austria, Belgium, Finland, France, Germany, Ireland, Italy, Luxembourg, the Netherlands, Portugal and Spain – met the necessary conditions to adopt the single currency. On May 2, 1998, EU finance ministers officially announced the bilateral parities between the currencies of the euro zone. Of course, reasonable arguments exist for dating the sample split even before the start of 1998. The convergence of forward deposit interest rates between Spain and Germany was nearly complete by mid-1997.

[28] Identical inferences come from other versions of tests for equality of variances in two samples (e.g., the standard F-test, Bartlett's test, Siegel–Tukey's test and Levene's test).

Table 6
Impacts of European Monetary Union on Spanish Treasury market yield volatility and bond relative pricing efficiency

Sample means and standard deviations for *levels* of fitted zero coupon yields (in %)					Tests of equality of variances in the two sample periods for first-differences of daily fitted zero coupon yields				
Term	First sample period: 1993–1997		Second sample period: 1998–2002		First sample period: 1993–1997		Second sample period: 1998–2002		Test for equality of variances Brown–Forsythe prob > F
	Mean	Standard deviation	Mean	Standard deviation	Mean × 10^2	Standard deviation	Mean × 10^2	Standard deviation	
Panel A									
2	7.72	2.68	4.03	0.68	−0.74	0.0859	−0.14	0.0500	0.000
3	7.90	2.69	4.24	0.64	−0.70	0.0819	−0.13	0.0424	0.000
4	8.09	2.67	4.43	0.60	−0.67	0.0807	−0.13	0.0437	0.000
5	8.26	2.63	4.60	0.57	−0.64	0.0816	−0.13	0.0444	0.000
6	8.39	2.59	4.75	0.53	−0.61	0.0811	−0.13	0.0440	0.000
7	8.50	2.54	4.88	0.50	−0.58	0.0787	−0.13	0.0430	0.000
8	8.59	2.49	4.99	0.48	−0.56	0.0760	−0.14	0.0421	0.000
9	8.66	2.45	5.09	0.45	−0.55	0.0755	−0.14	0.0422	0.000
10	8.72	2.40	5.17	0.44	−0.53	0.0797	−0.14	0.0437	0.000

Sample means[a] and standard deviations for *residuals*from Y^{d}_{lt} regression estimates of Eq. (8) of Table 5					Tests of equality of variances in the two sample periods for *residuals* from Y^{d}_{it} regression estimates of Eq. (8) of Table 5
Original issue maturity sector (years)	First sample period: 1993–1997		Second sample period: 1998–2002		Brown–Forsythe prob > F
	Mean × 10^2	Standard deviation	Mean × 10^2	Standard deviation	
Panel B					
10	0.000	0.035	0.000	0.031	0.000
5	0.000	0.060	0.000	0.034	0.000
3	0.000	0.072	0.000	0.034	0.000

[a] Regression residual sample means equal 0 by construction.

etary Union had no detectable impact on the dispersion of term structure arbitrage trading opportunities in the Spanish market. For each of the three original issue maturity sectors, Panel B of Table 6 presents tests of equality of residual variances from the Y_{it}^{d} regressions (8) in the 1993–1997 and 1998–2002 subsamples. The valuation equation residuals have lower estimated standard deviations in the latter period. The test statistics have *p*-values that indicate strong rejections of the null hypothesis of equal residual variances. We interpret these results as evidence that the new class of euro-based investors created under European Monetary Union has significantly increased pricing efficiency in the Spanish bond market.[29]

5. Summary and conclusions

This paper has examined liquidity and volatility in the Spanish Treasury bond market in the context of debt policy shifts engineered by the Spanish government in preparation for entrance into European Monetary Union. Empirically detectable impacts of Spain's mid-1997 debt management initiatives exist for both trading activity and debt market valuation. We interpret these impacts through shifts in the coefficients of a liquidity life cycle model relating individual Treasury bond market share to a bond's age (the time since its initial auction). Test for shifts in this market share function as a result of the Treasury's debt policy innovations clearly reject the hypothesis of no structural change in the post-initiatives sample period.

We also estimate the structure of liquidity premiums in the different maturity sectors within the Spanish bond market. We investigate liquidity effects within a framework that values the lifetime flow of liquidity services and distinguishes between a security's *current* liquidity and its average expected *future* liquidity. Our empirical results for 10- and 5-year Spanish Treasury bond sectors reveal statistically significant valuation impacts of expected future liquidity on current market value. Our expected future liquidity measure adds significant explanatory power to the traditional auction status dummy variable approach to assessing bond liquidity value.

Our results for data from 1993 to 1997 detect statistically significant pricing biases confirming that discount bonds were favored over high coupon, premium bonds. These results lend support to the Spanish Treasury's tactical decision to target high-coupon, premium bonds in its pre-EMU debt exchanges.

Finally, we examine the impacts of European Monetary Union on volatility of yields in the Spanish Treasury market. First, we use our basic fitted term structures to show that the standard deviation of zero coupon bond yields declined dramatically after the market began pricing European Monetary Union as certain to occur. Formal tests based on the first-differences of yields strongly reject the null hypothesis of no change in variance from the pre-EMU period. Such an impact on volatility is

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[29] Changes in the Spanish tax regime beginning in 1999 (e.g., newly-issued Treasuries began trading free of withholding tax for domestic institutions) may also have helped increase pricing efficiency.

generally acknowledged (and had been forecasted by EMU's early supporters). It is less widely recognized that European Monetary Union has also led to more efficient *relative* pricing in the Spanish Treasury bond market. Our results reveal that the residual variance of our liquidity and bond characteristic-augmented yield regressions fell sharply between our pre-EMU and post-EMU samples. Such improved pricing efficiency may be attributed to an important byproduct of European Monetary Union: the creation of a much larger universe of euro-based fixed income investors willing to focus attention on trading opportunities in Spain.

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