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PRICE DISCOVERY IN THE ITALIAN SOVEREIGN BONDS MARKET: THE ROLE OF ORDER FLOW

by Alessandro Girardi [(a)] and Claudio Impenna [(b)]

Abstract

This paper analyses the price discovery process and the informational role of trading in the Italian wholesale secondary markets for Treasury bonds: the B2B MTS cash and the B2C BondVision trading venues. Using daily data for a representative set of fixed rate government bonds over the period January 2007 - February 2012, we find that the B2C dealer-to-customer market contributes to the process of price formation to a greater extent than the B2B interdealer platform. The informational role of trading is found to be considerable: order flow is a key variable in the process of price formation and appears to continuously act on a cross market basis. Moreover, the explanatory role of order flow turns out to be stronger when liquidity conditions are poorer.

JEL Classification: G1, G2.
Keywords: bonds markets, price discovery, order flow, market microstructure, financial crisis.

Contents

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1. Introduction[1]

The literature on the microstructure of financial markets commonly explains the timely incorporation of information into market prices, the so-called process of price discovery, through the informational role of trading. Typically, trading activity is measured as the market share of nominal trades or number of contracts. As pointed out in Chordia et al. (2002), however, a reported nominal trading volume might be entirely due to a sell, a buy or a split between sell and buy orders, with each possibility having its own implications for market makers' order imbalances.

The order flow (the imbalance between buy- and sell-initiated trades) plays a fundamental role in price discovery, which is consistent with the common theories concerning information asymmetries in financial markets, as high order imbalances can signal private information being conveyed into the market. In turn, market makers can react by increasing bid-ask spreads and also by inducing large changes in price, as they struggle to minimize inventory risk. A number of empirical works broadly support this view and document that the information held by informed traders are incorporated in asset prices through order flow (Cohen and Shin, 2002; Green, 2004; Cheung et al., 2005; Chordia et al., 2008; Subrahmanyam, 2009).

Price discovery issues have been tackled mainly with regard to stock markets, where potential informational asymmetries about the true value of a share are most sensitive. Chordia et al. (2005) find positive order flow effects on stock market returns after controlling for aggregate trading volume and liquidity, while the response of stock prices to inventory stock adjustment can be differentiated according to trader size (Chordia et al., 2002) or

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strategies (Boehmer and Wu, 2008). Investigations of other financial segments - the FX and, especially, bonds markets - have so far been scarcer.[2] A special case is represented by sovereign bond markets. Although they represent one of the largest financial markets, the empirical microstructure analysis of electronic platforms for government securities has developed only in the last decade.

In the present phase, further analytical efforts in the sovereign bond markets area are encouraged by the ongoing financial crisis and its effects on market functioning. The crisis raises issues of concern for regulators, central banks in the first place, as these markets a) are crucially important from a financial stability perspective; b) play a unique role in the monetary policy transmission mechanism, through yield curve level and slope shifts; c) negotiate the assets most adopted as collateral *vis-à-vis* liquidity provision operations; and d) influence the evaluation of banks' assets and, in turn, are influenced by regulatory capital requirements.

This paper analyses the two wholesale Italian cash markets: the interdealer business-to-business (B2B) trading venue, MTS cash, and the business-to-customer (B2C) BondVision market. They represent an interesting and under-researched case of 'parallel markets', i.e. market places where the same assets are negotiated at the same time. We use a detailed and extended daily data set for a representative bucket of fixed rate medium and long-term sovereign bonds of various maturities. This allows us to make comparisons among the pre-crisis phase and the stages of the crisis along different segments of the yield curve.

Our empirical investigation innovates with respect to the existing literature on the microstructure of government bond markets in a number of respects: first, we extract time-

[2] Market microstructure factors behind exchange rate dynamics have been studied, among others, by Evans and Lyons (2002), Berger et al. (2008) and Cao et al. (2003), trying to separate permanent and transitory inventory effects.

varying measures of price discovery in two parallel cash markets; second; we analyse these measures in relation to some microstructure variables of both trading venues; third, we test whether and to what extent such relationships have changed at different stages of the crisis.

To this aim we tie together different strands of empirical research. Our work is naturally related to the studies that have examined the relationship between order flow, bonds prices and market liquidity. The vast majority of these analyses has focused so far on the US interdealer market. As a common element, these contributions share the comparison of order flow effects on Treasuries price adjustments and liquidity in normal, orderly trading conditions with those prevailing in a high volatility, low duration, and very uncertain environment. Green (2004) and Fleming and Remolona (1999) verify the influence of order flow and trading, respectively, around macroeconomic announcements, while Pasquariello and Vega (2009) generalize this analysis encompassing the effects of different beliefs among informed traders. Cohen and Shin (2002) and Brandt and Kavajecz (2004) select high volatility, non-announcement days to verify the relationship between order flow, liquidity and returns. Furfine and Remolona (2005) apply the VAR set-up developed by Hasbrouck (1991) for stock markets analysis to the Treasury market, whereas Mizrach and Neely (2006) and Brandt et al. (2007) examine the interaction of cash and future Treasury markets in bond price discovery. A limited set of papers focus on the European bond markets and, with few exceptions (Cheung et al., 2005; Paiardini, 2009, 2010; Valseth, 2011), they contribute mainly to institutional topics, like transparency (Balogh and Koczan, 2009; Persaud, 2006). In this respect the present paper fills a gap in the existing empirical literature.

Our analysis is also connected to the body of research which has investigated the functional interplay between B2B and B2C platforms in institutional investors' intermediation and dealers' inventory management, as discussed, among others, by Dunne et al. (2006) and (2010), and Green (2004). Generally, they stress dealers' inventory adjustment strategies –

and related risks – as the key variable in understanding the relationship between the two markets. In particular, Dunne et al. (2006) point out that dealers, which are active in both markets, typically get involved in a two-round trading process. In the first round dealers face a prevailing number of buy-side customer requests for a quote in the B2C venue (as we will show in Section 2 below). In this phase, they often benefit from their market power vis-à-vis clients. The second round takes place in the B2B market, where the dealer which 'won' the first round aims to adjust the new inventory position by trading with other dealers. But this strategy can be both difficult and costly, since the 'losers' react by changing their limit or market orders, precisely with the aim "to pre-empt the predictable action of the first round winner" (Dunne et al., 2006, p. 37). Our analysis represents the first attempt to empirically investigate such a topic.

Finally, the present work aims to contribute to the growing literature on the effects of the financial turmoil on fiscal developments for peripheral countries of the Eurozone. While a number of studies (Blommestein, 2009; Di Cesare et al., 2012, among others) have analysed the impact of the main crisis events on the relationship between fiscal stance and secondary market yields in the Eurozone, this paper adopts a purely market microstructure perspective: We empirically address price discovery issues in the Italian secondary cash market for sovereign securities across different stages of the crisis.[3]

Using daily data for 32 bonds with maturity at issuance ranging from 3 to 30 years over the period January 2007 - February 2012, we obtain the following results: a) although the B2B interdealer MTS cash market is predominant in terms of trading, over the whole sample price discovery is explained to a substantial extent by the B2C dealer-to-customer

[3] The Italian market is by far the largest in Europe and one of the most important worldwide, due to the high volume of public debt: at the end of 2011, general government outstanding debt amounted to €1,898 billion, of which three quarters in medium and long-term fixed rate bonds (Bank of Italy, 2012).

BondVision market. This finding can be attributed to some microstructure factors of the latter venue (primarily higher trading frequency), as well as to the greater attractiveness of its Request for Quote (RFQ) trading model during the crisis; b) the informational role of trading in the price discovery process is remarkable: together with liquidity, order flow is a key variable in price formation, and appears to continuously act on a cross market basis. More in detail, imbalances in the B2C market influence price discovery in the B2B market both before and after major turmoil events. Order flow in B2B trades is significant only after crisis events; c) the explanatory role of order flow is stronger when liquidity conditions are poorer, in line with previous empirical findings (Brandt and Kavajecz, 2004; Green, 2004).

The rest of the paper is organized as follows. Section 2 presents the main institutional features of the cash markets and the structure of the dataset. Some stylized facts on market characteristics during the ongoing financial crisis as well as according to the life-cycle of securities are also discussed. Section 3 illustrates the methodological framework we apply to estimate time-varying price discovery measures in both markets. The estimated results of each market contribution to price discovery are presented in Section 4, while Section 5 explores the links between those measures and selected microstructure determinants. Section 6 concludes.

2. Exchanges and data

2.1. MTS cash and BondVision

The MTS (screen-based secondary market in government securities) system is composed of several MTS cash markets at the national level and a centralized European market (EuroMTS), and is dedicated to trading government bonds. In Italy the MTS set-up comprises two broad components: the cash or spot markets (MTS and BondVision) and the repo markets (General Collateral and Special Repo). These markets are overseen - with

different institutional objectives - by the Ministry of the Economy and Finance, the Bank of Italy and the Italian Companies and Stock Exchange Commission (CONSOB).

The MTS cash market was introduced in Italy in 1988. It is the interdealer wholesale cash trading venue under consideration in this present paper. Only banks and financial investment firms are allowed to trade in MTS cash, apart from State Treasury Ministries and Central Banks; they buy and sell bonds on own account and on behalf of professional customers. Participants in MTS cash are divided into two categories: market makers and ordinary dealers. The former bear several market making obligations in the market and are committed to quoting at least an assigned number of bonds. Minimum trade sizes equal to € 0.5 million, whereas the minimum quoted volume is € 2.5 million. Market makers' performance is also assessed by the MTS Company on the basis of limited quoted bid-ask spreads and adequate daily quoting durations.[4] Quotes can be modified, cancelled, or hit by orders. A trade automatically takes place when a market participant accepts a market maker's proposal. Simple dealers can only accept or refuse proposals and do not share any obligation in the market. In view of the public debt management needs, the Ministry of the Economy and Finance selects a subset of specialists (primary dealers) among market makers, which have to be compliant with more stringent requirements. They are compensated for their greater responsibilities and duties in the secondary market by some forms of preferential treatment, e.g. in the primary market (by syndication leading) or in buy-back operations. In 2011, 66

[4] According to the MTS Cash Regulation, market makers are committed "to continuously input quotes during the trading hours, … for the purchase and sale of financial instruments allocated to each market maker". Each bond is allocated "to a number of market makers adequate to guarantee actual competition. Each market maker is assigned 31 financial instruments, among which four index linked BTPs, so that each market maker shall quote a basket representing the full yield curve and balanced in terms of liquidity. Each financial instrument is allocated to at least three market makers". They can also make quotes on bonds not assigned to them. Finally, bonds issued in the relevant month are considered as allocated to all market makers.

traders were active in MTS cash (95 in 2008), 28 of which are primary dealers. Among this set, 20 intermediaries were appointed as specialists, of which 17 are large foreign banks acceding to the market on a remote basis.[5]

MTS cash provides participants with real time information on quotes, prices, trade volumes and order flow on single bonds. An important element is anonymity of transactions, as each trader does not know its counterparty until the settlement phase. Since 2003 participants can benefit from a central counterparty (CCP) service which, though supplied on an optional basis, is now used in nearly all the transactions. By interposing itself between single buy and sell negotiations, the CCP eliminates the counterparty risk for participants, and also makes it possible to keep exchanges anonymous in the settlement phase. In MTS cash, trading hours are from 8.30 a.m. to 5.30 p.m.

BondVision was launched in 2001 as a multi-dealer-to-customer electronic market for Italian and other European public bonds, supranationals, agencies and covered bonds. Market makers in MTS cash trade in BondVision with customers (*end-users*), essentially investment firms, insurance companies, hedge and open-end funds. While in MTS cash participants close a trade by hitting bid or ask proposals, in BondVision end-users send a sell or buy Request for Quote (RFQ) to market makers. If they are willing to trade, end-users start an auction for the chosen security, which can involve up to 5 dealers; end-users are not obliged to accept an offer. BondVision is a wholesale market: minimum trading size is €0.5 million, like MTS cash. The minimum RFQ size is €0.5 million, too. Closing time is at 6 p.m., 30 minutes after MTS cash. In 2011, around 360 traders actively traded in Italian bonds on the BondVision trading platform.

[5] The sharp reduction in active traders is due to the greater attractiveness of BondVision during the crisis, in view of the RFQ functioning model (as discussed in Sections 2.3 and 5.2), but also to cases of consolidation among major international banks in that period.

Some market features are worth mentioning from a price discovery perspective. When dealers send a quote proposal to an RFQ, they know how many other dealers (to a maximum of 4) are participating in the same auction, but they know neither their identities, nor their proposed quotes. After a dealer 'wins' an auction, they know the differential between its prevailing quote and the first rejected proposal in the rank, a sort of indication of their efficiency/aggressiveness in book management. Finally, unlike MTS cash, BondVision is not an anonymous market: both end-users and dealers have known the counterparty since the pre-trade phase; moreover, in BondVision there is no role for CCP interposition, since its regulation does not envisage a particular settlement mode.

During 2011 the joint share of the two markets ranged between 40 and 60 per cent of the whole secondary trading in Italian government securities; MTS cash accounted for around 70 per cent of interdealer exchanges.[6] When comparing the value and number of contracts trades, classified per bond typology, in the B2B and B2C platforms several distinctive features emerge. As Table 1 shows, over the period from January 2007 to February 2012 the B2B market is largely predominant in terms of trading values, although it is less important when the number of trades is considered. In turn, this implies that negotiations take place in BondVision at a lower average value than in MTS cash. Moreover, the fixed rate BTPs (*Buoni del Tesoro Poliennali*) are by far the most important instrument for the Italian public debt. Finally, the crisis seems to have challenged the predominance of MTS cash, in a general context of decreasing trades; the reasons behind this trend will be investigated in the following sections.

[6] These figures are calculated on the basis of a periodical survey of specialists in the MTS cash market.

2.2. The dataset

Our database includes a wide set of daily time series for 32 BTPs, over a time horizon spanning from 2 January 2007 to 29 February 2012 (around 1,350 working days). The bucket of bonds includes ten BTPs with an original maturity of 3 years, nine with a 5-year maturity, eight with a 10-year maturity, three with a 15-year maturity and two BTPs with a 30-year maturity. In value terms, our sample accounted in 2011 for nearly 45 per cent of all MTS cash and BondVision negotiations in BTPs (38 per cent in terms of number of contracts). This set was selected so as to cover all maturities and to maximize the number of observations for each security. Basic identification data for individual bonds in the bucket (identification codes, issuance and maturity dates) are reported in Table 2.

The database also makes the following daily information available: the number and value of buy and sell-initiated contracts;[7] the last transaction (reference) price of the day, the daily average price weighted by trading values; the simple and weighted average bid-ask spread, and the bid and ask depth in value terms.

Figure 1 shows the logarithm of daily transaction prices determined in MTS cash and BondVision for four bonds, two 'on the run' (5 and 10 years) and two 'off the run' BTPs of the same maturities. A common time window of several months in 2010, when the public debt crisis was growing in Europe, is taken as an example. Clearly, the series overlap very closely, which indicates that the prices of the same bond recorded in parallel markets are not independent of each other. On the grounds of this evidence, in Section 3 below we investigate whether the two log-price series actually share a common factor driving their joint long-term behaviour.

[7] This information provides us with direct evidence of the order flow, without employing classification algorithms.

2.3. Some stylized facts

Some basic statistics on the trading activity recorded in MTS cash and BondVision for the selected bucket of BTPs are presented in Table 3. For each market we calculate the number of days during which at least one trade occurred (*atr*), the frequency of trading (*ftr*) computed as the ratio of the number of days when at least one exchange occurred in the market to the number of all the operational days in the period, the total nominal amount of trades (*qty*) and the total number of contracts (*cnt*).

While MTS cash turns out to be the predominant trading venue in value terms, the gap with BondVision is smaller when considering the number of contracts. The role of MTS cash is to a great extent explained by market obligations, which induce primary dealers to concentrate B2B trades in that venue, whereas the smaller market share of BondVision may reflect the fact that a significant proportion of B2C trades occurs either on an OTC basis or on concurrent electronic trading venues (like Tradeweb and the Bloomberg Bond Trader, BBT). However, anecdotal evidence would suggest that, at least for Italian government bonds, BondVision accounts for a large share of the fragmented B2C electronic RFQ trading (Dunne, 2010). An important indication emerging from Table 3 regards trading frequency, as negotiations are temporally more concentrated in MTS cash; conversely, trades occur more frequently on BondVision for all maturities over our sample span.[8] Based on the above evidence, it is hard to identify a dominant trading venue in terms of price discovery. Standard

[8] Some of the structural features of the MTS cash market, namely higher trade values and time concentration of trades, can to some extent be explained by the inventory adjustment activity carried out by large international primary dealers on more liquid bonds. Foreign traders' activity is quite strong in the Italian secondary markets. This feature is much more significant in the B2B venue, where in 2011 two thirds of all the trades in Italian bonds were closed between foreign intermediaries on both sides of the market; the corresponding figure was one quarter for BondVision. In contrast, trades closed between Italian players only were less than 5 per cent in both markets.

market microstructure literature does in fact predict that a fully efficient market will exhibit not only high trade values but also a high transaction frequency, since continuity in trading is a condition for lower price volatility and overall adequate liquidity (Caporale and Girardi, 2013).

We therefore enrich the analysis with other trading indicators: signed order flow (defined as the ratio between buy- minus sell-initiated trades over their sum) in terms of both nominal traded values and number of contracts, for MTS cash (otm and ocm, respectively) and BondVision (ocb and otb);[9] relative trading activity, i.e. the ratio of nominal traded values (and contracts) on the MTS cash market to the aggregated nominal trades (and contracts) on the two markets (trs and cns); average size of trades, i.e. the ratio between nominal traded value and number of contracts on MTS cash (avm) and BondVision (avb). We compute these variables at the different stages of the turmoil (Table 4), by issuance maturities (Table 5) and according to the status of each security in the market (Table 6).

In keeping with the calendar of the crisis adopted by the ECB (2010) we identify five phases: *pre-crisis*, ending on 8 August 2007; *beginning-of-the-crisis*, spanning from 9 August 2007 (when three money market funds suspended asset values calculation due to sub-prime overexposures) to 12 September 2008; *global crisis*, from 15 September 2008 (the day Lehman defaulted) to 2 December 2009, when the ECB announced the partial removal of unconventional liquidity measures; *phasing out*, from 3 December 2009 to 6 May 2010, when the sovereign *debt crisis* started in eurozone peripheral countries.

As for the status of the securities, a newly-issued security is classified as 'on the run' in its maturity class, while it is conventionally considered the 'benchmark' when it becomes

[9] In MTS cash a buy or sell proposal can be accepted by another participant (the 'aggressor'). For each bond, net order flow is calculated as the difference between all aggressors' purchases and sales. Since BondVision is an order-driven RFQ market, net order flow is calculated as the difference between contracts coming from end-users requests for buy and for sell quotes.

the most traded bond at that maturity for an adequate period of time. In order to simplify nomenclature we equalize the 'on the run' to benchmark status, defining the most recently issued security (*On*) as such once it has been traded more than other bonds of the same maturity for at least seven continuous working days. Differentiation between 'on the run' and (first) 'off the run' (*I Off*) and among the various 'off the run' (*I Off* vs *II Off*, and so forth) stages follows the same criterion.[10]

Joint consideration of Tables 4-6 suggests that the evolution of the crisis coincides with a sharp decline in the share of MTS cash, more markedly in terms of number of trades (Table 4), to the advantage of BondVision. Perspective end-user traders in BondVision are largely on the buy side. The B2C venue share has increased essentially on shorter maturities, while net buying imbalances affect considerably BTPs with longer maturities (Table 5) when they are most liquid, i.e. at the 'on the run' or initial 'off the run' phases (Table 6). These results suggest that institutional investors have sought to replenish their inventory on the longer segment of the yield curve. On the other hand, MTS cash still accounts for around three quarters of the market (in value terms) on longer maturities. Its trading share is higher on liquid issues, quickly declining afterwards, and net selling order flows generally prevail.[11]

Overall, the evidence is fully in line with the predictions of previous studies (e.g. Furfine and Remolona, 2005), who point out that buyer-initiated transactions are

[10] This method is consistent with the standard practice followed by the Italian Ministry of the Economy and Finance. However, adopting alternative rules (e.g. with different temporal windows) does not alter the results. It is worth mentioning that the 'on the run' bucket allows us to control for auction effects on the price discovery process. Unless it can be classified as the 'on the run' in its maturity class, a newly issued bond is not considered in the analysis.

[11] Incidentally, it is of some interest that for 3-year BTPs net selling order flows predominate in both markets (Table 5), since this helps to clarify the phenomenon of yield curve flattening, which was observed for Italian sovereign bonds in the most acute phases of the crisis.

physiological in a B2C venue and more common in relation to liquid assets. The above results are also consistent with 'two-rounds' trading process hypothesis recalled in the Introduction about the role normally played in both markets by primary dealers: they buy new Treasury bonds at auction and then gradually trade in their more liquid positions at the next auction, in accordance with the commitment to 'make market' on these securities in the B2B segment. Thus, primary dealers progressively reduce stocks of liquid issues by actively offering quotes to perspective buyers in the RFQ market.

Another indication stemming from the results discussed so far is that activity on the two trading platforms has been profoundly influenced by the evolution of the financial crisis. A proper econometric investigation is therefore required in order to capture both the existence and nature of the 'common factor' joining the two log-price series and the possible, structural shifts in their causal linkages. This is a necessary step to ultimately obtain deeper insights into price discovery and other microstructure features.

3. The econometric framework

3.1. The empirical model

Following the strand of the empirical literature on the process of price discovery in a multi-market context, we employ the Component Share (CS) approach (Harris et al., 1995) and the Information Share (IS) method (Hasbrouck, 1995) to quantify each market's contribution to the disclosure of the efficient price. Both the IS and the CS methods assume that the efficient price of a bond follows a random walk process shared by the two transaction prices.

Consider a bond traded on MTS cash (M) and on BondVision (B). Let $p_t = (p_{M,t}, p_{B,t})'$ denote a 2×1 vector of (log) prices observed in the two markets. Since the elements in p_t share such an efficient price that they should not drift far from each other, and

are therefore cointegrated as follows:

$$\beta' p_t - \mu = p_{M,t} - p_{B,t} - \mu \sim I(0) \tag{1}$$

We can test whether the two log-price series, albeit individually non-stationary, are actually linked to one another by a stationary long-run equilibrium condition, in the context of a dynamic system for a pair ($p_{M,t}$, $p_{B,t}$). Adopting the same notation as above, we apply the Vector Error Correction (VEC) model (Johansen, 1991):

$$\begin{bmatrix} \Delta p_{M,t} \\ \Delta p_{B,t} \end{bmatrix} = \Pi \cdot \begin{bmatrix} p_{M,t-1} \\ p_{B,t-1} \end{bmatrix} + \sum_{j=1}^{k-1} A_j \cdot \begin{bmatrix} \Delta p_{M,t-j} \\ \Delta p_{B,t-j} \end{bmatrix} + \begin{bmatrix} u_{M,t} \\ u_{B,t} \end{bmatrix}, \; E\left(u_t \cdot u_t'\right) = \Sigma = \begin{bmatrix} \sigma_M^2 & \rho\sigma_M\sigma_B \\ \rho\sigma_M\sigma_B & \sigma_B^2 \end{bmatrix} \tag{2}$$

where Δ is the first difference operator, As are matrices of autoregressive coefficients up to the order $k-1$, u's are the residuals with variance-covariance matrix Σ, with ρ being the correlation coefficient and σs standard deviations. If condition (1) holds, we expect a rank equal to 1 for matrix Π, i.e. that the log-two price series share a common stochastic factor. In this case, the long-run matrix can be factored as:

$$\Pi = \alpha\beta' = \begin{bmatrix} \alpha_M \\ \alpha_B \end{bmatrix} \cdot \begin{bmatrix} 1 & -1 \end{bmatrix} \tag{3}$$

with $\alpha_M < 0$ and $\alpha_B > 0$.

Harris et al. (1995) attribute superior price discovery to the market that adjusts less to price movements in the other market by decomposing the common factor itself:

$$\gamma_M = \frac{\alpha_B}{\alpha_B - \alpha_M}, \; \gamma_B = \frac{\alpha_M}{\alpha_M - \alpha_B} \tag{4}$$

where the contribution of MTS cash (BondVision) to price discovery, γ_M (γ_B), is defined as a function of both αs. On the other hand, based on the Cholesky factorization of the matrix Σ Hasbrouck's model assumes that the degree of price discovery occurring in a market is (positively) related to its contribution to the variance of innovations to the common factor (the market's 'information share'). With price innovations correlated across markets, the IS

approach can only provide upper and lower bounds. For MTS cash these bounds are:

$$S_M^{ub} = \frac{(\gamma_M \sigma_M + \rho\gamma_B \sigma_B)^2}{(\gamma_M \sigma_M + \rho\gamma_B \sigma_B)^2 + \gamma_B^2 \sigma_B^2 (1-\rho^2)}, \; S_M^{lb} = \frac{\gamma_M^2 \sigma_M^2 (1-\rho^2)}{\gamma_M^2 \sigma_M^2 (1-\rho^2) + (\rho\gamma_M \sigma_M + \gamma_B \sigma_B)^2}$$

respectively. However, Baillie et al. (2002) argue that the simple average of these bounds

$$\zeta_M = \frac{1}{2}(S_M^{ub} + S_M^{lb}) \tag{5}$$

provides a sensible estimate of the markets' roles in the mechanism of determination of the efficient price. Both γ_M and ζ_M are found at the interval [0, 1], where high (low) values of the two statistics indicate a sizable (limited) contribution of MTS cash (BondVision) to price discovery.[12]

3.2. Time-varying price discovery measures

As our analysis encompasses different phases of turmoil, it is desirable to use a flexible approach so as to admit possible parameter instability. As shown in Dötz (2007) and Silvério and Szklo (2012), among others, the CS approach is well suited to the issue at stake.[13] Accordingly, we estimate time-varying parameter models for the loading weights using a

[12] See Baillie et al. (2002) for a detailed discussion and a formal derivation of the two price discovery measures.

[13] A further motivation in favour of the CS metrics stems from the lack of very high frequency transaction data, as not all bonds are intensively day traded. Relatively low data frequency (high duration) induces high correlation in the estimated residuals, which translates into a substantial divergence between the upper and lower IS bounds. As pointed out by Hasbrouck (1995), shortening the observation interval could help obtain tighter bounds. However, even using prices sampled at intervals of a few minutes intervals (a very high frequency for the case of euro-denominated government securities), a number of works (Baillie et al., 2002; Huang, 2002; Eun and Sabherwal, 2003) have found wide gaps between the upper and lower bounds. Wide IS bounds are inevitable in the present context.

Kalman filter approach, rather than resorting to rolling estimates (as in Arce et al., 2011).[14] Kalman filtering consists of a state equation, describing the evolution over time of non-observable state variables, and of a measurement equation, showing to what extent observable variables are driven by state ones. This modelling strategy does not impose a priori restrictions on the timing of structural breaks in the relationships. Instead, the timing of breaks are allowed to evolve freely and can be very informative about financial turmoil effects on the price discovery process.[15]

In our specific context, the equations of the bivariate VEC model (2) represents the measurement equations. Keeping the elements of the estimated autoregressive matrices Γ invariant over time, model (2) can be restated as follows:

$$\tilde{y}_{i,t} = \tilde{x}_t \alpha_{i,t} + e_{i,t} \tag{6}$$

with $\tilde{y}_{i,t} \equiv \Delta p_{i,t} - \sum_{j=1}^{k-1} \Gamma_{[i,]j} \Delta p_{i,t-j}$, $\tilde{x}_t \equiv (\beta' p_{t-1} - \mu)$, $i = M, B$, $e_{i,t} \sim N(0, h_i)$, and where $\Gamma_{[i,]j}$ denotes the i-th row of the j-th matrix of the VEC model. The adjustment parameters $\alpha_{i,t}$ are instead the state equations:

$$\alpha_{i,t} = \alpha_{i,t-1} + v_t \tag{7}$$

[14] The Kalman filter approach is extremely useful to investigate the issue of parameter constancy, as it is an updating method producing estimates based on all the available information (smoothing). It is important to realise that recursive (or moving window) estimation is not a suitable technique to use here, since it is essentially a test of structural stability carried out under the assumption that the parameters are constant, and it does not provide consistent estimates of a time-varying parameter (Barassi et al., 2005).

[15] As pointed out by Hendry (2000), a change in the long-run structure of the system could occur through shifts in the long-run relationship itself and/or in causality links (the loading factors). However, a model allowing for both types of changes could not be easily estimated, due to identification problems. Furthermore, as no arbitrage argument suggests long-run co-movement in prices of identical assets traded in multiple markets, it is reasonable to assume the cointegrating vectors are constant but the direction of causality can change.

with $v_{i,t} \sim N(0, q_i)$ and $q_i = \lambda h_i$, where λ denotes the signal-to-noise ratio (SNR).

According to condition (7), the elements of matrix α follow a random walk process, hence possibly varying considerably over time. With the $(1\ -1)'$ cointegrating relationship kept fixed, such an assumption allows us to detect any structural change that may occur in the causal link between two variables (Barassi et al, 2005). By computing the metrics in (4) as time-varying price discovery measures we thus investigate the occurrence of breaks in the causal structure of the factors linking prices in the two markets:

$$\gamma_{M,t} = \frac{\alpha_{B,t}}{\alpha_{B,t} - \alpha_{M,t}},\ \gamma_{B,t} = \frac{\alpha_{M,t}}{\alpha_{M,t} - \alpha_{B,t}} \tag{8}$$

4. Assessing markets' contribution to price discovery

4.1. Full sample analysis

Standard cointegration methods require equally spaced data without missing values. Following Upper and Werner (2002), in the presence of missing observations we use the last available transaction price ('fill-in' method). The estimation horizon ranges from 427 to 1281 observations, with 811 daily data points on average.

According to standard unit root and stationarity tests the 64 individual transaction price series (expressed in logarithms) are integrated processes of order 1. Moreover, the Horvath and Watson (1995) cointegration test for the null of no cointegration against the alternative of rank 1 with $\beta = (1\ -1)'$ strongly supports the existence of a $(1\ \ -1)'$ cointegration vector in all 32 pairs ($p_{M,t}$, $p_{B,t}$).[16] The dynamic properties of the 32 estimated VEC systems (2) reveal that feedback coefficients associated with the 64 individual equations are correctly signed and statistically significant at the 1 per cent level in all but three models, as Table 7 shows. Moreover, departures from the equilibrium condition are corrected for the most part in MTS

[16] Complete results are available on request.

cash, with the average value for $|\alpha_M|$ equal to 0.44 compared with 0.31 for $|\alpha_B|$.

Price discovery measures (4) and (5) are a direct way to assess the markets' relative contribution in conveying information to determine the (unobservable) efficient price. Table 8 reports the estimated values for all the BTPs in our bucket. As for MTS cash, γ_M ranges from 4.4 to 80 per cent, whereas the ζ_M measure gives values from 19.8 to 64.7 per cent. In particular, MTS cash market's contribution turns out to be below 50 per cent in most cases (for 21 bonds according to γ, for 23 bonds according to ζ).

Averaging across all the 32 securities we get encouraging results, since the mean and median values are almost identical following either approach (40.5. and 41.1 per cent respectively for γ_M, 40.9 and 41.3 for ζ_M). A standard t-test for the equivalence of the mean (γ_M minus ζ_M) returns test statistics of -0.10 with a p-value of 0.92, further indicating that estimated market contributions are equivalent irrespective of which of the two price discovery measures is adopted. Moreover, the two metrics are highly correlated (coefficient equal to 0.92), indicating that the two measures lead to non-conflicting conclusions. As a check of robustness of the results, the same estimation exercises are replicated by using daily weighted average prices (instead of daily closing prices). The estimation results are almost identical to those discussed above, as Table 9 shows.

4.2. Allowing for structural changes

From an economic perspective, the higher information efficiency of the B2C platform with respect to the B2B platform seems quite surprising, as the vast majority of trades (in value terms) take place on MTS cash (see Section 2). Indeed, a number of studies have found a strong linkage between trading activity and the degree of price discovery in various financial segments, including stocks (among others Eun and Sabherwal, 2003, and

Chakravarty et al., 2004) and euro-denominated sovereign fixed-income securities (Caporale and Girardi, 2013).

There are (at least) two possible explanations for such a conundrum. First, evidence of a relatively low contribution to price discovery in a market may be a consequence of less frequent trading activity, in spite of that market being the prevailing one in terms of overall exchanges (as discussed in Section 2.3). As trading frequency in MTS cash is lower than in BondVision, price discovery estimates could simply reflect this circumstance. The 'fill-in' method does not affect the estimates of the long-run relationship equilibrium, but it might influence short-term information flow, since it may attribute a lower information share for the less frequent trading market even if negotiations that take place contain information (Lehmann, 2002). By re-estimating all models only for days when trades occur in both markets, however, we obtain qualitatively and quantitatively similar results, suggesting that the 'fill-in' procedure does not seem to affect the above conclusions in terms of markets' relative contributions to price discovery.[17]

Second, it is unlikely that a single fixed-parameter model could apply meaningfully over a period covering different phases (under both a quantitative and a qualitative perspective) of the crisis. In this respect, the full sample estimates can be viewed as the result of an 'average' specification, possibly missing important shifts in the causal linkages of trades on the two markets. In order to ascertain the stability over time of results in Table 8, we analyse the process of price discovery in a time-varying framework by recasting the VEC model (2) - with the constraint $(1\ -1)'$ imposed in the cointegration space - into a state space

[17] In 7 out of 32 models we obtain wrongly signed feedback coefficients. Averaging the remaining 25 models, according to CS and IS metrics, MTS cash contributes to price discovery for about 45 and 49 per cent, respectively, thus confirming that the B2C market plays a more important role in the process of BTP price formation (though the contribution of the B2B venue may be slightly under-estimated in the figures reported in the main text). Complete results are available on request.

form, as implied by conditions (6) and (7). Figure 2 plots the evolution over time of MTS market's contribution for each BTP, where "wrongly" signed αs are replaced by zero as in Blanco et al. (2005).

The graphs clearly indicate substantial gyrations of the CS metrics over time, suggesting that a static approach covering the entire sample span can induce misleading conclusions.[18] Indeed, for the majority of bonds MTS cash dominates BondVision in terms of information disclosure in some phases, whilst the opposite holds in other periods.

Although distinctive patterns are difficult to identify at the individual bond level, if we aggregate time-varying price discovery measures by stage of the crisis, maturity, and life of the bonds, it is possible to give a more straightforward interpretation of our findings. Figure 3 shows that the evolution of the crisis has had an impact on aggregate price discovery measures: MTS cash incidence increased in the initial crisis period, very likely as a result of the relaxation of some binding obligations for specialists (set by MTS Corporation in March 2008 to restore the quote driven market activity) and of an increase in net purchases from abroad.[19] Further, the MTS cash contribution to price discovery dropped after Lehman defaulted, and has remained at around 40 per cent since then, even when the crisis has affected the sovereign bonds market more heavily. The temporal pattern of the MTS cash market contribution to price discovery is consistent with the evolution of relative trading shares (see Section 2.3) and with the widely held view that in the risk averse and uncertain crisis environment the trading RFQ model has generally become more attractive. There are several reasons for this: compared to MTS cash, traders in BondVision avoid posting ask and bid quotes of a committing nature, can benefit by knowing their perspective counterparties

[18] These results are based on a SNR calibrated to 0.01. Setting the SNR equal to 0.05 and 0.10 produces virtually identical figures to those reported in the main text.

[19] The share of Italian public securities held by forcing investors increased from 50.9 to 53.8, between 2007 and 2008 (Bank of Italy, 2009).

(i.e. no anonymity), and exchange at lower average amounts.

As expected, the B2B market role decreases as bonds become less liquid, and prevails for longer maturity issues, in line again with the evidence discussed before in Section 2.3 with (generally) higher trading activity on longer durations, and more liquid bonds in MTS cash (Tables 5 and 6).

All in all, there seem to be several factors at work to influence price discovery pattern changes. A deeper insight into the relationship between microstructure variables and the information efficiency of either market can shed light on the role of trading flows and, ultimately, on the interplay between the two trading venues.

5. Price discovery and bond market characteristics

5.1. The full sample approach

In order to delve deeper into the effects of primary dealers' inventory imbalances on the process of price discovery, we use a battery of time-series cross-sectional regressions based on the following fixed effects model:

$$\gamma^{*}_{M,it} = \psi_i + \sum_{l=1}^{2} \theta_l of_{l,it} + \sum_{m=1}^{Q} \vartheta_m z_{m,it} + \sum_{h=1}^{H} \kappa_h dc_t + \sum_{s=1}^{S} \eta_s ds_{s,t} + \varepsilon_{it} \qquad (9)$$

where $\gamma^{*}_{M,it} = \ln[\gamma_{M,it}/(1-\gamma_{M,it})]$ indicates the logit transformation of the time-varying CS measure for the MTS cash platform for bond i on day t, ψ_i is the individual constant term of bond i, of_{it} indicates a measure of order flow, and z_{it} stands for generic independent variables which may affect the process of price discovery, such as those introduced in Section 2.3. Furthermore, we take quote-based variables into account, namely simple and weighted bid-ask spreads (ssp and wsp, respectively) and the percentile distribution of book depth (the mid-sum of quoted values for the five best quotes in bid and ask, pwi), available only for

the MTS cash quote-driven market. In all specifications, common (dcs) and bond-specific (dss) time dummy variables are also included to control for crisis phases and bond status.[20]

As a preliminary step, we investigate the relationship between price discovery and market microstructure variables by exploiting full sample information. Four different specifications are considered in Table 10: Model [1] includes signed relative order flow in the same market (otm) and in BondVision (otb) without any additional zs. Model [2] embeds the previous specification and makes the response variable dependent on MTS cash market share in value terms (trs). In Model [3] the set of regressors is augmented by introducing average trade size in the two markets (avm and avb). Finally, Model [4] takes into account not only trading activity variables but also proxies for liquidity conditions (namely, ssp and pwi).

Estimation results emphasize the role of liquidity measures, order flow and trading variables as driving forces in determing price discovery (Table 10). Higher liquidity (epitomized by lower bid-ask spreads and higher width volumes) exerts a remarkable, positive effect linked to price discovery, confirming previous empirical results for the US stock market (Eun and Sabherwal, 2003; Chakravarty et al., 2004; Anand and Subrahmanyam, 2008) and the European market for government securities (Caporale and Girardi, 2013).

Imbalances in BondVision significantly and negatively impact the MTS cash's relative contribution, indicating that information generated by trades in the B2C platform co-determines price discovery in the B2B interdealer one, independently of the inclusion of other activity and microstructure variables. These findings are in line with the functional interlinkages between the two markets which, as discussed above, are ultimately rooted in dealers' inventory adjustment strategies – and related risks.

[20] In order to reduce the possible influence of outliers in both the dependent variable and the regressors, all models are estimated winsorizing all variables at the 1 and 99 percent.

Finally, higher trading shares and average trade size coefficients seem to reflect the activity of larger dealers in the B2B market, in a way consistent with the preference of larger dealers for anonymity (the 'large dealer blessing' in Scalia and Vacca, 1999) and with the findings of Anand and Subrahmanyam (2008), who have documented that relatively larger trades are associated with greater price discovery than smaller trades.

As a check of the sensitiveness of our findings to modifications of the baseline model, we carry out two robustness exercises. First, trading values order flow and market share variables are replaced by those calculated on the number of contracts (Models [5] - [8] in Table 11). This allows us to take into account the discrepancies in each market share as measured by the number or value of trades (see Section 2) and is in line with the approach of Chordia et al. (2001), Boehmer and Wu (2008) and Fleming (2003). Second, we use weighted averages of the spread and nominal width to test alternative model specifications (Models [9] - [14] in Table 11). The results from these robustness checks are very similar to those of the baseline specification and corroborate our previous conclusions. As supplementary evidence, the average trade value in BondVision significantly - and negatively - affects the price discovery contribution of MTS cash whenever the number of contracts is used as the market share variable (Models [12] - [14]), a likely side effect of the lower values of such variable in the B2B market during the crisis.

5.2. A closer look at the effects of the crisis

The ongoing crises has pushed analysts to study the reactions of the financial markets to two main crisis episodes, namely the Lehman default in September 2008 and the start of the Greek public debt problem in May 2010. As for euro-denominated sovereign bonds markets, Blommestein (2009) and Schuknecht et al. (2011) discuss how markets have become much more careful to discriminate between public issuers on the basis of fiscal performance

and public debt sustainability in the aftermath of the events of 2008. Other contributions (Giordano et al., 2012; Di Cesare et al., 2012) have described the marked market sensitiveness to fundamentals after the Greek crisis as a "wake-up call". In this section we assess whether and how the two main episodes have affected the microstructure of the Italian markets for Treasury bonds. Table 13 reports the results of estimating the above baseline model (see Table 10) around the time of the two episodes.

In both pre-crisis periods liquidity factors play a key role, whereas the trading activity indicators do not seem to be relevant in explaining the process of price formation. A notable exception is the coefficient associated with the order flow on the B2C platform, which is statistically significant. This result corroborates the view of a functional linkage normally in place between the two cash markets, which as discussed in previous sections, is embodied by the activity of primary dealers. Along this line Green (2004) specifically considers a case where order flow in the B2B market is informationally weaker that that in the parallel B2C venue: "If dealers are able to trade at more favourable prices with their customers, then they may be willing to submit quotes in the interdealer market that appear suboptimal in the sense that they do not fully reflect the information in order flow". This circumstance is linked to the use of the interdealer market as a source of liquidity, and leads ultimately to lower transaction costs for dealers themselves (Green, 2004, p. 1214).

Interestingly, the informational role of trading seems to increase after the events and the consequent reduction in exchanges: both market share and average trade size turn out to be statistically significant only after the events. The same holds true for the MTS cash order flow, while imbalances in BondVision affect price discovery both before and after the two main turmoil episodes. The two liquidity variables are significant in both periods but, notably, after the Greek crisis the coefficient referring to posted width overcomes the bid-ask spread coefficient, which became increasingly volatile. Results for both post-crisis periods are

consistent with the previous empirical financial literature on the joint effects of microstructure variables during times of turmoil or major macro-announcements (Brandt and Kavajecz, 2004; Cheung et al. (2005); Green, 2004). This is because trade imbalances exert a more significant influence on the bonds price formation process when overall liquidity conditions are poorer or after a major announcement, since dealers extract more information from the order flow when uncertainty about the 'true' price is stronger, liquidity is low, and more informed traders could be at work, therefore raising the level of information asymmetries.[21]

The evidence in Table 13 confirms that the functioning of the Italian secondary markets for government securities has been deeply affected by the Lehman default and, more markedly, by the European sovereign debt crisis, with liquidity shifts and trading activity simultaneously influencing the price adjustment process. Risk aversion and fiscal fragilities have acted essentially through the yield spread of the Italian public bonds on less risky securities, as is well known. In parallel, the microstructure of sovereign markets has become more complex, being influenced by various trading variables – including a stronger role of imbalances – ultimately signalling informational asymmetries and greater uncertainty.

6. Concluding remarks

This paper analyses the price discovery process and the informational role of trading in the Italian wholesale Treasury bond secondary cash markets, the B2B MTS cash and the parallel B2C BondVision trading venue, over the period January 2007 - February 2012. Our analysis aims to contribute to the strand of empirical works concerning the microstructure of

[21] Beber et al. (2009) come to the same conclusion when estimating the impact of net order flow and liquidity variables on the spread between sovereign bonds and risk-free asset yields. Again, traders' evaluation of liquidity is higher around stressful events, when portfolios are 'defensively' rebalanced towards less risky, more liquid assets. In these circumstances, trade shifts can be described as 'flights to liquidity', more appropriately than 'flights to quality'.

bond markets by developing time-varying price discovery measures in both markets and relating these results to some fundamental market variables, namely trading imbalances, trading activity and liquidity. We also assess how the different stages of the ongoing crisis have had an impact on the price formation mechanism. Apart from their academic merits, these issues have become increasingly important for all the involved stakeholders - the sovereign issuer, banks and other institutional traders, and the central bank as market regulator - since the financial crisis has evolved over time with varying intensity and with so far under-investigated effects.

We document that the B2C contribution to price discovery of government fixed rate bonds is considerable, and generally greater than that expressed by MTS cash, though the latter venue attracts higher trading activity in value and fewer contacts in number terms. This result seems to be mainly explained by the trading model of BondVision, an order driven, RFQ market, which during the crisis is more favoured by risk-averse traders for several reasons. However other factors, more directly related to the functional interplay between a B2B and a B2C market can be at work, too. In particular, order flow and liquidity measures are key variables in determining the informational efficiency of the markets, both before and after the start of the public debt crisis. Moreover, trading imbalances in BondVision are remarkably informative in explaining the relative price discovery contribution of MTS cash. Finally, order flow plays a stronger informational role when liquidity conditions are poor, suggesting that informational asymmetries are at work even in the public bonds markets.

Some issues which are potentially important for the price formation mechanism are not addressed in this paper, such as the role played by information asymmetries among market participants or by diverging trading strategies of different types of dealers, e.g. by applying sequential trading or duration models (which would require a high–frequency data set). These topics are left for future research.

Tables and figures

Table 1 – Trading activity by security type

Average daily traded value (millions of euros)

	BOT		BTP		BTPi		CCT		CTZ	
	BondVision	MTS cash	BondVision	MTS	BondVision	MTS	BondVision	MTS	BondVision	MTS
2007	0.441	1.376	0.555	3.447	0.025	0.243	0.279	1,015	0.138	0.446
2008	0.282	0.613	0.485	1.858	0.029	0.261	0.169	0.465	0.105	0.241
2009	0.212	0.573	0.623	1.495	0.029	0.110	0.208	0.434	0.160	0.225
2010	0.274	0.671	0.683	1.855	0.027	0.144	0.197	0.413	0.155	0.345
2011	0.304	0.894	0.706	1.582	0.035	0.206	0.132	0.366	0.171	0.317
2012	0.402	0.730	1.004	1.169	0.081	0.126	0.158	0.186	0.266	0.230

Average daily number of contracts

	BOT		BTP		BTPi		CCT		CTZ	
	BondVision	MTS	BondVision	MTS	BondVision	MTS	BondVision	MTS	BondVision	MTS
2007	115.4	323.5	191.3	596.1	9.4	41.8	61.7	261.8	30.4	98.6
2008	92.4	141.6	174.9	326.8	14.4	30.3	51.4	128.6	28.6	50.9
2009	57.2	94.4	236.1	260.7	15.8	30.0	48.6	95.3	35.6	35.3
2010	40.0	109.7	204.7	337.6	24.0	39.4	52.8	84.7	32.7	49.6
2011	58.4	127.6	258.8	278.9	26.0	56.3	37.5	70.5	54.8	44.7
2012	58.5	96.1	295.4	241.0	29.7	41.6	33.8	36.7	48.8	34.4

Note. BOT (*Buoni Ordinari del Tesoro*) are Treasury bills - short-term securities with maturities up to 365 days; BTP (*Buoni del Tesoro Poliennali*) are Treasury bonds - medium/long-term securities, ranging from 3 to 30 years; BTPi (*Buoni del Tesoro Poliennali Indicizzati all'inflazione*) are Treasury bonds linked to Euro-zone inflation with a maturity of 5, 10, 15 or 30 years; CCT (*Certificati di Credito del Tesoro*) are Treasury credit certificates - floating rate securities with a 7 year maturity; CTZ (*Certificati del Tesoro Zero coupon*) are Zero coupon Treasury certificates - bonds issued with maturities of 24 months. Figures for 2012 are based on averages of the data for January and February.

Table 2 – Description of the sample bonds

ISIN code	Bucket	Issuance date	Maturity date
IT0004008121	3 years	30-Jan-06	01-Feb-09
IT0004085244		28-Jun-06	15-Jun-09
IT0004196918		27-Feb-07	01-Mar-10
IT0004254352		30-Jul-07	01-Ago-10
IT0004332521		28-Feb-08	01-Feb-11
IT0004404973		28-Aug-08	01-Set-11
IT0004467483		26-Feb-09	01-Mar-12
IT0004508971		26-Jun-09	01-Jul-12
IT0004564636		30-Dec-09	15-Dec-12
IT0004612179		28-May-10	01-Jun-13
IT0004026297	5 years	13-Mar-06	15-Mar-11
IT0004112816		14-Sep-06	15-Set-11
IT0004220627		13-Apr-07	15-Apr-12
IT0004284334		11-Oct-07	15-Oct-12
IT0004365554		15-Apr-08	15-Apr-13
IT0004448863		14-Jan-09	15-Dec-13
IT0004505076		11-Jun-09	01-Jun-14
IT0004568272		13-Jan-10	15-Apr-15
IT0004615917		11-Jun-10	15-Jun-15
IT0004019581	10 years	27-Feb-06	01-Ago-16
IT0004164775		28-Dec-06	01-Feb-17
IT0004273493		30-Aug-07	01-Feb-18
IT0004361041		29-Apr-08	01-Ago-18
IT0004423957		01-Sep-08	01-Mar-19
IT0004489610		29-Apr-09	01-Set-19
IT0004536949		29-Sep-09	01-Mar-20
IT0004594930		30-Mar-10	01-Set-20
IT0004009673	15 years	26-Jan-06	01-Ago-21
IT0004356843		01-Feb-08	01-Ago-23
IT0004513641		01-Mar-09	01-Mar-25
IT0004286966	30 years	16-Oct-07	01-Ago-39
IT0004532559		09-Sep-09	01-Set-40

Table 3 – Trading activity indicators: averages by buckets

Bucket	MTS cash				Bondvision			
	atr	*ftr*	*qty*	*cnt*	*atr*	*ftr*	*qty*	*cnt*
3 years	546	80.4	405679	60270	636	93.7	150916	45604
5 years	701	76.4	410038	64882	849	92.5	132497	45900
10 years	713	74.9	449572	79019	829	87.1	125660	46061
15 years	800	78.6	109390	26073	832	81.8	40672	13833
30 years	678	76.0	43242	12377	703	78.7	11348	5457

Note. *atr* indicates the number of days during which at least one trade has occurred; *ftr* is the frequency of trading, computed as the ratio of the number of days when at least one exchange has occurred in the market to the number of all the operational days in the period; *qty* is the total nominal amount of trades (millions of euros); *cnt* indicates the total number of contracts.

Table 4 – Market characteristics by stages of the crisis

	Pre crisis	Beginning	Global crisis	Phasing out	Debt crisis
cns °	71.8	63.8	51.3	57.5	51.1
trs °	84.8	79.4	70.2	73.6	71.5
avm °°	6.5	5.8	5.8	6.4	5.8
avb °°	3.6	3.0	3.3	4.0	3.5
otm °	3.3	-2.6	-1.8	-3.7	-2.2
otb °	13.8	10.8	4.5	6.7	9.6
ocm °	5.5	-0.8	-0.1	-4.1	-2.2
ocb °	25.2	18.0	3.8	-0.1	6.8

Note. According to the ECB (2010), the *pre-crisis* period ended on 8 August 2007; the *beginning-of-the-crisis*, spans from 9 August 2007 to 12 September 2008; the *global crisis*, goes from 15 September 2008 to 2 December 2009; *phasing out* embraces the period from 3 December 2009 to 6 May 2010; the *debt crisis* started on 9 May 2010. Signed order flows are defined as the ratio between buy- minus sell-initiated trades over their sum) in terms of both nominal traded values and number of contracts, separately for MTS cash (*otm* and *ocm*, respectively) and BondVision (*ocb* and *otb*); the related trading activity on the MTS cash market is measured as the ratio of nominal traded values (and contracts) to the aggregated nominal trades (and contracts) on the two markets (*trs* and *cns*); the average size of trades on MTS cash (*avm*) and BondVision (*avb*) are computed as the ratio between nominal traded value and number of contracts. Lastly, ° indicates percentage values; °° stands for millions of euros.

Table 5 – Market characteristics by issuance maturities

	3 years	5 years	10 years	15 years	30 years
cns	52.9	53.7	55.8	60.4	59.4
trs	71.2	74.0	74.3	73.8	76.1
avm	6.8	6.3	5.6	4.1	3.5
avb	3.9	3.1	3.4	3.8	2.1
otm	-5.1	1.1	-0.4	-1.6	-12.6
otb	-6.5	1.2	20.1	27.4	27.2
ocm	-4.0	2.0	0.7	-2.1	-12.7
ocb	-5.2	0.4	17.8	29.2	28.2

Note. See Table 4.

Table 6 – Market characteristics by bond status

	On	I Off	II Off	III Off	Further Off
cns	68.1	61.7	63.9	61.3	51.1
trs	80.9	78.3	77.6	77.8	71.1
avm	3.9	4.3	5.3	6.1	6.3
avb	2.8	2.4	3.9	3.0	3.6
otm	-2.1	-9.3	-0.6	-4.6	-1.1
otb	21.9	27.7	20.0	9.7	2.7
ocm	-2.6	-9.4	0.3	-1.7	-0.4
ocb	22.4	31.6	25.5	20.5	-0.25

Note. A newly issued security is classified as on the run (*On*) once it is traded more than other bonds of the same maturity for at least seven continuous working days. Differentiation between 'on the run' and (first)' off the run' (*I Off*) and among the various 'off the run' (*I Off* vs *II Off*, and so forth) stages follows the same criterion. "Further Off" aggregates all switches after the third off the run status (*III Off*). See also Table 4.

Table 7 – Individual VEC model estimates: feedback coefficients

ISIN code	α_M		α_B	
	Coefficient	Standard error	Coefficient	Standard error
IT0004008121	-0.5894	0.0000	0.5225	0.0001
IT0004085244	-0.3038	0.0035	0.4184	0.0000
IT0004196918	-0.6507	0.0000	0.1664	0.0472
IT0004254352	-0.4508	0.0000	0.3762	0.0000
IT0004332521	-0.4080	0.0000	0.3177	0.0000
IT0004404973	-0.4805	0.0000	0.5272	0.0000
IT0004467483	-0.2175	0.0001	0.4602	0.0000
IT0004508971	-0.4426	0.0000	0.3033	0.0000
IT0004564636	-0.4302	0.0000	0.6732	0.0000
IT0004612179	-0.4284	0.0000	0.1802	0.0014
IT0004026297	-0.6025	0.0000	0.1490	0.0063
IT0004112816	-0.3990	0.0000	0.0383	0.3036
IT0004220627	-0.4110	0.0000	0.2318	0.0000
IT0004284334	-0.5905	0.0000	0.3816	0.0000
IT0004365554	-0.3995	0.0000	0.4797	0.0000
IT0004448863	-0.7091	0.0000	0.1228	0.0754
IT0004505076	-0.5859	0.0000	0.0258	0.6226
IT0004568272	-0.3670	0.0000	0.0413	0.3884
IT0004615917	-0.3633	0.0000	0.1185	0.0083
IT0004019581	-0.6711	0.0000	0.1724	0.0001
IT0004164775	-0.4340	0.0000	0.1350	0.0044
IT0004273493	-0.5299	0.0000	0.3778	0.0000
IT0004361041	-0.3029	0.0000	0.3597	0.0000
IT0004423957	-0.6006	0.0000	0.3787	0.0000
IT0004489610	-0.5673	0.0000	0.3426	0.0000
IT0004536949	-0.2023	0.0000	0.2537	0.0000
IT0004594930	-0.5767	0.0000	0.3127	0.0000
IT0004009673	-0.3128	0.0000	0.6809	0.0000
IT0004356843	-0.3880	0.0000	0.3365	0.0000
IT0004513641	-0.2976	0.0000	0.4298	0.0000
IT0004286966	-0.2144	0.0000	0.2704	0.0000
IT0004532559	-0.1239	0.0219	0.4949	0.0000

Note. Estimated coefficients of matrix α. See condition (3) of the main text.

Table 8 – The relative contribution of markets to price discovery

ISIN code	γ		ζ	
	MTS cash	BondVision	MTS cash	BondVision
IT0004008121	0.4699	0.5301	0.4953	0.5047
IT0004085244	0.5793	0.4207	0.5207	0.4793
IT0004196918	0.2037	0.7963	0.3906	0.6094
IT0004254352	0.4549	0.5451	0.4768	0.5232
IT0004332521	0.4378	0.5622	0.4374	0.5626
IT0004404973	0.5231	0.4769	0.5009	0.4991
IT0004467483	0.6791	0.3209	0.5747	0.4253
IT0004508971	0.4066	0.5934	0.3665	0.6335
IT0004564636	0.6101	0.3899	0.5413	0.4587
IT0004612179	0.2961	0.7039	0.293	0.707
IT0004026297	0.1983	0.8017	0.3259	0.6741
IT0004112816	0.0876	0.9124	0.2633	0.7367
IT0004220627	0.3606	0.6394	0.4021	0.5979
IT0004284334	0.3925	0.6075	0.4375	0.5625
IT0004365554	0.5457	0.4543	0.5005	0.4995
IT0004448863	0.1476	0.8524	0.3406	0.6594
IT0004505076	0.0422	0.9578	0.1977	0.8023
IT0004568272	0.1011	0.8989	0.199	0.801
IT0004615917	0.246	0.754	0.1457	0.8543
IT0004019581	0.2043	0.7957	0.2686	0.7314
IT0004164775	0.2373	0.7627	0.3066	0.6934
IT0004273493	0.4162	0.5838	0.3727	0.6273
IT0004361041	0.5429	0.4571	0.4852	0.5148
IT0004423957	0.3867	0.6133	0.3353	0.6647
IT0004489610	0.3765	0.6235	0.3762	0.6238
IT0004536949	0.5564	0.4436	0.4838	0.5162
IT0004594930	0.3516	0.6484	0.3358	0.6642
IT0004009673	0.6852	0.3148	0.6017	0.3983
IT0004356843	0.4645	0.5355	0.4236	0.5764
IT0004513641	0.5909	0.4091	0.5021	0.4979
IT0004286966	0.5578	0.4422	0.5337	0.4663
IT0004532559	0.7997	0.2003	0.6465	0.3535

Note. Price discovery metrics are computed according to conditions (4) and (5) of the main text.

Table 9 – The relative contribution of markets to price discovery (weighted prices)

ISIN code	γ		ζ	
	MTS cash	BondVision	MTS cash	BondVision
IT0004008121	0.4172	0.5828	0.4781	0.5219
IT0004085244	0.3439	0.6561	0.4731	0.5269
IT0004196918	0.0768	0.9232	0.3903	0.6097
IT0004254352	0.9070	0.0930	0.7452	0.2548
IT0004332521	0.3507	0.6493	0.3814	0.6186
IT0004404973	0.3834	0.6166	0.4220	0.5780
IT0004467483	0.7235	0.2765	0.5889	0.4111
IT0004508971	0.3974	0.6026	0.3608	0.6392
IT0004564636	0.3054	0.6946	0.4641	0.5359
IT0004612179	0.1339	0.8661	0.2938	0.7062
IT0004026297	0.1800	0.8200	0.3054	0.6946
IT0004112816	0.2578	0.7422	0.3751	0.6249
IT0004220627	0.325	0.675	0.3840	0.6160
IT0004284334	0.4190	0.5810	0.4523	0.5477
IT0004365554	0.5248	0.4752	0.4859	0.5141
IT0004448863	0.1261	0.8739	0.3266	0.6734
IT0004505076	0.0773	0.9227	0.2295	0.7705
IT0004568272	0.1566	0.8434	0.2161	0.7839
IT0004615917	0.1145	0.8855	0.0862	0.9138
IT0004019581	0.0847	0.9153	0.2308	0.7692
IT0004164775	0.1314	0.8686	0.2617	0.7383
IT0004273493	0.3473	0.6527	0.3360	0.6640
IT0004361041	0.4762	0.5238	0.4502	0.5498
IT0004423957	0.4732	0.5268	0.4093	0.5907
IT0004489610	0.4380	0.5620	0.4162	0.5838
IT0004536949	0.5493	0.4507	0.3951	0.6049
IT0004594930	0.2645	0.7355	0.2855	0.7145
IT0004009673	0.7398	0.2602	0.6622	0.3378
IT0004356843	0.5548	0.4452	0.4926	0.5074
IT0004513641	0.5213	0.4787	0.4679	0.5321
IT0004286966	0.6330	0.3670	0.5719	0.4281
IT0004532559	0.6389	0.3611	0.5472	0.4528

Note. See Table 8.

Table 10 – Determinants of price discovery: baseline specifications

	Model [1]	Model [2]	Model [3]	Model [4]
otm	0.0203**	0.0202**	0.0206**	0.0195**
	(0.0091)	(0.0091)	(0.0091)	(0.0091)
otb	-0.0317***	-0.0299***	-0.0290***	-0.0277***
	(0.0086)	(0.0087)	(0.0087)	(0.0087)
trs		0.1172***	0.0829**	0.0721**
		(0.0274)	(0.0324)	(0.0325)
avm			0.0108***	0.0090***
			(0.0026)	(0.0026)
avb			-0.0011	-0.0012
			(0.0013)	(0.0013)
ssp				-0.1388***
				(0.0374)
pwi				0.0793**
				(0.0364)

Note. The dependent variable is the logit transformation of the time-varying CS measure for the MTS cash platform ($\gamma^{*}_{M,it} = \ln[\gamma_{M,it}/(1-\gamma_{M,it})]$) for the i -th bond observed at time t . Simple bid-ask spreads, *ssp* , and the percentile distribution of book depth (the mid-sum of quoted values for the five best quotes in bid and ask, *pwi* , complement the set of regressors discussed in Section 2.3. Albeit not reported, all models include crisis and status dummies. Robust standard errors are in parenthesis. Single, double and triple asterisks indicate statistically significant coefficients at the 10, 5, and 1 per cent level, respectively.

Table 11 – Determinants of price discovery: baseline specifications (contracts)

	Model [5]	Model [6]	Model [7]	Model [8]
ocm	0.0202**	0.0198**	0.0205**	0.0195**
	(0.0093)	(0.0093)	(0.0093)	(0.0093)
ocb	-0.0396***	-0.0390***	-0.0362***	-0.0340***
	(0.0100)	(0.0100)	(0.0100)	(0.0101)
cns		0.0931***	0.0893***	0.0823***
		(0.0312)	(0.0314)	(0.0316)
avm			0.0119***	0.0099***
			(0.0026)	(0.0025)
avb			-0.0029**	-0.0028**
			(0.0012)	(0.0012)
ssp				-0.1338***
				(0.0375)
pwi				0.0844**
				(0.0365)

Note. See Table 10.

Table 12 – Determinants of price discovery: robustness checks

	Model [9]	Model [10]	Model [11]	Model [12]	Model [13]	Model [14]
otm	0.0197**	0.0197**	0.0195**			
	(0.0091)	(0.0091)	(0.0091)			
otb	-0.0280***	-0.0281***	-0.0278***			
	(0.0087)	(0.0087)	(0.0087)			
ocm				0.0196**	0.0196**	0.0195**
				(0.0093)	(0.0093)	(0.0093)
ocb				-0.0345***	-0.0346***	-0.0340***
				(0.0101)	(0.0101)	(0.0101)
trs	0.0715**	0.0725**	0.0730**			
	(0.0325)	(0.0325)	(0.0325)			
cns				0.0795**	0.0804**	0.0833***
				(0.0315)	(0.0315)	(0.0316)
avm	0.0090***	0.0090***	0.0090***	0.0099***	0.0099***	0.0099***
	(0.0026)	(0.0026)	(0.0026)	(0.0026)	(0.0026)	(0.0025)
avb	-0.0012	-0.0012	-0.0012	-0.0028**	-0.0028**	-0.0028**
	(0.0013)	(0.0013)	(0.0013)	(0.0012)	(0.0012)	(0.0012)
ssp	-0.1535***			-0.1497***		
	(0.0367)			(0.0367)		
wsp		-0.1439***	-0.1291***		-0.1402***	-0.1241***
		(0.0355)	(0.0362)		(0.0356)	(0.0363)
nwi	0.0000*	0.0000*		0.0000*	0.0000*	
	(0.0000)	(0.0000)		(0.0000)	(0.0000)	
pwi			0.0821**			0.0873**
			(0.0363)			(0.0365)

Note. Simple and weighted bid-ask spreads, *ssp* and *wsp* , and the percentile and nominal book depth, *pwi* and *nwi* , complement the set of regressors presented in Section 2.3. See also Table 10.

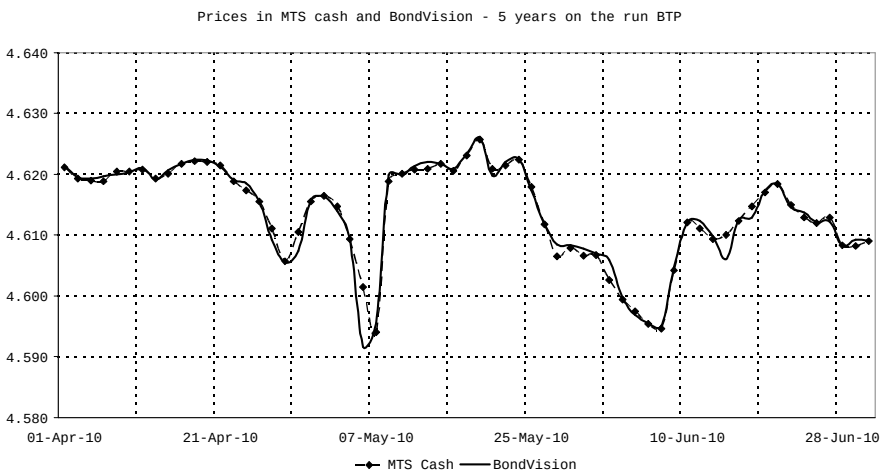
Table 13 – Determinants of price discovery: sub-sample analysis by crisis

	Lehman default		Greek crisis inception	
	Pre	Post	Pre	Post
otm	0.0034	0.0247**	0.0091	0.0248**
	(0.0119)	(0.0118)	(0.0102)	(0.0114)
otb	-0.0298***	-0.0332***	-0.0204**	-0.0270**
	(0.0114)	(0.0113)	(0.0097)	(0.0111)
trs	-0.0575	0.1066*	-0.0314	0.1400**
	(0.0541)	(0.0602)	(0.046)	(0.0617)
avm	0.0910	0.1561***	0.0791	0.1114***
	(0.0599)	(0.0390)	(0.0541)	(0.0351)
avb	-0.0352	0.0015	-0.0459	0.0372
	(0.0473)	(0.0483)	(0.0396)	(0.0481)
ssp	-0.4841***	-0.0956**	-0.2200***	-0.1053***
	(0.0882)	(0.0387)	(0.07)	(0.0405)
pwi	0.1819***	0.0835	0.0972**	0.1856***
	(0.0475)	(0.0537)	(0.043)	(0.0503)

Note. See Table 10.

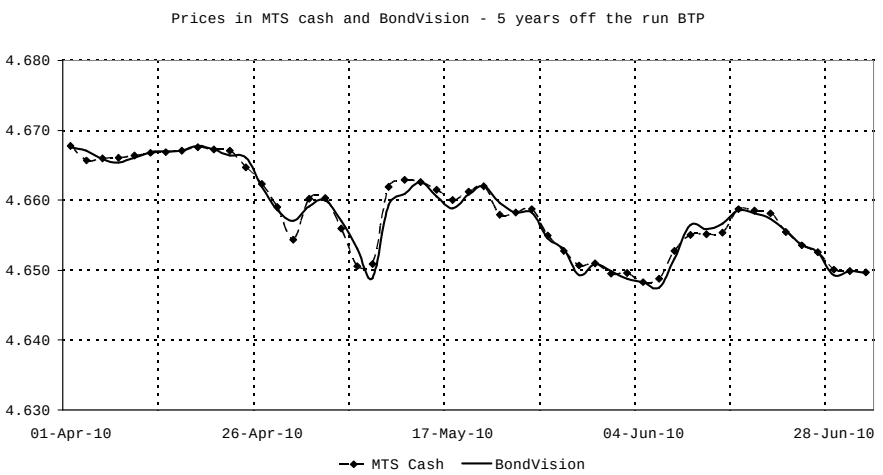
Figure 1 – Logarithms of daily prices (weighted averages).

5 years: on the run



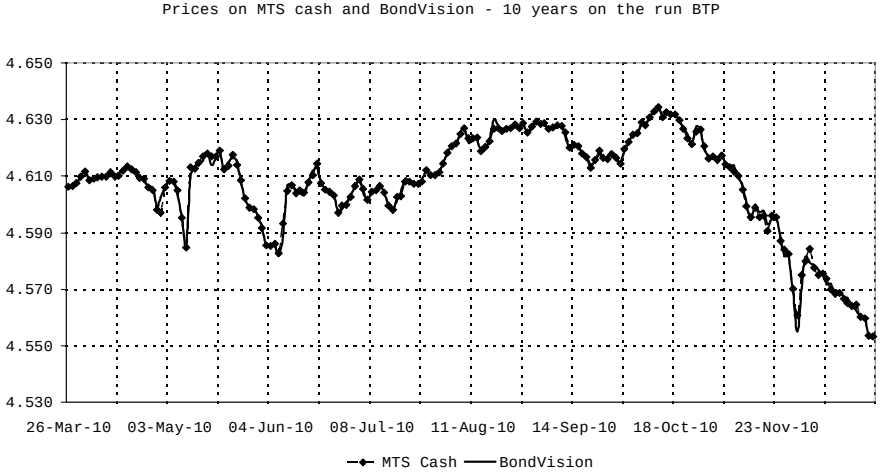
ISIN IT0004568272 expiring on 15-04-2015

5 years: off the run



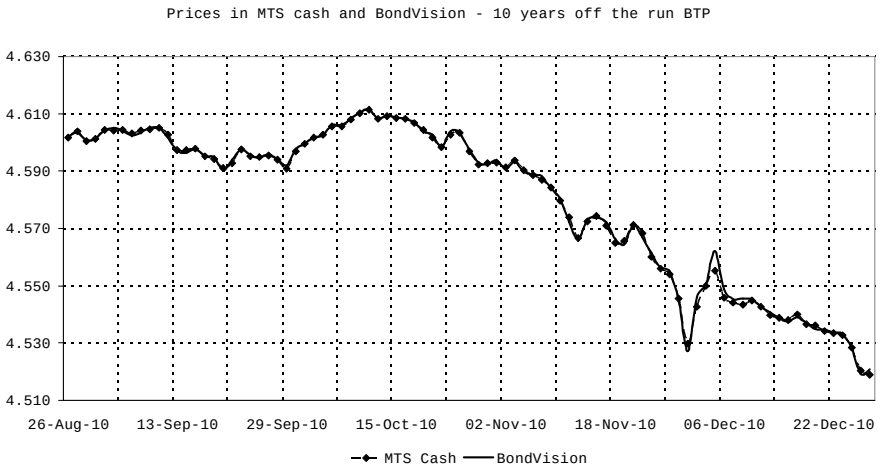
ISIN IT0004284334 expiring on 15-10-2012

10 years: on the run



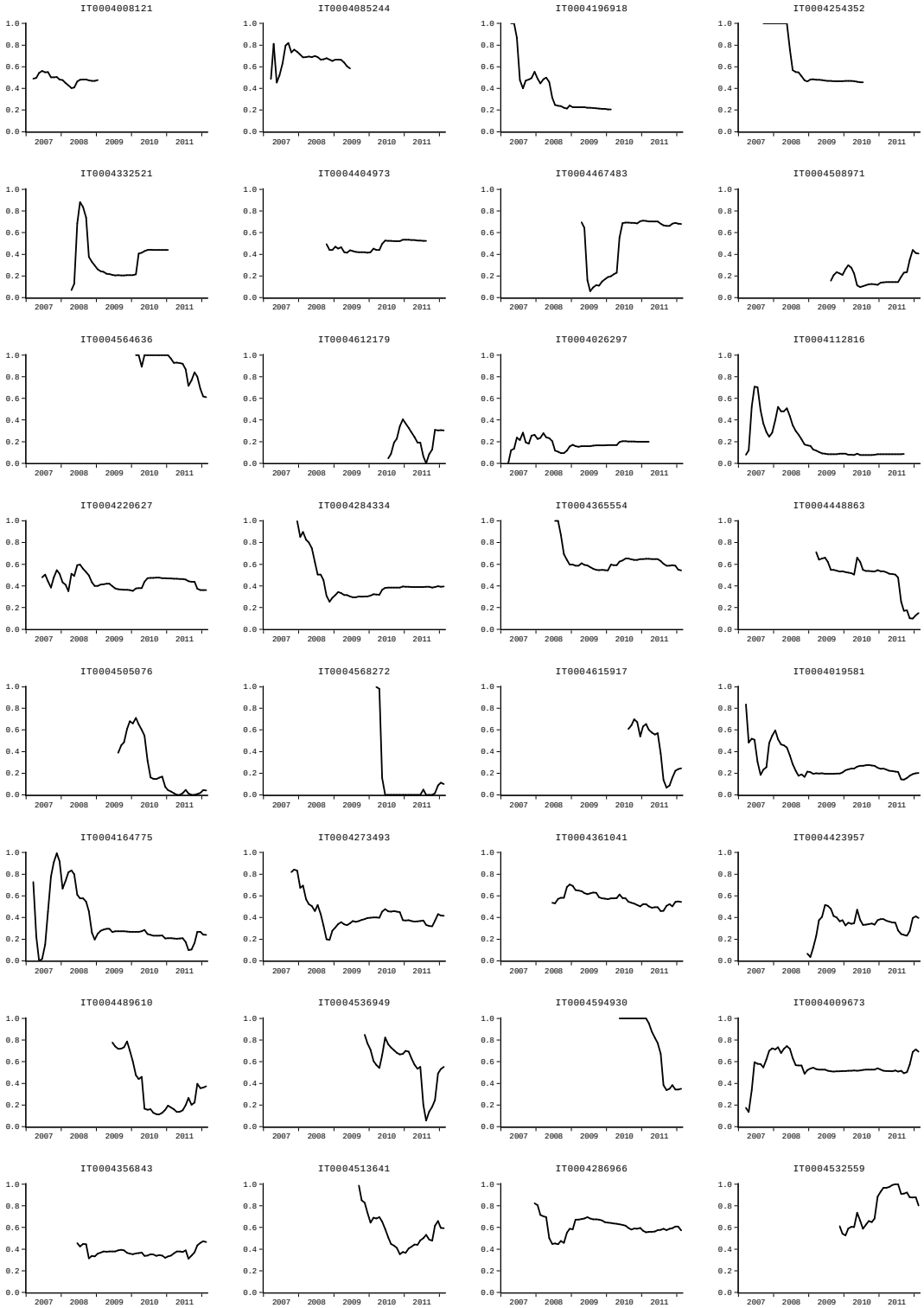
ISIN IT0004594930 expiring on 01-09-2020

10 years: off the run



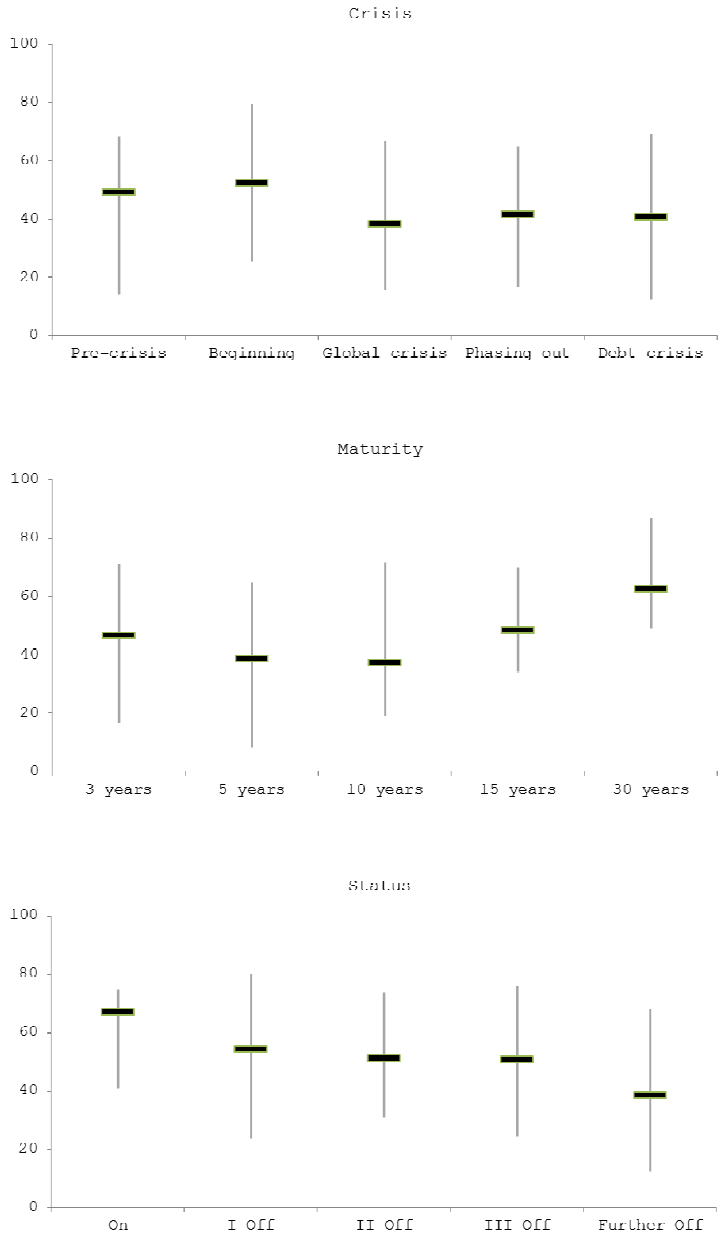
ISIN IT0004634132 expiring on 01-03-2021

Figure 2 – Time-varying MTS cash market's contribution to price discovery: individual bonds



Note. The graphs plot the evolution over time of MTS market's contribution for each BTP, obtained from the estimation of model (6) under condition (7) of the main text. "Wrongly" signed feedback coefficients with respect to the assumptions in model (3) of the main text are replaced by zero as in Blanco et al. (2005).

Figure 3 – Time-varying MTS cash market's contribution to price discovery by crisis, maturity, and bond status



Note. The graphs report the median value (horizontal dark lines) and the 10^{th} - 90^{th} percentile range (vertical light lines) of the estimated time-varying price discovery measure according to the various stages of the crisis (upper graph), the maturity at issuance of the securities (central graph), and the status of the bonds (lower graph), as defined in Section 2.3 of the text. Se also Tables 4 and 6.

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