Sovereign bond auctions in the euro area

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Chapter 3

Bid-to-cover and yield changes around public debt auctions in the euro area

3.1 Introduction

During the recent crisis public debt auctions in the euro area were under close scrutiny as the outcome of the auctions was often regarded as a test case for the creditworthiness of the governments. A key variable measuring the success of an auction is the "bid-to-cover ratio", i.e. the total amount of the bids placed during the auction over the total amount of the new debt issued. This chapter explores how the bid-to-cover ratio realized at public debt auctions affects yield changes in the secondary market for euro-area debt. In particular, using a sample of Belgian, French, German and Italian auctions, we find that a more successful auction, i.e. one in which the bid-to-cover ratio is higher relative to (recent) historical values, leads to lower secondary market yields after the auction. This effect is present in the auctioned issue itself (if it is a re-opening of an existing issue) and in existing issues that are close substitutes of the auctioned issue. We also find that the dampening effect on yields of a higher bid-to-cover ratio is stronger the higher is the volatility in the market.

Both results, the effect of the bid-to-cover ratio on yield changes and the role of volatility in this regard, follow from a simple theoretical model of primary dealer behavior that we develop. The model allows for asymmetric information in the form of the primary dealers receiving private signals about the fundamental value of the auctioned asset. The signal can come from the demand of the end-users of the asset. If the signal is positive, this generates a large demand relative to the amount of debt auctioned, thereby also generating a higher asset price after the auction, or, equivalently, a lower yield.

There are a number of reasons why our analysis should be of interest for policy purposes. First, it helps to highlight the cost of undersubscribed auctions. These may have damaging consequences for the government's credibility, hence causing future public borrowing costs to rise.[18] *Prior* to an auction the Treasury (or its agent) announces a target volume. Hence, in its pre-auction communication the Treasury faces a trade-off between announcing a high target, which increases the chance that a given auction fails and yields are driven up, and announcing a low target, which forces it to more frequently organize auctions, and incur the associated costs and risks, given the amount of new debt that needs to be issued.

Second, this chapter ties in with a recent literature on auction cycles, in which secondary-market yields rise *prior* to new public debt issues and then fall again. Our results help to quantify the dampening effect of the success of the auction, as measured by the bid-to-cover ratio, on the magnitude of the secondary-market auction cycle. Our empirical analysis focuses on yield changes in the secondary market rather than in the primary market, because we do not avail of pre-auction yields in the primary market. In any case, most of the auctions are re-openings in which an existing benchmark instrument is issued. In other cases, the maturity difference between the existing benchmark and the issued instrument tends to be relatively small. Hence, the two instruments are

[18] A very concrete example concerns the undersubscribed auction for UK gilts (attracting just £1.62 billion of bids for a sale of £1.75 billion of 40-year gilts) on 25 March 2009, described by Ongena *et al*. (2016), who write "gilt prices slumped, the UK pound weakened against the U.S. dollar and the euro, the opposition accused the government of losing control of public finances, and media commentators said the gilt failure further undermined the Prime Minister's reputation for economic competence." See also The Guardian (2009), http://www.theguardian.com/business/2009/mar/25/uk-economic-rescue-in-crisis.

highly substitutable, implying that any information generated in the primary market should be relevant for the secondary market as well. Given the high degree of substitutability between auctioned instrument and the secondary market instrument (in most cases, they are the same), we can in this way obtain a rough estimate of the reduction in debt issuance costs associated with a more successful auction.

Third, the chapter highlights the role of market circumstances, as captured by current volatility, and shows that during more turbulent periods a less successful auction, as captured by a lower bid-to-cover ratio, leads to a stronger increase in the yield on the new debt than during less turbulent periods. We illustrate the consequences of this finding by comparing the effect of a one standard deviation lower bid-to-cover ratio when market volatility is at its average versus when it is at its historical peak. For an average-size 30-year Italian debt issue, the difference in the effect on the yield after the auction implies 20 million euros lower proceeds of the auction when volatility is high. Hence, the Treasury may want to set a lower target volume when financial markets are particularly turbulent, thereby reducing the chances of a failed auction when the cost associated with such a failure is relatively high. Of course, if the total amount of new debt to be issued is constant, this implies that more debt needs to be issued later. However, when current market turbulence is unusually high, future market turbulence and the associated cost of a failed auction can be expected to be lower. Such a strategy requires a certain degree of flexibility on the side of the Treasury, in particular the possibility to bridge the temporary remaining financing needs with other instruments, such as additional short-term borrowing. This is likely to be more expensive when market uncertainty is higher. However, the higher cost will be incurred over a shorter period.

Fourth, the relationship between the bid-to-cover ratio and the secondary market yield suggests that price formation on the secondary market is partly based on new information released during the auction. Primary dealers participating in sovereign bond auctions receive signals in the run-up to an auction, in particular through the order flow they receive from their clients *prior* to the auction. During the auction, the primary dealers reveal their information through their submitted demand schedules (the combination of the quantities and the limit prices at which they are willing to buy these quantities), which in turn affect the bid-to-cover ratio. The fact that bid-to-cover ratios are reported by newswires and newspapers does indeed suggest that these ratios contain information relevant for market participants. Hence, exerting effort to extract pre-auction information from the primary dealers about the demand from the end-users in the days *prior* to the auction may help the debt agency in setting target volumes that are conducive to smoothing yields.[19] In particular, given the overall volume to be auctioned in a year, the target volume could be set higher when the expected demand unusually high, and vice versa.

This chapter relates to a limited literature that studies the relationship between auction outcomes and secondary market yields. Spindt and Stolz (1989) develop a model in which the expected stop-out price in a discriminatory auction depends on the bid-to-cover ratio. An increase in the number of bidders raises the bid-to-cover ratio and results in a higher stop-out price. Consistent with their model, Spindt and Stolz (1992) find that the observed underpricing of auctioned U.S. treasury bills relative to the secondary market is smaller for auctions with a higher bid-to-cover ratio. Goldreich (2007) obtains a similar result for U.S. treasury bonds, while Forest (2012) finds a negative relationship between the

[19] Note that most, if not all, debt agencies already hold regular meetings with their primary dealers.

unexpected component in the bid-to-cover ratio and the secondary market yield for auctions of 5- and 10-year U.S. Treasury bonds. Cammack (1991) obtains a related result. She shows that secondary market prices are higher when the number of competitive bidders in the auction is higher than expected.

A more recent strand of the literature explores the existence of auction cycles in secondary market yields around public debt auctions. Fleming and Rosenberg (2007) and Lou *et al.* (2013) establish such a pattern for secondary market yields of U.S. treasury bonds, while Beetsma *et al*. (2016) detect a similar pattern around Italian public debt auctions, in particular during the sovereign debt crisis in the euro area. In a similar vein, for a sample of the six largest euro area debt markets Beetsma *et al.* (2018b) find that public debt auctions can cause cross-border auction cycles. Our chapter differs from the earlier and this more recent strand in the literature by exploring the role of the success of new public debt auctions, as captured by bid-to-cover ratios, for secondary market yields of euro-area debt, the role of the crisis and market volatility in this connection, and rationalizing these roles in an asymmetric information framework.

This chapter is also, albeit somewhat more remotely, related to the expanding literature on the sovereign debt yields in the Eurozone during the crisis. Examples are Beber *et al*. (2009), Favero *et al*. (2010), Von Hagen *et al*. (2011), Monfort and Renne (2014), Ejsing *et al.* (2015), Pozzi and Wolswijk (2012), Mohl and Sondermann (2013), Christiansen (2014), De Santis (2014) and Cipollini *et al*. (2015). However, these papers do not specifically study primary debt auctions and the relationship between their success and the formation of secondary-market yields. Some of these papers focus on country risk and liquidity, while others study the integration of the Eurozone bond markets.

The remainder of this chapter is structured as followed. The next section describes the auctioning process. Section 3 presents the theoretical model, while Section 4 describes the data and provides some key statistics. In Section 5 we present and discuss the regression results. Finally, Section 6 concludes the main body of the paper.

3.2 Description of the debt auctioning processes

Issuance and management of national public debt in the euro area is carried out by the national debt management offices. Based on the expected government deficit and the amount of maturing government debt that has to be rolled-over, the debt management office decides on an annual funding target. Auctions are the most important mechanism through which the debt management offices fulfill their funding targets. Participation in auctions is limited to a selected group of primary dealers who have to satisfy minimum participation requirements in the auction and minimum quoting obligations on the secondary market.[20]

The debt management office announces the auction dates in an annual calendar that is published before the new calendar year starts. It has the discretion to change the calendar during the year. To inform market participants of calendar changes and provide them with additional information about the auction in a timely manner, most debt management offices publish a monthly or quarterly update to the annual calendar.[21]

[20] Strictly speaking, Germany does not use a primary dealer system. Provided it meets a minimum participation requirement in the primary market, any credit institution domiciled in the EU can access the “Bund Issues Auction Group”. Nevertheless, the participants in this Group are typically the major financial institutions.

[21] France issues a monthly calendar with auction dates. Germany issues a quarterly calendar with the specific bond to be issued and an indicative amount. Italy publishes a quarterly calendar with minimum amounts for re-openings of previously issued bonds and coupons for new issues. Belgium does not publish updates to the annual calendar.

Figure 3.1 depicts the process for an auction at date *t*. A few days before the auction, the debt management office announces the auction in a press statement. The statement confirms the auction date, states the maturity of the bond(s) to be auctioned and provides a target volume or a target range for the volume. The German and Italian debt management offices make this announcement respectively six and three days before the auction. The French debt management office makes the announcement on the Friday before an auction, which takes place on Tuesdays or Thursdays. In the case of Belgium, the auction date is confirmed and the specific bond to be auctioned is announced on the Monday of the week before the week in which auction takes place, while the target range for the volume is published on the Friday before the auction.

On auction date *t*, primary dealers submit their bids during the pre-announced time window. The German, Italian, Belgian and French auctions all take place before noon. The results are published as soon as possible after the auction. They are published in a press statement that contains information on the amount bid, the amount issued and the bid-to-cover ratio. Market participants are often updated on the auction outcomes via newswires that provide them with real-time market information. Our own inspection of a screenshot from a Bloomberg terminal shows the bid-to-cover ratio in comparison to the bid-to-cover ratio in the previous auction and the average bid-to-cover ratio in the previous four auctions.

Settlement of the auctioned bonds takes place on the second working day after the auction, *t+2*. The secondary market yield at the end of day *t-1* is thus observed after the auction has been announced, while the secondary market yield at the end of auction date *t* is observed after the auction results have been made public.

While the auctions of the different countries in our sample share many features, there are also some differences. Belgium, France and

Germany use multiple-price auctions, in which successful bidders pay the price quoted in their bid, while Italy uses single-price auctions, in which all successful bidders pay the cut-off price. Moreover, France, Italy and Belgium offer primary dealers the possibility to purchase a limited amount of bonds in a non-competitive round after the auction results have been made public.

3.3 A theoretical framework

The auction mechanisms for public debt of the countries in our sample assign a key role to the primary dealers for the formation of the price of the issued debt. Here, we present a simple portfolio model that relates the eventual price of the security that is auctioned, and of other securities in the portfolio of the primary dealers, to the bid-to-cover-ratio in the auction.

There are K bonds with $K \times 1$ stochastic pay-off vector v. We assume that Bond 1 is auctioned. The other bonds, which we shall refer to as "Bonds 2" are already traded in the secondary market and one or more of them may be close substitutes to Bond 1, or even be identical to Bond 1 in the case of a reopening of an existing instrument. *Prior* to the auction, the expected pay-off of the bonds based on all public information, including information from previous auctions, is $E[v] = \bar{v}$. There are $N > 2$ primary dealers, who bid for both Bond 1 and trade in Bonds 2. *Just before and during* the auction, information is released about the "quality" of Bond 1 that affects its demand. This information, in the form of an individual signal $s_{1,n} = v_1 - \bar{v}_1 + \varepsilon_{1,n}$ to primary dealer n, may come for example from observing the order flow from the primary dealer's customers (e.g., see Lyons, 1995). Here, v_1 is normally distributed with mean $\bar{v}_1$, while all individual noise terms $\varepsilon_{1,n}$ are normally distributed with mean zero and variance σ_ε^2. Further, v_1 and all $\varepsilon_{1,n}$ are uncorrelated.

A stronger order flow suggests a higher demand for the asset compared to the target volume and, hence, a higher pay-off on the asset. Primary dealers shift their demand schedule outward implying a higher bid-to-cover ratio and, hence, a higher equilibrium price at which the auction is settled. For bonds closely substitutable to the auctioned bond and already traded on the secondary market we will for a given before-auction yield observe a lower yield after the auction. We will also see that the reduction in the post-auction yield will be larger the more uncertain the fundamental value of the asset is. Our empirical results in the ensuing sections will be strongly in line with these theoretical findings.

An alternative to the model set up here would be to use a framework that models the auctioning process explicitly. However, the typical auction model, see e.g. Back and Zender (1993), applied to public debt auctions answers questions that differ from the ones we focus on, and does not embed the information arising from the bid-to-cover ratio that has an effect on secondary markets – an effect for which we report substantial evidence later in the paper. The typical auction model also does not allow for any role of market volatility to affect the strength of the signalling effect.

We assume that the primary dealers take the price impact of their trades in the auction of Bond 1 into account. This follows Kyle (1989). The situation in the market can be viewed as a simplified version of that in the debt auction model of Boyarchenko *et al.* (2016). Apart from the primary dealers, who also trade in Bonds 2, there are also M large traders, who only trade in Bonds 2 and have no special information. Both the primary dealers and the large traders take the prices of the Bonds 2 as given. In view of the fact that the secondary market is larger than the primary market, this seems a reasonable assumption. Unlike Boyarchenko *et al.* (2016) we assume that there are no noise traders.[22] To obtain closed-form expressions, we need to assume that all traders are equally risk averse with absolute risk aversion $A \equiv A_n = A_m$ for all $n = 1,..,N$ and $m = 1,..,M$.

We focus on a rational-expectations equilibrium such that the primary dealers use their individual signal and the equilibrium price vector p as information, while the large traders use p as information. We postulate, and later see this confirmed, that the information set $(s_{n,1}, p)$ or p is equivalent to the average signal $\bar{s}_1 = \frac{1}{N}\sum_{n=1}^{N} s_{1,n}$. Denote the *conditional* variance-covariance matrix of the bond values given the average signal $\bar{s}_1$ as

$$Var(v|\bar{s}_1) = \begin{pmatrix} \sigma_{11} & \sigma_{12} \\ \sigma_{21} & \Sigma_{22} \end{pmatrix}.$$

To analyze the equilibrium, it is convenient to introduce a hedged Bond 1* with price $p_1^* = p_1 - \beta' p_2$ with p_1 the price of Bond 1, p_2 the price vector of Bonds 2 and $\beta = \Sigma_{22}^{-1}\sigma_{12}$. It is easy to see that the conditional variance-covariance matrix of the pay-offs of the hedged Bond 1* and the vector of Bonds 2 is:

$$Var\left(\begin{matrix} v_1 - \beta' v_2 \\ v_2 \end{matrix} \middle| \bar{s}_1\right) = \begin{pmatrix} \sigma_{11}^* & 0 \\ 0 & \Sigma_{22} \end{pmatrix},$$

where $\sigma_{11}^* \equiv \sigma_{11} - \sigma_{12}\Sigma_{22}^{-1}\sigma_{21}$. Each primary dealer $n \in \{1,..,N\}$ maximizes a one-period CARA utility function. Hence, using standard

[22] As a result, the equilibrium price in our setting will fully reveal the average signal $\bar{s}_{1,n}$. This will greatly simplify the algebra, but not materially change the results associated with the bid-to-cover ratio, because noise does not lead to a systematic bias in the prices.

theory (see de Jong and Rindi, 2009, Subsection 2.3), his demand for hedged Bond 1* is

$$x_{1,n}^* = \frac{E[v_1^*|\bar{s}_1] - p_1^*}{A\sigma_{11}^* + \lambda_1},$$

with $\lambda_1 \equiv dp_1/dx_{1,n}$ the effect on the Bond 1 price of dealer n's demand $x_{1,n}$ for Bond 1. We will solve for λ_1 below and confirm that it is positive. A less noisy signal implies a lower conditional variance σ_{11}^* and, hence, for a given price p_1^*, a good signal leading to a higher posterior valuation $E[v_1^*|\bar{s}_1]$ of Bond 1* has a stronger positive effect on demand. More risk aversion A makes demand less sensitive to the difference between the posterior valuation $E[v_1^*|\bar{s}_1]$ and the price p_1^*.

Similarly, the optimal demand of primary dealer n for the other Bonds 2 is the sum of the speculative demand for Bonds 2,

$$x_{2,n}^* = A^{-1}\Sigma_{22}^{-1}(E[v_2|\bar{s}_1] - p_2),$$

and the demand that comes from the hedge of Bond 1. Hence, the total demands for Bonds 1 and 2 by primary dealer n are:

$$x_{1,n} = x_{1,n}^*,\ x_{2,n} = x_{2,n}^* - \beta x_{1,n}^*.$$

The (one-period CARA utility maximizing) large trader m only has a speculative demand for Bonds 2:

$$x_{2,m} = A^{-1}\Sigma_{22}^{-1}(E[v_2|\bar{s}_1] - p_2).$$

The price impact λ_1 follows from the equilibrium condition in the hedged Bond 1*. Taking the demands of the other dealers and p_2 as given, the demand of primary dealer n for Bond 1 must satisfy:

$$\lambda_1 = \frac{dp_1}{dx_{1,n}} = \left[(N-1)\frac{1}{A\sigma_{11}^* + \lambda_1}\right]^{-1}$$

This can be solved to give:

$$\lambda_1 = (N-2)^{-1}A\sigma_{11}^*.$$

Substituting this into the demand function for Bond 1 gives:

$$x_{1,n} = \frac{E[v_1^*|\bar{s}_1] - p_1^*}{A^*\sigma_{11}^*},$$

where $A^* \equiv A(N-1)/(N-2)$. Market equilibrium in Bond 1 gives the condition:

$$X_1 = N\frac{E[v_1^*|\bar{s}_1] - p_1^*}{A^*\sigma_{11}^*}.$$

Rewriting, and using the expression for p_1^*, we get

$$p_1 = E[v_1|\bar{s}_1] - \beta'(E[v_2|\bar{s}_1] - p_2) - N^{-1}A^*\sigma_{11}^*X_1 .$$

The equilibrium condition for Bonds 2 is:

$$X_2 = \sum_{n=1}^{N} x_{2,n} + \sum_{m=1}^{M} x_{2,m}$$

$$= (N+M)A^{-1}\Sigma_{22}^{-1}(E[v_2|\bar{s}_1] - p_2) - \beta\sum_{n=1}^{N} x_{1,n}$$

which implies, substituting $X_1 = \sum_{n=1}^{N} x_{1,n}$ and using the definition of β,

$$p_2 = E[v_2|\bar{s}_1] - (N+M)^{-1}A(\sigma_{21}\, X_1 + \Sigma_{22}\, X_2).$$

Substituting this into the above equilibrium price for p_1 yields:

$$p_1 = E[v_1|\bar{s}_1] - \beta'(N+M)^{-1}A(\sigma_{21}\, X_1 + \Sigma_{22}\, X_2) - N^{-1}A^{*}\sigma_{11}^{*}X_1.$$

Working this out and collecting the coefficients on X_1 and X_2 we can write:

$$p_1 = E[v_1|\bar{s}_1] - (N+M)^{-1}A(\tilde{\sigma}_{11}\, X_1 + \sigma_{12}\, X_2)\,,$$

with $\tilde{\sigma}_{11} \equiv \left(1+\frac{M}{N}\right)\left(\frac{N-1}{N-2}\right)\sigma_{11}^{*} + \sigma_{12}\Sigma_{22}^{-1}\sigma_{21}$.

This expression warrants some remarks. First, the presence of large traders, $M > 0$ produces a lower market risk aversion $(N+M)^{-1}A$, implying a reduction in the effect of the supply of the assets on the price of Bond 1. Second, the fact that the primary dealers take into account the price impact of their demand is responsible for the term $\frac{N-1}{N-2} > 1$ in $\tilde{\sigma}_{11}$ and magnifies the effect of X_1 on p_1.

Finally, the equilibrium price equations for p_1 and p_2 confirm our hypothesis that observing the average signal is equivalent to observing the equilibrium prices, because

$$E\left[v_j|\bar{s}_1\right] = \bar{v}_j + \frac{Cov\left(v_j, \bar{s}_1\right)}{Var(\bar{s}_1)}\bar{s}_1$$

and, hence, the equilibrium prices p_1 and p_2 are functions of $\bar{s}_1$ and known parameters. Note that observing the dealer's private signal $s_{1,n}$ does not provide any information in addition to $\bar{s}_1$, because it is easily shown that $E\left[v_j|\bar{s}_1, s_{1,n}\right] = E\left[v_j|\bar{s}_1\right]$. In practice, primary dealers submit their demand schedule, i.e. an order size conditional on the market price. The schedule thus indicates how much they will buy at which maximum price.

Some further clarification of the price formation mechanism in the secondary market may be useful. Our dealers simultaneously trade in the primary and secondary markets, optimally and rationally using their information. Secondary markets are frictionless. However, the institutional setup of the auction produces a friction, because the primary dealers are forced to absorb the full quantity of the auction supply. This equilibrium condition implies a downward pressure on the price of the auctioned Bond 1, as well as a hedging pressure on the prices of Bonds 2 in the secondary market, due to the simultaneous trading by the dealers in both the primary and secondary market.

3.3.1 Bid-to-cover ratio with inelastic supply

Now assume that Bond 1 is auctioned, creating an additional supply $\bar{Q}_1$, whereas there is no auction of Bonds 2. We use our model to perform a 'marginal' analysis, looking at the impact of the additional supply on the equilibrium prices. Hence, we choose $(X_1, X_2) = (\bar{Q}_1, 0)$ and the bond prices on the auction day (indicated by superscript "a") are:

$$p_1^a = \bar{v}_1 + \frac{Cov(v_1,\bar{s}_1)}{Var(\bar{s}_1)}\bar{s}_1 - \tilde{A}\tilde{\sigma}_{11}\bar{Q}_1 \,, \tag{3.1}$$

$$p_2^a = \bar{v}_2 + \frac{Cov(v_2,\bar{s}_1)}{Var(\bar{s}_1)}\bar{s}_1 - \tilde{A}\sigma_{21}\bar{Q}_1 \,,$$

with $\tilde{A} \equiv (N+M)^{-1}A$. The bid-to-cover ratio in the auction for Bond 1 is determined by a reservation price p_1^R set in advance by the Treasury agent. The reservation price is unobservable to us. However, as will become clear below, for our purposes there is no need to directly observe it. It is likely to be implicit in reality, in that there is an understanding between the Treasury agent and the primary dealers that bids at unrealistically low prices will not only not get accepted, but can even be detrimental for the on-going relationship of the primary dealer with the Treasury agent. The reservation price likely reflects information that is available before the auction. The amount bid at the reservation price, $\tilde{Q}_1$, follows from the equilibrium price curve (3.1) for Bond 1:

$$p_1^R = \bar{v}_1 + \frac{Cov(v_1, \bar{s}_1)}{Var(\bar{s}_1)} \bar{s}_1 - \tilde{A}\tilde{\sigma}_{11}\tilde{Q}_1 \ ,$$

Notice that $\tilde{Q}_1$ depends on the signal $\bar{s}_1$ and is therefore only realized after the auction. In line with the empirical observation that bid-to-cover ratios generally exceed one, we assume that the reservation price p_1^R is sufficiently small that the likelihood that $\tilde{Q}_1$ falls below $\bar{Q}_1$ is low. In the rare cases in which $\tilde{Q}_1$ falls below $\bar{Q}_1$, the Treasury agent simply limits the actual supply to $\tilde{Q}_1$. However, in the following we will not deal with these cases. We can also derive a relationship between the equilibrium prices of the bonds and $\tilde{Q}_1$. Combining the above expressions for p_2^a and p_1^R, after some re-writing we find

$$p_2^a = \bar{v}_2 + \frac{\sigma_{21}}{\sigma_{11}} \left(p_1^R - \bar{v}_1 + \tilde{A}\tilde{\sigma}_{11}\tilde{Q}_1 \right) - \tilde{A}\sigma_{21}\bar{Q}_1 \ , \qquad (3.2)$$

where we have used that, given the structure of the signals, $Cov(v_j, \bar{s}_1) = Cov(v_j, v_1)$ and that the relationship between the conditional covariance σ_{21} and the unconditional covariance $Cov(v_2, v_1)$ is given by $\sigma_{21} = Cov(v_2, v_1)\left[1 - \frac{Var(v_1)}{Var(s_1)}\right] = \frac{Cov(v_2,v_1)}{Var(v_1)}\sigma_{11}$, hence that $\frac{\sigma_{21}}{\sigma_{11}} = \frac{Cov(v_2,v_1)}{Var(v_1)}$.[23] This equation gives an immediate relationship between the prices of Bonds 2 and the bid-to-cover ratio $\tilde{Q}_1/\bar{Q}_1$ of the form:

$$p_2^a = \bar{v}_2 + \frac{\sigma_{21}}{\sigma_{11}}(p_1^R - \bar{v}_1) - \bar{A}\sigma_{21} + \frac{\sigma_{21}}{\sigma_{11}}\bar{A}\tilde{\sigma}_{11}\left(\frac{\tilde{Q}_1}{\bar{Q}_1}\right), \qquad (3.3)$$

where $\bar{A} \equiv \tilde{A}\bar{Q}_1$. With the exception of the bid-cover ratio $\tilde{Q}_1/\bar{Q}_1$, all the elements on the right-hand side of this equation are predetermined before the auction outcome is known. We see that the prices of Bonds 2 on the auction day depend on the bid-to-cover ratio with a coefficient that is proportional to the "beta" of Bonds 2 with respect to the auctioned bond, i.e. $\frac{\sigma_{21}}{\sigma_{11}}$; the risk aversion in the market relative to the amount auctioned, i.e., $\bar{A}$; and the uncertainty, given the aggregate signal $\bar{s}_1$, about the auctioned bond's pay-off, i.e. $\tilde{\sigma}_{11}$. A better realization of the bid-cover ratio is the result of a better aggregate signal $\bar{s}_1$. Because the latter is the sum of the fundamental value, or "quality" of the auctioned instrument, and a noise term, a better realization of the fundamental value tends to shift the demand curve for the auctioned bond to the right and will on average produce higher bid-to-cover ratios. More uncertainty about the fundamental value produces more uncertainty in the bid-to-cover ratio,

[23] Using the expression for the reservation price, we can write $\frac{Cov(v_1,\bar{s}_1)}{Var(\bar{s}_1)}\bar{s}_1 = p_1^R - \bar{v}_1 + \tilde{A}\tilde{\sigma}_{11}\tilde{Q}_1$. The expression for p_2^a we can write as $p_2^a = \bar{v}_2 + \frac{Cov(v_2,\bar{s}_1)}{Cov(v_1,\bar{s}_1)}\frac{Cov(v_1,\bar{s}_1)}{Var(\bar{s}_1)}\bar{s}_1 - \tilde{A}\sigma_{21}\bar{Q}_1$. Hence, $p_2^a = \bar{v}_2 + \frac{Cov(v_2,v_1)}{Cov(v_1,v_1)}\frac{Cov(v_1,\bar{s}_1)}{Var(\bar{s}_1)}\bar{s}_1 - \tilde{A}\sigma_{21}\bar{Q}_1 = \bar{v}_2 + \frac{Cov(v_2,v_1)}{Cov(v_1,v_1)}\left(p_1^R - \bar{v}_1 + \tilde{A}\tilde{\sigma}_{11}\tilde{Q}_1\right) - \tilde{A}\sigma_{21}\bar{Q}_1$, after substituting. This simplifies to (3.2).

which translates into more uncertainty in the secondary-market yield after the auction.

Most of the auctions are re-openings of existing issues. In this case, the dealers can hedge perfectly in the secondary market, so that $\sigma_{11}^* = 0$ and $\sigma_{12}\Sigma_{22}^{-1}\sigma_{21} = \sigma_{11}$, hence $\tilde{\sigma}_{11} = \sigma_{11}$.[24] In this case, the auction price equation (3.3) simplifies to

$$p_2^a = \bar{v}_2 + \frac{\sigma_{21}}{\sigma_{11}}(p_1^R - \bar{v}_1) + \sigma_{21}\bar{A}\left(\frac{\tilde{Q}_1}{\bar{Q}_1} - 1\right). \qquad (3.3')$$

For the re-opened instrument, the following testable implications may be drawn from the expression for p_2^a:

(i) a higher bid-to-cover ratio $\tilde{Q}_1/\bar{Q}_1$ will be associated with a higher price, or a lower yield of the secondary market instrument, after the auction,

(ii) the positive effect of a given increase in the bid-to-cover ratio on the secondary market yield of the instrument will be larger if fundamental uncertainty about the value of the instrument σ_{11} is higher.

The intuition for testable implication (ii) is that higher market volatility produces more steeply downward-sloping demand curves, *ceteris paribus*. Hence, to generate the same increase in the bid-to-cover ratio, a more positive average signal is needed, resulting in a higher post-auction price. We measure the uncertainty about the fundamental value of the auctioned instrument using the observed volatility in the secondary market yield. In

[24] Technically, we can solve this setting more easily by removing the 'hedged' asset 1 and including the auctioned bond in a vector of all traded bonds. All traders (dealers and large traders) then act as price takers in all bonds. This method also leads to auction price equation (3').

other words, when market volatility is higher, we expect to find that a higher post-auction price, i.e. a lower post-auction yield, is associated with a higher bid-to-cover ratio.

When the auctioned and the secondary market instruments are not identical, we will always consider situations in which the two are highly substitutable, because they are of the same type, the same country and almost the same maturity. We can write $\tilde{\sigma}_{11} = \sigma_{11} + \left(\frac{M}{N}\right)\left(\frac{N-1}{N-2}\right)(\sigma_{11} - \sigma_{12}\Sigma_{22}^{-1}\sigma_{21})$. Hence, if the secondary-market instrument is a close substitute for the newly-issued bond, the latter can be hedged well with the secondary-market instrument and $\tilde{\sigma}_{11}$ is close to σ_{11}. Combined with the fact that the "beta" of the secondary market instrument with the auctioned instrument is positive in this case, this implies that testable implication (ii) continues to hold. Because $\tilde{\sigma}_{11}$ is close to σ_{11}, which in turn is close to the conditional variance of the fundamental value of the secondary-market instrument when substitutability is high, we proxy $\tilde{\sigma}_{11}$ with the observed yield volatility on our secondary-market instrument.

3.3.2 Bid-to-cover ratio with elastic supply

So far, we assumed that the supply in the auction is fixed. It is conceivable that the debt management office adjusts the supply of the issued bond to the success of the auction. For example, as discussed in more detail below, the German and Italian debt agents allow themselves the possibility to vary the eventual supply. Hence, a higher auction price induces more supply:

$$Q_1^s = \bar{Q}_1 + \theta(p_1 - p_1^R), \tag{3.4}$$

where $\bar{Q}_1$ could be interpreted as a minimum target supply, which is achieved when the auction price equals the reservation price p_1^R, while variations in p_1 relative to p_1^R trace out the actual supply. Appendix 3.A shows that now:

$$p_2^a = \bar{v}_2 + \frac{\sigma_{21}}{\sigma_{11}}(p_1^R - \bar{v}_1) - \frac{\bar{A}\sigma_{21}}{1+\theta\tilde{A}\tilde{\sigma}_{11}} + \frac{\sigma_{21}}{\sigma_{11}}\frac{\bar{A}\tilde{\sigma}_{11}}{1+\theta\tilde{A}\tilde{\sigma}_{11}}\frac{\tilde{Q}_1}{\bar{Q}_1}\left(1 + \theta\tilde{A}\frac{MN-1}{NN-2}\sigma_{11}^*\right) \tag{3.5}$$

A higher bid-to-cover ratio $\tilde{Q}_1/\bar{Q}_1$ will be associated with a higher price, or a lower yield on the secondary market instrument, after the auction. In the case of a re-opening, $\sigma_{11}^* = 0$ and $\tilde{\sigma}_{11} = \sigma_{11}$. Hence, the price effect of a given increase in the bid-to-cover ratio will be larger if uncertainty about the fundamental value of the instrument is higher.[25] Moreover, in this case a given increase in the bid-to-cover ratio produces a smaller increase in the price after the auction when the elasticity of the supply θ is higher: a more favorable signal pushes the auction price up and induces the Treasury agent to expand the supply, which in turn dampens the price increase. In the case of the issuance of a new instrument and a highly substitutable secondary-market instrument, σ_{11}^* is small and $\tilde{\sigma}_{11}$ is close to σ_{11}, which suggests that testable implication (ii) continues to hold.

3.4. Data description and key statistics

The theoretical implications of our simple model will be tested on changes in secondary market yields around the auction. The use of secondary market data allows us to calculate yield changes on the same instrument before and after the auction, which would not be possible for newly issued

[25] This is seen immediately by noting that the term in front of the bid-to-cover ratio is increasing in $\tilde{\sigma}_{11}$.

instruments. In this case, the new instrument will become the secondary market benchmark instrument in one of the following days. Because the newly created and the existing instrument are essentially identical, except for relatively small differences in maturity and liquidity, their pay-offs should be highly correlated and any information released through the auction should be relevant also for secondary market instruments with the same headline maturity.[26] In fact, most of the auctions are re-openings in which an existing instrument is auctioned. However, even when the auctioned instrument already exists, primary and secondary market yields may not be directly comparable. For example, the Italian Treasury provides primary dealers with discounts for having collected bids from the public. One may expect such discounts to be taken into account by the primary dealers in their bidding decisions. Other peculiarities may affect this and other primary markets. Hence, rather than using the difference between the primary market post-auction and the secondary market pre-auction yields for our analysis, we use the change in the secondary market yield of existing instruments around the auction.

We intend to link secondary market yield movements in euro area debt markets to the success of new debt auctions. This success will be measured by the bid-to-cover ratio. A key question is how to measure the bid to cover ratio. One possibility is to use the total amount bid over the amount that is actually allotted. The complication here is that, in line with the case of the elastic supply discussed in the previous section, some treasuries have the possibility to restrict the volume supplied if during the auction demand turns out to be lower than foreseen. We will make no attempt at estimating the Treasury's supply curve, but instead calculate the bid-to-cover-ratio used in our empirical analysis as the total amount

[26] The empirical analysis in Beetsma *et al*. (2016) shows that yield changes on instruments with maturity differences of one year tend to be very similar around public debt auctions.

bid over (as detailed below) the target volume or the upper end of the target range announced before the auction, because these can be taken as pre-determined in the regression analysis.

We combine data on sovereign bond auctions in Germany, Belgium, France and Italy with data on secondary market yields for the period from 1 January 1999 until 31 July 2014. We focus on the 2-, 5-, 10- and 30-year maturity segments.[27] Based on the outstanding amounts of sovereign debt, these are the four largest euro area countries for which we can construct bid-to-cover ratios.[28] The French and Belgian debt management offices announce a target range for the combined volume of all the issued maturities on the auction day. For these countries, we calculate the bid-to-cover ratio as the sum of the amounts bid for the all maturities issued on the auction day over the upper bound of the target range. The Italian debt management office used to announce the exact auction volume, so the debt management office did not have the discretion to scale down bids. However, from October 2008 onwards, it started to announce a target range for each issued maturity on the auction day. Hence, before October 2008 we calculate the bid-to-cover ratio for Italy as the amount bid over the target volume. From October 2008 onwards, the bid-to-cover ratio is calculated as the amount bid over the upper bound of the target range. In the case of 2-year zero coupon bonds (the so-called "CTZs"), this switch (and the corresponding adjustment in our calculation) took place in December 2011. The situation in Germany is slightly different. The German debt agency announces a target volume for each individual auction of sovereign bonds. However, during the auction the Treasury issues only a portion of the target volume. In contrast to the

[27] For Belgium, the number of auctions with a 2-year maturity is limited, so we replace these auctions with those of the 3-year maturity debt instead.

[28] Beetsma *et al.* (2016b) also include The Netherlands and Spain in their analysis. We do not avail of data on the target supply for Spain, while The Netherlands issues bonds via tap auctions, in which bids are instantaneously allotted and the bid-to-cover ratio is one by construction.

other countries in our sample, the German debt management office tends to retain a substantial amount of the targeted supply. The amounts retained are on average 15.6%, 18.0%, 18.4% and 17.3% of the target volumes for the 2-, 5-, 10- and 30-year auctions. This leaves Germany with greater discretion to scale down bids than the other countries in our sample. Again, to avoid issues of endogeneity, we calculate the bid-to-cover ratio for Germany as the ratio of the amount bid and the announced target volume for the auction.

Data on primary market issuance are taken from Bloomberg, which reports for each auction the auction date, the maturity of the new issue, the total amount bid, the total amount allotted and the average accepted yield or the marginal yield. We cross-check the Bloomberg data with data from the countries' debt management offices, from which we also collect data on the targeted auction supplies. Data on secondary market yields are also taken from Bloomberg.

Table 3.1 shows the means and standard deviations of the daily yield changes on the secondary markets for 2-, 5-, 10- and 30-year debt for the countries in our sample. The yield changes are on average negative, hence the yields are on a downward trend on average during the sample period. We observe that the volatility of the daily yield changes, as measured by their standard deviations, tends to be highest for Italy and lowest for Germany. Volatility also tends to be higher for shorter maturities than for long maturities.

Table 3.2 reports summary statistics for the sovereign bond auctions. The frequencies and the sizes of the issues are larger for the 2-, 5- and 10-year maturities than for the 30-year maturities. Our sample consists of 491 auctions of the 2-year maturity, 534 auctions of the 5-year maturity, 545 auctions of the 10-year maturity and 200 auctions of the 30-year maturity. The average auction size is largest for the 10-year auctions and smallest for the 30-year auctions. The frequencies and sizes of the auctions also differ across the countries. Italy and France have a higher frequency than Germany and Belgium. The average allotment is highest in Germany and France. The average bid-to-cover ratio is highest for France, ranging from 2.36 for 30-year auctions to 2.87 for 2-year auctions.

Figure 3.2 shows the bid-to-cover ratios and the histograms of their frequency distributions for the countries in our sample. Visual inspection suggests that the bid-to-cover ratio is on average reasonably stable over time, except maybe in the case of Italy where there seems to be some tendency for it to fall over the sample period. To a lesser extent this also seems to be the case for France. Table 3.3 reports summary statistics for the bid-to-cover ratio. We are particularly interested in the spread of the bid-to-cover ratio. Standard deviations range from 0.35 to about 0.80, while the difference between the maximum and minimum values can exceed 4.5. Finally, Figure 3.3 depicts secondary-market yield changes on auction days and their frequency distributions. Exceptionally large yield changes appear to be very rare.

3.5 Estimation results

3.5.1. Baseline regressions

For a given maturity *m* and for a panel of countries *j* consisting of Germany, France, Belgium and Italy, we estimate

$$\Delta y_t^j = c_0^j + AUC_t^j\left(\alpha + \beta \widetilde{BC}_t^j\right) + \varepsilon_t^j, \qquad (3.6)$$

where c_0^j is a country-specific constant, Δy_t^j is the change in the secondary market closing yield between the end of day *t* and the end of day *t*-1 for the benchmark maturity-*m* bond, AUC_t^j is a dummy that takes a value of 1 if an auction of a bond with maturity *m* takes place at time *t* in country *j* and a value of zero otherwise, and $\widetilde{BC}_t^j$ is the value of the bid-to-cover ratio for the maturity-*m* auction at time *t* in country *j*, potentially in deviation of its sample average or from some other benchmark value. Further, ε_t^j is a disturbance term. Equation (3.6) is estimated separately for 2-, 5-, 10- and 30-year auctions as a panel using ordinary least squares with country-fixed effects and Newey-West adjusted standard errors to control for potential serial correlation and heteroscedasticity in the errors. The fixed effects may capture potential systematic differences in yield changes arising from differences in the type of auction or from factors specific to the country under consideration. All variables in (3.6), including the bid-to-cover ratio in deviation from its benchmark, are maturity specific. However, to save on notation, we abstain from attaching a maturity index to the symbols in (3.6).

Our theoretical model is only a one-period model that does not account for the possibility that the Treasury updates its reservation price as a function of the outcomes of previous auctions. According to equation (3.3), this would imply a time-varying intercept in the regressions. Because such updating behavior may be empirically relevant, we will consider variants of (3.6) with the bid-to-cover ratio in deviation from some plausible benchmark.[29] It is *a priori* not clear what should be the best benchmark. The debt management office brings out a press release about the outcome of the auction and reports the bid-to-cover ratio itself, while, in line with their customers' preferences, newswires often choose their own way of presenting the auction outcome in deviation from the

[29] Allowing for the benchmark to change on the basis of preceding auction results effectively produces a time-varying intercept and circumvents the problem of not being able to directly observe the reservation price. Notice from (3.3) that $\tilde{Q}_1$ varies with the reservation price. Hence, changes in the benchmark for the bid-to-cover ratio can capture updates of the reservation price on the basis of previous auction results.

performance of previous auctions. Because there is no uniform way in which newswires present auction outcomes, we will consider some commonly-used benchmarks to measure the success of the auction.

In total we consider four versions of equation (3.6), each with a different specification for $\widetilde{BC}_t^j$. The first column of Table 3.4 reports estimates when we include the bid-to-cover ratio in deviation of its sample average. The second column of Table 3.4 is based on the bid-to-cover ratio in deviation of its previous value, the third column on the bid-to-cover ratio in deviation of the average over the preceding four auctions and the fourth column on the bid-to-cover ratio in deviation of its average over the year preceding the current auction.

Table 3.4 shows that auctions are typically associated with an increase in secondary market yields, which is in line with the findings in the literature (Lou *et al.*, 2013, and Beetsma *et al.*, 2016). This finding can be explained by the fact that primary dealers and other investors need to be compensated for the market risk in their inventories of assets that are perfectly or closely substitutable for the newly-issued debt (see Section 3). The coefficient on AUC_t^j can be interpreted as the average yield increase between the end of the auction day and the end of the preceding day. This average yield increase ranges from 0.7 to 1.5 basis points. For all four specifications and all maturities in our sample, in line with our theoretical model, we estimate a highly significant negative effect of the bid-to-cover ratio in deviation from its benchmark on the secondary market yield change. An increase in the bid-to-cover ratio by one, holding constant the benchmark, reduces the yield in the secondary market after the auction by one to two basis points *ceteris paribus*. These results suggest that market participants do indeed pay attention to whether the current bid-to-cover ratio is “unusually” high or low.[30]

To check whether the cross-country equality of the regression coefficients imposed in the panel estimation of (3.6) is justified, we also estimate (3.6) for each of our four countries individually. We report the results in Appendix 3.B. Although the precision of the coefficient estimates obviously falls, we still observe that the estimate of the coefficient of $\widetilde{BC}_t^j$ is negative in sixty-one out of the sixty-four cases. In many instances it is significant or highly significant. In none of the instances in which the coefficient estimate is positive is it significant. In addition, the estimate of the constant in the regression is positive in an overwhelming majority of the cases.[31] These findings provide support for our panel set-up, to which we stick henceforth.

Based on our estimates, and following the more detailed illustration in Beetsma *et al.* (2016), we can make a back-of-the-envelope calculation of the proceeds of an auction that performs worse than expected. We estimate the effect on the proceeds by exploiting information on the yield movements in the secondary market of an asset that is identical to or very closely substitutable for the asset that is auctioned. Ruling out arbitrage ensures that the unobserved yield

[30] As a check we also estimated the model for auction days only. As a result we could no longer estimate α. The estimates for β remained numerically completely identical. Further, we estimated the model on the full sample by including in (3.6) as an additional regressor at each date t the latest value of the bid-to-cover ratio in deviation from its benchmark. All original parameter estimates remained numerically almost identical, as well as always the same in terms of significance. The coefficient on the additional regressor was always close to zero and insignificant. Finally, while the Newest-West correction produces autocorrelation- (and heteroscedasticity-) consistent estimates, we also estimated (3.6) including in addition a first lag of the yield change. The bid-to-cover ratio in deviation from its benchmark always remained highly significant.

[31] We also calculate the explanatory power of the bid-to-cover ratio (in deviation from its benchmark) as one minus the ratio of the sum of the squared residuals of the baseline regression and the sum of the squared residuals when the bid-to-cover ratio (in deviation from its benchmark) is dropped from the regression. Because auctions take place only on a minority of the days, the samples underlying these regressions are limited to auction days only. Averaged over the maturities per country, our explanatory power measure ranges from 1% to 20%. However, we cannot discern a systematic pattern in these numbers. Hence, to save space we do not report them.

movement in the primary market should be very similar to the yield movement in the secondary market around the auction. We illustrate the calculation for a new 30-year Italian debt issue and consider the case of a bid-to-cover ratio that falls by one standard deviation (0.44 basis points). Based on the estimate of β reported in the (say) first column of Table 3.4, the yield on the new debt issue would be higher by roughly 0.87 basis points. For an issue of an average size of 1.55 billion euros (see Table 3.2), and an average duration of the 30-year bond of 16.36 years,[32] this translates into a reduction in the auction proceeds (value of the bond issue) by around 0.0087 * 16.36 * 1550 = 2.2 million euros.

3.5.2. Robustness

In this subsection we explore the robustness of our baseline regression results. Our first robustness test concerns the replacement of the end-of-previous day yield by the opening yield on the auction day. This allows us to explore whether the differences in the yield changes are mainly attributable to information released during the auction itself, or whether information released *prior* to the trading day also plays a role: it is conceivable that there exists *prior* information pointing to the potential success of the auction. In that case, overnight yields might already move in anticipation of the auction. Table 3.5 reports the results. For all three specifications and all maturities, a successful auction, as measured by a high bid-to-cover ratio in deviation from its benchmark, continues to exert a highly significant downward pressure on the secondary market yield. The estimates of the coefficient on the bid-to-cover ratio in deviation from its benchmark are very close to their baseline values.

[32] This average duration was calculated over three randomly chosen 30-year Italian auctions in 2006 and three randomly chosen 30-year Italian auctions in 2013.

We can also expand the event window by taking the difference between the yield at the end of the auction day with the yield at the end of two days before the auction or three days before the auction. To preserve space, we report the estimates in the Appendix 3.C. The responses of the yield changes to the bid-to-cover ratio (in deviation from its benchmark) remain essentially the same. The estimates of the direct effect of the auction dummy tend to increase somewhat if we expand the window before the auction, which is in line with the evidence of an auction cycle emerging a few days before the auction actually takes place (see Beetsma *et al*., 2016, 2018b).

Our baseline results in Table 3.4 are based on a pool of countries consisting of Germany, Belgium, France and Italy. Differences in auction procedures may result in different effects of auctions on secondary market yields across countries. For example, the withholding of a relatively large portion of the targeted new supply is unique for Germany. Hence, to check the robustness of our results we estimate the baseline regression while excluding one country at a time. The results for the full sample period are reported in Table 3.6. Generally, the coefficient estimates are close to the baseline estimates in magnitude, while they remain highly significant. Only when we exclude the 10-year German and 30-year Italian debt issues are the results weaker than under the baseline. This may be due to the fact that the number of 30-year debt issues is relatively small, while the relationship between the bid-to-cover ratio (in deviation from its benchmark) and the secondary market yield around the auction is quite strong for Italy.

Next, we explore whether the results are driven by individual observations, in which case the estimated values of the coefficients could be rather unreliable. Most interesting in this regard are the most extreme observations. Therefore, we drop for a given maturity for each country the observation associated with the largest value of $\widetilde{BC}_t^j$ and the observation associated with the smallest (i.e., most negative) value of $\widetilde{BC}_t^j$. Because there are four countries in the panel, in each estimation we drop eight "extreme" observations. The new estimates are reported in Table 3.7. They remain close to the baseline estimates in Table 3.4, hence the results are unlikely to be driven by some individual large (in absolute magnitude) observations.

The results in Table 3.4 could potentially also be influenced by market events that take place on auction days and that have an effect on changes in secondary market yields. Table 3.8 adds several variables to the specification in Table 3.4 to control for market conditions. In particular, the table controls for the first differences of the "Euro Stoxx Index", an index of stock prices in the Eurozone, the "Euro Stoxx Bank Index", an index of the stocks of banks in the Eurozone, the "CBOE Volatility Index" (VIX), to control for market volatility, and the "Euro Overnight Index Average" (EONIA), to control for interbank funding conditions. We include lags to rule out feedback effects, although using contemporaneous values would yield very similar results. Again, we find that the results of the extended specification in Table 3.8 are similar to those of the baseline specification in Table 3.4.

As a final robustness check, we control for potential changes in sovereign risk, which we measure by changes in the 5-year sovereign CDS-spread. Because we only have complete data on sovereign CDS-spreads from April 1, 2003 onwards, Table 3.9 reports estimates of the basic model (Panel A) and the model extended with the lagged change in the CDS spread (Panel B) over the period 1 April 2003 to 31 July 2014. Work by Shen *et al*. (2014) and Xiao *et al*. (2017) suggests that CDS prices may contain information that is not fully embedded in secondary-market bond prices. While the lagged change in the CDS spread always enters with a significantly positive coefficient, its presence as an explanatory variable never affects the significance of the bid-to-cover ratio (in deviation of its benchmark) and leaves the estimated size of its coefficient virtually unaffected.[33]

3.5.3. The role of the crisis

Previous work (Beetsma *et al.*, 2016, 2018b) has shown that the strength of the response of secondary market yields to new debt auctions is affected by the (intensity of the) recent economic and financial crisis. The occurrence of a crisis manifests itself in higher market volatility and, according to our theoretical model, we might expect the effect of the bid-to-cover ratio (in deviation of its benchmark) to be stronger than outside a crisis period. To explore this, we split the full sample period into the period before the recent economic and financial crisis, which we define as the period 1 January 1999 until 30 June 2007 and refer to as the "pre-crisis period", and the period since the start of the crisis, which we define as the period 1 July 2007 until 31 July 2014, and which we refer to as the "crisis period".

Table 3.1 reports the mean daily secondary-market yield changes and their standard deviations for the two sub-periods. We observe that the negative trend in the debt yield is almost exclusively confined to the crisis period. We also observe that during the pre-crisis period the volatilities of the different countries are very close to each other. Again, they tend to fall with the maturity of the outstanding debt. For each country and each

[33] We also find that the coefficient estimates on the lagged change in the CDS spread are virtually unaffected if we drop the bid-to-cover ratio (in deviation from its benchmark) from the regression equation. Including the current change in the CDS spread also leaves the coefficients on the bid-to-cover ratio virtually unaffected, although the estimates of the coefficient on the change in the CDS spread rise. This is not surprising, as changes in secondary market yields are likely to respond to changes in perceived default risk. Overall, we can conclude that bid-to-cover ratios and changes in CDS spreads are essentially orthogonal as driving forces behind secondary-market yield changes.

maturity, the volatility is higher during the crisis than during the pre-crisis period. During the crisis period the differences in the volatilities across the countries also start to widen. Italian volatilities are clearly higher than the volatilities of the other countries, while Belgium clearly comes as second highest in terms of volatilities. These clear differences for the two sub-periods justify the sample split in this subsection. Table 3.2 reports the summary statistics of the auctions for the two sub-periods. Except for Belgium we observe that the average bid-to-cover ratio falls between the pre-crisis and the crisis period.

Table 3.10 reports the estimates for the baseline regression when we make the parameters, and in particular the responses of the yield changes, dependent on the sub-sample periods. Specifically, we estimate the following equation:

$$\Delta y_t^j = DPRE * \left[c_0^{j,pre} + AUC_t^j * \left(\alpha + \beta \widetilde{BC}_t^j\right)\right] + (1 - DPRE) * \left[c_0^{j,crisis} + AUC_t^j * \left(\gamma + \delta \widetilde{BC}_t^j\right)\right] + \varepsilon_t^j, \tag{3.7}$$

where *DPRE* is a pre-crisis dummy with a value of 1 for the period January 1, 1999 – June 30, 2007, and zero, otherwise. Comparing the responses to a deviation of the bid-to-cover ratio from its benchmark, we observe that the responses during the crisis are systematically larger in absolute magnitude, i.e. more negative, than the pre-crisis responses, as is also clear from the in most cases significant or highly significant Wald test for the difference between the relevant coefficients. An increase in the current bid-to-cover-ratio by one reduces the yield change by between 0.5 and 1.7 basis points during the pre-crisis period, and by between 2.4 and 6.7 basis points during the crisis period. The test outcomes tend to be a bit weaker in the second column, where the benchmark for the current auction is the previous auction, which suggests that the other specifications may to be more appropriate to model the new information in the bid-to-cover ratio. Finally, except in one instance, the Wald test for the joint hypotheses $\alpha = \gamma$ and $\beta = \delta$ is always significant or highly significant. Overall, the success of the auction seems to provide a stronger signal to the secondary markets during the crisis than during the pre-crisis period.

Until now, we have demarcated the crisis by simply splitting the full sample into sub-samples. The implicit assumption was that during the entire second sub-sample the severity of the crisis was uniform. In reality, however, the intensity of the crisis varied a lot over this period. There were episodes of high tensions in the financial markets, while at other moments the markets were relatively tranquil. We now drop the division of the sample into sub-periods, and capture the intensity of the crisis directly through the volatility of the relevant market. Indeed, Beetsma *et al.* (2016) find that for the case of Italy yield movements in the secondary market around auction moments are larger when market volatility is higher. To investigate the effect of market volatility on our estimates for auctions of maturity *m* public debt, we construct the measure $StDev_t^j$ as a 30-day moving standard deviation of changes in the daily yield of country *j* and maturity *m* public debt. Figure 4 shows a chart of our volatility measure over time. For all maturities, we find that volatility peaks in 2011 and 2012.

We now estimate the following generalization of equation (3.6):

$$\Delta y_t^j = c_0^j + AUC_t^j \left(\alpha + \beta VOL_t^j + \widetilde{BC}_t^j \left(\gamma + \delta VOL_t^j\right)\right) + \varepsilon_t^j, \qquad (3.8)$$

where $VOL_{t+l}^{j} = StDev_{t+l}^{j} - \overline{StDev}^{j}$. By including the deviation of $StDev_{t}^{j}$ from its average over all auction days, $\overline{StDev}^{j}$, we expect the original estimates of the coefficients on the auction dummy and the bid-to-cover ratio in Table 3.4 to remain largely the same. Both the bid-to-cover ratio in deviation from its benchmark and our volatility measure enter the regression equation directly as well as through an interaction term. Table 3.11 reports the results. Again, the mere presence of an auction, as captured through α, has a significant positive effect on the yield change, while in all instances the bid-to-cover ratio in deviation from its benchmark, as captured through γ, enters with a highly significant negative sign. Hence, again, an improvement of the bid-to-cover ratio (relative to its benchmark) adds a direct negative effect to the yield change. The direct effect of higher market volatility, as captured by the coefficient β, does not exhibit a systematic pattern. For 2-year debt it is always significantly negative, for 5-year debt it is almost always significantly positive, while for 10- and 30-year debt it is always insignificant. Again, the direct effect of a higher bid-to-cover ratio is to lower the yield after the auction compared to before the auction. However, most interesting is the effect of the interaction between our volatility measure and the bid-to-cover ratio (in deviation of its benchmark), which is captured by the coefficient δ. In all, but one, instances it enters with a significant negative sign. In most instances the interaction term is highly significant. This indicates that the beneficial effect of a more successful auction on secondary-market yield movements is stronger when markets are more volatile, in line with our theoretical framework.

These estimates suggest that the cost of a failed auction is larger during a crisis period when markets are volatile than during calmer periods. To the extent that the Treasury has some flexibility in reallocating new debt issuances over time, and assuming that the likelihood of a failed auction is at least as high during volatile periods as it is in tranquil periods, the Treasury may want to issue more new debt when markets are calm than when they are nervous. The potential savings in the form of lower interest payments on the new debt can be quite large. To illustrate, consider again the new issue of 30-year Italian debt and compare the case of a bid-to-cover ratio that is lower by one standard deviation of 0.44 basis points at the peak of the crisis on December 12, 2011, when our volatility measure $VOL_{t+l}^{j} = StDev_{t+l}^{j} - \overline{StDev}^{j}$ for j = Italy and m = 30 years reaches a maximum of about 13 basis points, versus when our volatility measure is at its average value of zero. Based on the estimate of δ reported in the (say) first column of Table 3.11, in the former case the yield on the new debt issue would be higher by roughly 8 basis points. For the average issue size of 1.55 billion euros and the average duration of 16.36 years used in the earlier calculation, in the high volatility case the total reduction in the auction proceeds would then amount to around 20 million euros.[34] Obviously, given that our comparison is based on a difference between the peak of the crisis and the average situation, this figure is likely an upper-bound, in particular also because there will likely be costs associated with shifting auction activity over time, for example because postponing an issuance increases the funding requirement in the remainder of the calendar year which may affect issuance costs. In addition, debt agencies face uncertainty about the degree of volatility in the future. Nevertheless, our illustration suggests that the savings from well-timed auction activity to avoid issuance at times of severe market stress can potentially be quite large.

[34] In the case of a difference in volatility equal to its own standard deviation of 2.24, this number would shrink to around 3.5 million euros.

3.5.4 Spillovers

In this subsection we explore two direct extensions of the baseline model. We first investigate the existence of spillovers of auctions to secondary market yields for debt with other maturities, and then explore the presence of cross-border effects of auctions on secondary markets. The model in Section 3 covers these potential spillovers as the set of "Bonds 2" imposes no restrictions on the maturity or country of origin of the bonds included in this set. The proposed extensions are natural as primary dealers tend to be active in multiple markets.

For maturity-*m* bonds, we now estimate specifications of the following format:

$$\Delta y_t^{j,m} = c_0^{j,m} + AUC_t^{j,m}\left(\alpha + \beta \widetilde{BC}_t^{j,m}\right) + AUC_t^{j,l}\left(\gamma + \delta \widetilde{BC}_t^{j,l}\right) + \varepsilon_t^{j,m},$$

where γ and δ are the coefficients for the auctions of another maturity *l*. To avoid reporting too many numbers, we focus on the variant in which $\widetilde{BC}_t$ is the deviation of the bid-to-cover ratio from its average over the preceding year – the other variants give similar results. Table 3.12 reports the estimates. We observe that the effect of the own-maturity bid-to-cover is always largest, (highly) significant and very similar to that under the baseline reported in Table 3.4. In half of the instances reported, there is a significant spillover from other-maturity auctions. Not surprisingly, in view of the fact that instruments closer in maturity are more highly substitutable in investor portfolios, spillovers tend to be more likely and stronger for the adjacent maturities in our sample.

For the cross-border spillovers, we estimate specifications of the following format:

$$\Delta y_t^j = c_0^j + AUC_t^j\left(\alpha + \beta\widetilde{BC}_t^j\right) + \sum_{k(\neq j)} AUC_t^k \left(\gamma + \delta w_t^k \widetilde{BC}_t^k\right) + \varepsilon_t^j,$$

which allows for spillovers from same-maturity auctions by foreign country $k(\neq j)$ to the home country j. Here, w_t^k is the weight given to country k. We report estimates based on an equal weighting of foreign auctions, i.e. $w_t^k = 1/\sum_{k(\neq j)} AUC_t^k$. Weighting by the targeted volume gives very similar results. Table 3.13 reports the estimates. The coefficients on the home bid-to-cover ratio (in deviation from benchmark) always remain highly significant and rather close to their values in the baseline estimation. There is strong evidence of spillovers of foreign auctions. Except when the benchmark is the sample average, the coefficient on the average foreign bid-to-cover ratio (in deviation from its benchmark) is always (highly) significantly negative, but, as expected, smaller in absolute size than that on the home bid-to-cover ratio (in deviation from its benchmark). These findings suggest that the success of each country's sovereign debt auctions may be a common concern of the entire Eurozone.

3.6. Concluding remarks

We have explored movements in secondary market yields of euro area public debt around primary debt auctions. In line with our theoretical framework, which is based on a setup in which primary dealers receive a signal about the fundamental value of the asset issued, we find that higher bid-to-cover ratios are associated with a lower secondary market yield after the auction relative to the secondary market yield before the auction. Also in line with our theoretical framework, we find that this effect is larger when market volatility is higher. Hence, the yield-reducing effect of successful auctions tends to be particularly strong during the recent crisis. Our findings may have some potentially interesting policy implications. First, if it possesses some flexibility, the Treasury could set a lower target volume when financial markets are particularly turbulent, thereby reducing the chance of a failed auction when the cost associated with a failure is relatively high. Regressions (available upon request) reveal at most a very weak link between the announced target volumes or upper-ends of the target ranges and our time-varying volatility measure, which suggests that there are potentially unexploited gains from more tightly linking announced issuance volumes to the market circumstances. Second, extracting information *prior* to the auction about the demand that primary dealers receive from their clients would allow the Treasury to calibrate target volumes more accurately, thereby reducing the chance of a failed auction and its associated costs. Finally, our finding of cross-border effects of foreign auctions suggests that the success of each country's sovereign debt auctions may be a common concern of the entire Eurozone.

Table 3.1: Means and standard deviations of daily yield changes

			2-year	5-year	10-year	30-year
Belgium	Mean	Full sample	-0.07	-0.08	-0.06	-0.07
	(in basis points)	Pre-crisis	0.06	0.04	0.03	-0.02
		Crisis	-0.24	-0.23	-0.17	-0.12
	Standard deviation	Full sample	5.58	5.44	4.65	4.31
	(in basis points)	Pre-crisis	4.60	4.57	3.94	3.77
		Crisis	6.56	6.32	5.39	4.88
Italy	Mean	Full sample	-0.06	-0.05	-0.03	-0.02
	(in basis points)	Pre-crisis	0.07	0.07	0.05	0.02
		Crisis	-0.22	-0.18	-0.11	-0.06
	Standard deviation	Full sample	8.23	7.37	5.95	4.82
	(in basis points)	Pre-crisis	4.10	4.36	3.90	3.64
		Crisis	11.34	9.83	7.72	5.93
France	Mean	Full sample	-0.07	-0.07	-0.06	-0.05
	(in basis points)	Pre-crisis	0.07	0.06	0.03	0.00
		Crisis	-0.24	-0.22	-0.17	-0.12
	Standard deviation	Full sample	4.57	4.92	4.37	4.18
	(in basis points)	Pre-crisis	4.13	4.39	3.99	3.70
		Crisis	5.04	5.48	4.79	4.71
Germany	Mean	Full sample	-0.08	-0.07	-0.07	-0.07
	(in basis points)	Pre-crisis	0.06	0.05	0.03	0.00
		Crisis	-0.24	-0.23	-0.18	-0.14
	Standard deviation	Full sample	4.43	4.85	4.41	4.26
	(in basis points)	Pre-crisis	4.09	4.37	3.85	3.70
		Crisis	4.80	5.37	5.01	4.85

Notes: Sub-period “Pre-crisis” ranges from 1 January 1999 until 31 June 2007, while sub-period “Crisis” ranges from 1 July 2007 until 31 July 2014.

Table 3.2: Summary statistics of auctions

	Full Sample Period			
Germany	2Y	5Y	10Y	30Y
Number of auctions	131	107	122	36
Av. amount bid (bn.)	11.15	8.64	8.78	5.07
Av. amount allotted (bn.)	5.24	4.57	5.03	3.09
Av. bid-to-cover ratio	1.80	1.55	1.41	1.34
Av. yield movement	0.56	1.98	1.13	-0.57
France	2Y	5Y	10Y	30Y
Number of auctions	140	167	155	64
Av. amount bid (bn.)	7.18	7.12	8.08	3.36
Av. amount allotted (bn.)	2.37	2.95	3.48	1.44
Av. bid-to-cover ratio	2.87	2.78	2.36	2.36
Av. yield movement	0.78	0.54	0.10	1.45
Belgium	3Y	5Y	10Y	30Y
Number of auctions	13	63	86	27
Av. amount bid (bn.)	2.16	1.93	2.34	1.33
Av. amount allotted (bn.)	0.92	0.89	1.19	0.71
Av. bid-to-cover ratio	2.06	2.00	1.96	1.92
Av. yield movement	-3.78	0.43	0.52	0.41
Italy	2Y	5Y	10Y	30Y
Number of auctions	207	197	182	73
Av. amount bid (bn.)	4.31	4.07	4.28	2.57
Av. amount allotted (bn.)	2.22	2.47	2.75	1.55
Av. bid-to-cover ratio	2.09	1.72	1.59	1.72
Av. yield movement	1.02	2.02	0.80	2.00

	Pre-Crisis Period				Crisis Period			
Germany	2Y	5Y	10Y	30Y	2Y	5Y	10Y	30Y
Number of auctions	54	43	52	14	77	64	70	22
Av. amount bid (bn.)	14.84	11.46	12.16	7.42	8.56	6.75	6.27	3.57
Av. amount allotted (bn.)	5.94	5.35	6.21	4.45	4.75	4.05	4.16	2.23
Av. bid-to-cover ratio	2.20	1.77	1.67	1.42	1.52	1.40	1.22	1.29
Av. yield movement	-0.48	1.45	0.66	0.09	1.29	2.34	1.48	-0.99
France	2Y	5Y	10Y	30Y	2Y	5Y	10Y	30Y
Number of auctions	74	81	83	37	66	86	72	27
Av. amount bid (bn.)	7.47	7.24	7.96	3.45	6.87	6.99	8.22	3.22
Av. amount allotted (bn.)	2.15	2.69	3.11	1.38	2.62	3.18	3.90	1.52
Av. bid-to-cover ratio	3.26	3.12	2.52	2.59	2.42	2.45	2.18	2.06
Av. yield movement	0.61	0.97	1.11	1.87	0.97	0.13	-1.06	0.88
Belgium	3Y	5Y	10Y	30Y	3Y	5Y	10Y	30Y
Number of auctions	2	26	37	15	11	37	49	12
Av. amount bid (bn.)	0.78	2.04	2.55	1.18	2.41	1.86	2.16	1.52
Av. amount allotted (bn.)	0.31	0.89	1.21	0.59	1.03	0.89	1.17	0.87
Av. bid-to-cover ratio	1.91	2.14	2.02	1.95	2.08	1.91	1.92	1.87
Av. yield movement	-0.15	2.65	1.74	2.11	-4.45	-1.13	-0.45	-1.70
Italy	2Y	5Y	10Y	30Y	2Y	5Y	10Y	30Y
Number of auctions	122	109	95	51	85	88	87	22
Av. amount bid (bn.)	4.10	4.02	4.33	2.68	4.62	4.13	4.23	2.30
Av. amount allotted (bn.)	1.83	2.15	2.49	1.54	2.78	2.87	3.04	1.57
Av. bid-to-cover ratio	2.40	1.94	1.77	1.82	1.65	1.45	1.40	1.47
Av. yield movement	0.71	1.56	0.68	1.72	1.47	2.59	0.94	2.64

Notes: See *Notes* to Table 3.1. “Av. yield movement” is average yield movement on auction days.

Table 3.3: Descriptive statistics bid-to-cover ratio

	Mean	Maximum	Minimum	Standard
Germany				
2-Year	1.80	5.55	0.86	0.67
5-Year	1.55	3.28	0.81	0.45
10-Year	1.41	3.49	0.65	0.54
30-Year	1.34	2.30	0.76	0.38
France				
2-Year	2.87	5.79	1.55	0.83
5-Year	2.78	5.79	1.25	0.81
10-Year	2.36	4.47	1.34	0.57
30-Year	2.36	4.47	1.34	0.64
Belgium				
3-Year	2.06	2.65	1.09	0.43
5-Year	2.00	4.14	1.09	0.45
10-Year	1.96	4.14	1.34	0.41
30-Year	1.92	4.14	1.34	0.51
Italy				
2-Year	2.09	4.97	1.01	0.70
5-Year	1.72	3.10	1.00	0.46
10-Year	1.59	4.09	1.07	0.35
30-Year	1.72	3.75	1.00	0.44

Table 3.4: Bid-to-cover ratio and changes in secondary market yields

$\Delta y_t^j = c_0^j + AUC_t^j(\alpha + \beta \widetilde{BC}_t^j) + \varepsilon_t^j$, estimated for a panel consisting of Germany, Belgium, France and Italy.

Full sample period (January 1,1999 - July 31, 2014)				
	Deviation BC from sample average	Deviation BC from previous auction	Deviation BC from average over previous 4 auctions	Deviation BC from average over preceding year
2-year α	0.80***	0.80***	0.77***	0.75***
2-year β	-1.10***	-1.68***	-1.97***	-1.58***
5-year α	1.48***	1.48***	1.40***	1.47***
5-year β	-1.18***	-1.12***	-2.18***	-2.06***
10-year α	0.71***	0.72***	0.69***	0.70***
10-year β	-1.34***	-1.89***	-1.75***	-1.62***
30-year α	1.21***	1.15***	1.00***	1.31***
30-year β	-1.97***	-2.23***	-1.89***	-1.73***

Notes: Estimation method is Ordinary Least Squares (OLS) with fixed effects and Newey-West adjusted standard errors. Further, *, ** and *** denote significance at the 10%-, 5%- and 1%-levels, respectively.

Table 3.5: Bid-to-cover ratio and changes in secondary market yields – opening yields

$\Delta y_t^j = c_0^j + AUC_t^j(\alpha + \beta \widetilde{BC}_t^j) + \varepsilon_t^j$, estimated for a panel consisting of Germany, Belgium, France and Italy.				
Full sample period (January 1,1999 - July 31, 2014)				
	Deviation BC from sample average	Deviation BC from previous auction	Deviation BC from average over previous 4 auctions	Deviation BC from average over preceding year
2-year α	0.67**	0.66**	0.62**	0.60*
2-year β	-0.72*	-1.35***	-1.96***	-1.70***
5-year α	0.85***	0.85***	0.76***	0.84***
5-year β	-0.75*	-1.10***	-1.97***	-1.93***
10-year α	0.22	0.22	0.18	0.20
10-year β	-1.19***	-1.93***	-1.93***	-1.76***
30-year α	0.89***	0.85***	0.76**	1.03***
30-year β	-1.72***	-2.10***	-1.97***	-1.82***

Notes: see Table 3.4.

Table 3.6: Excluding one country at a time

$\Delta y_t^j = c_0^j + AUC_t^j(\alpha + \beta \widetilde{BC}_t^j) + \varepsilon_t^j$, estimated for a panel consisting of Germany, Belgium, France and Italy.				
Full sample period (January 1,1999 - July 31, 2014)				
	Deviation BC from sample average	Deviation BC from previous auction	Deviation BC from average over previous 4 auctions	Deviation BC from average over preceding year
Panel: France, Belgium, Italy				
2-year α	0.86**	0.86**	0.85**	0.80**
2-year β	-0.92**	-1.67***	-2.07***	-1.65***
5-year α	1.32***	1.32***	1.25***	1.31***
5-year β	-1.01**	-0.81*	-2.05***	-1.87***
10-year α	0.55**	0.56**	0.53**	0.56**
10-year β	-0.73	-1.53***	-1.14*	-0.89
30-year α	1.59***	1.54***	1.35***	1.71***
30-year β	-1.70***	-2.36***	-1.60**	-1.75**
Panel: Germany, Belgium, Italy				
2-year α	0.77**	0.78**	0.74**	0.71**
2-year β	-1.39***	-1.91***	-1.94***	-1.59**
5-year α	1.86***	1.87***	1.76***	1.85***
5-year β	-1.65**	-1.04*	-2.25***	-2.07***
10-year α	0.92***	0.94***	0.91***	0.88***
10-year β	-2.25***	-2.38***	-2.21***	-2.53***
30-year α	1.06***	0.98**	0.87**	1.21***
30-year β	-3.69***	-2.71***	-3.14***	-2.32***
Panel: Germany, France, Italy				
2-year α	0.93***	0.93***	0.89***	0.87***
2-year β	-1.11***	-1.71***	-1.97***	-1.57***
5-year α	1.61***	1.62***	1.56***	1.60***
5-year β	-1.19***	-1.20***	-2.23***	-2.05***
10-year α	0.73***	0.74***	0.72***	0.73***
10-year β	-1.09**	-1.54***	-1.49**	-1.26**
30-year α	1.32***	1.27***	1.13***	1.40***
30-year β	-2.03***	-2.18***	-1.73**	-1.86***
Panel: Germany, France, Belgium				
2-year α	0.56*	0.56*	0.51*	0.51*
2-year β	-1.00**	-1.32***	-1.83***	-1.48***
5-year α	1.08***	1.08***	0.96***	1.06***
5-year β	-1.13***	-1.43***	-2.25***	-2.29***
10-year α	0.63***	0.64***	0.60**	0.62**
10-year β	-1.46***	-2.22***	-2.18***	-1.92***
30-year α	0.73*	0.66*	0.50	0.80**
30-year β	-1.04	-1.75***	-1.41*	-1.10

Notes: See Table 3.4.

Table 3.7: Excluding the most extreme observations

$\Delta y_t^j = c_0^j + AUC_t^j(\alpha + \beta\widetilde{BC}_t^j) + \varepsilon_t^j$, estimated for a panel consisting of Germany, Belgium, France and Italy.				
Full sample period (January 1,1999 - July 31, 2014)				
	Deviation BC from sample average	Deviation BC from previous auction	Deviation BC from average over previous 4 auctions	Deviation BC from average over preceding year
2-year α	0.84***	0.86***	0.81***	0.75***
2-year β	-1.20***	-1.99***	-2.24***	-1.59***
5-year α	1.52***	1.46***	1.42***	1.43***
5-year β	-1.31***	-1.28***	-2.75***	-2.11***
10-year α	0.65***	0.73***	0.67***	0.67***
10-year β	-1.21**	-2.23***	-1.86***	-1.71***
30-year α	1.18***	1.13***	1.05***	1.43***
30-year β	-2.17***	-2.28***	-2.65***	-2.46***

Notes: See Table 3.4.

Table 3.8 Controlling for market conditions

$\Delta y_t^j = c_0^j + AUC_t^j(\alpha + \beta\widetilde{BC}_t^j) + \gamma\Delta X_{t-1} + \varepsilon_t^j$, where X_t is a vector consisting of the Euro Stoxx Bank Index, the Euro Stoxx Index, the CBOE Volatility Index (VIX) and the Euro Overnight Index Average (EONIA), estimated for a panel consisting of Germany, Belgium, France and Italy.				
Full sample period (January 1,1999 - July 31, 2014)				
	Deviation BC from sample average	Deviation BC from previous auction	Deviation BC from average over previous 4 auctions	Deviation BC from average over preceding year
2-year α	0.70**	0.68**	0.65**	0.63**
2-year β	-0.85**	-1.51***	-1.80***	-1.49***
5-year α	1.46***	1.46***	1.37***	1.44***
5-year β	-1.11**	-1.13***	-2.07***	-1.95***
10-year α	0.74***	0.76***	0.73***	0.74***
10-year β	-1.17**	-1.77***	-1.65***	-1.47***
30-year α	1.35***	1.32***	1.11***	1.51***
30-year β	-2.31***	-2.50***	-1.88***	-1.98***

Notes: See Table 3.4.

Table 3.9: Controlling for sovereign CDS spreads

(A)

$\Delta y_t^j = c_0^j + AUC_t^j(\alpha + \beta \widetilde{BC}_t^j) + \varepsilon_t^j$, estimated for a panel consisting of Germany, Belgium, France and Italy.

	Deviation BC from sample average	Deviation BC from previous auction	Deviation BC from average over previous 4 auctions	Deviation BC from average over preceding year
2-year α	1.01***	1.00***	0.99***	0.96***
2-year β	-1.71**	-2.24***	-2.80***	-2.44***
5-year α	1.34***	1.34***	1.32***	1.30***
5-year β	-3.28***	-1.67***	-3.49***	-3.34***
10-year α	0.62**	0.63**	0.62**	0.61**
10-year β	-3.39***	-2.92***	-3.03***	-3.06***
30-year α	0.74*	0.67*	0.58	0.75*
30-year β	-5.33***	-3.22***	-3.13***	-3.22***

(B)

$\Delta y_t^j = c_0^j + AUC_t^j(\alpha + \beta \widetilde{BC}_t^j) + \gamma \Delta CDS_{t-1}^j + \varepsilon_t^j$, where CDS_t^j is the 5-year sovereign CDS-spread for country j.

	Deviation BC from sample average	Deviation BC from previous auction	Deviation BC from average over previous 4 auctions	Deviation BC from average over preceding year
2-year α	1.12***	1.13***	1.12***	1.09***
2-year β	-1.89**	-2.33***	-2.87***	-2.53***
2-year γ	0.12***	0.12***	0.12***	0.12***
5-year α	1.43***	1.42***	1.42***	1.40***
5-year β	-3.28***	-1.49**	-3.39***	-3.27***
5-year γ	0.14***	0.14***	0.14***	0.14***
10-year α	0.62**	0.62**	0.63**	0.62**
10-year β	-3.41***	-2.98***	-2.99***	-3.01***
10-year γ	0.09***	0.09***	0.09***	0.09***
30-year α	0.62	0.59	0.51	0.71*
30-year β	-5.02***	-2.94***	-2.59**	-3.01***
30-year γ	0.06***	0.06***	0.06***	0.06***

Notes: See Table 3.4. The model is estimated for a panel consisting of Germany, Belgium, France and Italy over the sample period April 1, 2003 – July 31, 2014.

Table 3.10: Bid-to-cover interacted with a crisis-period dummy

$\Delta y_t^j = DPRE * [c_0^{j,pre} + AUC_t^j * (\alpha + \beta \widetilde{BC}_t^j)] + (1 - DPRE) * [c_0^{j,crisis} + AUC_t^j * (\gamma + \delta \widetilde{BC}_t^j)] + \varepsilon_t^j$, where *DPRE* is a pre-crisis dummy with value 1 over the period January 1,1999 – June 30, 2007, and zero, otherwise.				
	Deviation BC from subsample average	Deviation BC from previous auction	Deviation BC from average over previous 4 auctions	Deviation BC from average over preceding year
Full sample period (January 1,1999 – July 31, 2014)				
2-year α (pre-crisis)	0.37	0.37	0.31	0.30
2-year γ (crisis)	1.28***	1.28***	1.28***	1.26***
2-year β (pre-crisis)	-0.81*	-1.34***	-1.28**	-1.11**
2-year δ (crisis)	-2.38**	-2.77***	-4.07***	-3.33***
Wald test $\alpha = \gamma$	2.85*	2.79*	3.04*	3.11*
Wald test $\beta = \delta$	1.88	2.07	5.26**	3.47*
Joint Wald test	2.36*	2.45*	4.25**	3.44**
5-year α (pre-crisis)	1.46***	1.47***	1.34***	1.48***
5-year γ (crisis)	1.54***	1.52***	1.45***	1.44***
5-year β (pre-crisis)	-0.58	-0.63	-0.94	-0.98
5-year δ (crisis)	-4.30***	-2.43***	-5.00***	-4.74***
Wald test $\alpha = \gamma$	0.02	0.01	0.04	0.01
Wald test $\beta = \delta$	11.52***	3.59*	13.84***	11.29***
Joint Wald test	5.77***	1.80	6.97***	5.64***
10-year α (pre-crisis)	0.95***	1.00***	0.98***	0.99***
10-year γ (crisis)	0.49	0.49	0.45	0.42
10-year β (pre-crisis)	-0.64	-0.64	-0.59	-0.49
10-year δ (crisis)	-5.78***	-4.34***	-4.87***	-5.25***
Wald test $\alpha = \gamma$	1.19	1.45	1.44	1.77
Wald test $\beta = \delta$	19.06***	15.61***	13.36***	16.21***
Joint Wald test	10.13***	8.50***	7.30***	8.78***
30-year α (pre-crisis)	1.64***	1.56***	1.37***	1.68***
30-year γ (crisis)	0.60	0.62	0.55	0.69
30-year β (pre-crisis)	-1.30*	-1.67***	-0.98	-0.87
30-year δ (crisis)	-6.65***	-3.57***	-4.54***	-4.37***
Wald test $\alpha = \gamma$	2.72*	2.14	1.57	2.29
Wald test $\beta = \delta$	10.80***	2.63	5.78**	5.97**
Joint Wald test	6.76***	2.38*	3.61**	4.15**

Notes: See Table 3.4.

Table 3.11: The bid-to-cover ratio and crisis intensity

$\Delta y_t^j = c_0^j + AUC_t^j \left(\alpha + \beta VOL_t^j + \widetilde{BC}_t^j \left(\gamma + \delta VOL_t^j\right)\right) + \varepsilon_t^j$, estimated for a panel consisting of Germany, Belgium, France and Italy.

	Deviation BC from sample average	Deviation BC from previous auction	Deviation BC from average over previous 4 auctions	Deviation BC from average over preceding year
2-year α	0.71**	0.70**	0.67**	0.65**
2-year β	-0.27***	-0.21***	-0.23***	-0.19***
2-year γ	-1.35***	-2.22***	-2.32***	-1.86***
2-year δ	-0.27	-0.97***	-0.83***	-0.60***
5-year α	1.39***	1.49***	1.39***	1.46***
5-year β	0.06	0.17**	0.17**	0.18**
5-year γ	-1.28***	-1.07**	-2.20***	-2.08***
5-year δ	-0.48**	-0.32*	-0.69***	-0.48**
10-year α	0.53**	0.71***	0.63***	0.65***
10-year β	-0.15	0.05	0.00	0.00
10-year γ	-1.74***	-1.99***	-2.00***	-1.81***
10-year δ	-1.18***	-0.81***	-0.91***	-0.86***
30-year α	1.15***	1.17***	1.11***	1.36***
30-year β	-0.23	-0.05	0.09	0.03
30-year γ	-2.16***	-2.00***	-1.97***	-1.69***
30-year δ	-1.43***	-0.96***	-1.39***	-1.30***

Notes: See Table 3.4.

Table 3.12: The effect of the bid-to-cover ratio of other maturity auctions

$\Delta y_t^{j,m} = c_0^{j,m} + AUC_t^{j,m}(\alpha + \beta \widetilde{BC}_t^{j,m}) + AUC_t^{j,l}(\gamma + \delta \widetilde{BC}_t^{j,l}) + \varepsilon_t^{j,m}$, estimated for a panel consisting of Germany, Belgium, France and Italy. $\widetilde{BC}_t^j$ is the deviation of the bid-to-cover ratio from its average over the preceding year.				
Full sample period (1-1-1999 - 31-7-2014)				
	m = 2 year	*m* = 5year	*m* = 10 year	*m* = 30 year
α		1.53***	0.71***	1.33***
β		-1.81***	-1.62***	-1.76***
γ, *l* = 2 year		-0.28	0.18	0.08
δ, *l* = 2 year		-0.85*	-0.73*	-0.54
α	0.51*		0.57***	1.04***
β	-1.38***		-1.49***	-1.58**
γ, *l* = 5 year	1.08***		0.76***	0.76***
δ, *l* = 5 year	-0.99*		-1.39***	-1.29***
α	0.75***	1.43***		1.03***
β	-1.57***	-1.98***		-1.26*
γ, *l* = 10 year	0.03	0.22		0.66***
δ, *l* = 10 year	-0.35	-0.87		-1.02**
α	0.75***	1.45***	0.59***	
β	-1.58***	-1.99***	-1.40***	
γ, *l* = 30 year	0.66	0.46	0.93**	
δ, *l* = 30 year	-0.52	-0.69	-0.85	

Notes: See Table 3.4.

Table 3.13: Spillovers across countries, unweighted average of foreign bid-to-cover

$\Delta y_t^j = c_0^j + AUC_t^j\left(\alpha + \beta \widetilde{BC}_t^j\right) + \sum_{k(\neq j)} AUC_t^k \left(\gamma + \delta w_t^k \widetilde{BC}_t^k\right) + \varepsilon_t^j$, with $w_t^k = 1/\sum_{k(\neq j)} AUC_t^k$, estimated for a panel consisting of Germany, Belgium, France and Italy.

	Deviation BC from sample average	Deviation BC from previous auction	Deviation BC from average over previous 4 auctions	Deviation BC from average over preceding year
2-year α	0.82***	0.82***	0.79***	0.76***
2-year β	-1.09***	-1.67***	-1.96***	-1.57***
2-year γ	0.22	0.23	0.23	0.20
2-year δ	-0.36*	-0.76***	-1.09***	-0.70**
5-year α	1.53***	1.53***	1.45***	1.52***
5-year β	-1.19***	-1.13***	-2.21***	-2.10***
5-year γ	0.85***	0.86***	0.79***	0.86***
5-year δ	-0.23	-0.50**	-1.09***	-1.08***
10-year α	0.73***	0.74***	0.71***	0.72***
10-year β	-1.33***	-1.89***	-1.74***	-1.61***
10-year γ	0.42***	0.42***	0.38***	0.41***
10-year δ	-0.26	-0.81***	-0.91***	-0.82***
30-year α	1.26***	1.20***	1.05***	1.36***
30-year β	-1.97***	-2.23***	-1.89***	-1.73***
30-year γ	1.34***	1.31***	1.19***	1.38***
30-year δ	-1.03***	-1.73***	-1.14***	-0.87**

Notes: See Table 3.4.

Figure 3.1: The auctioning process

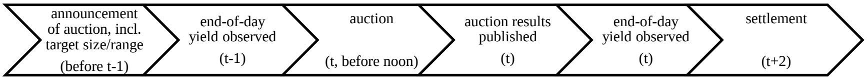
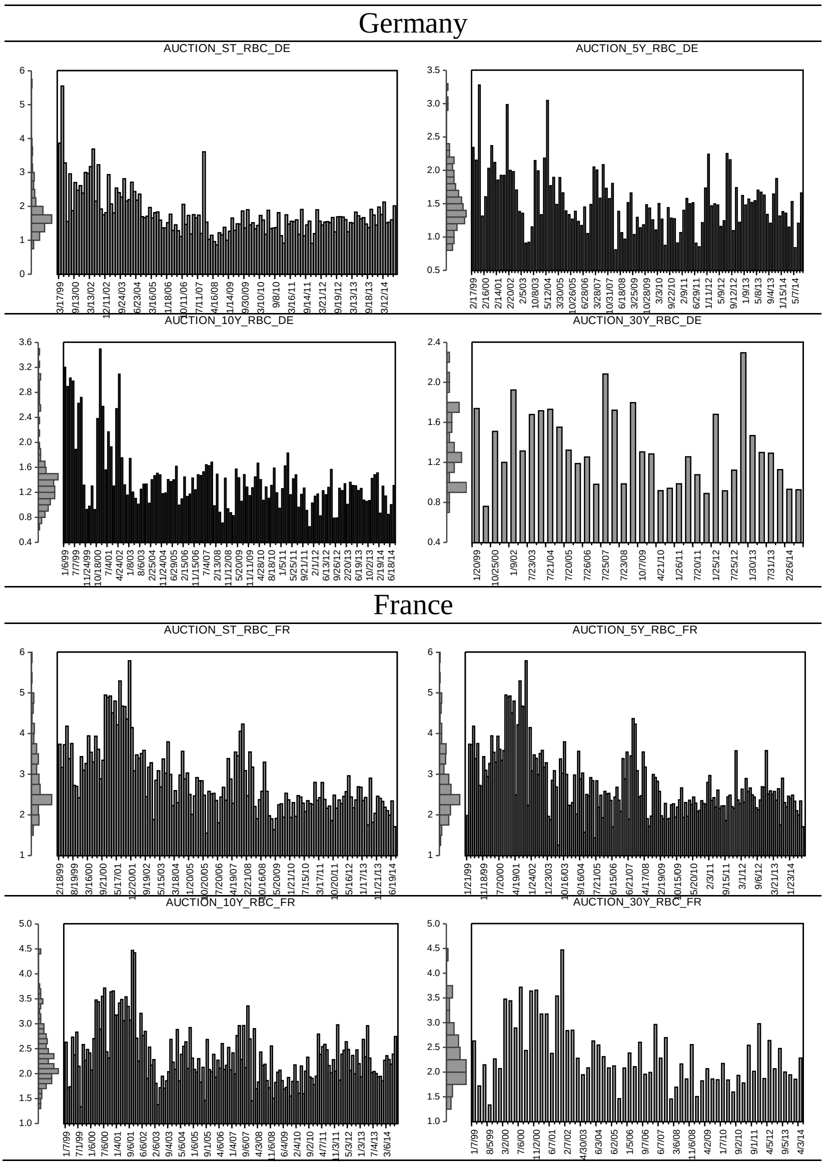
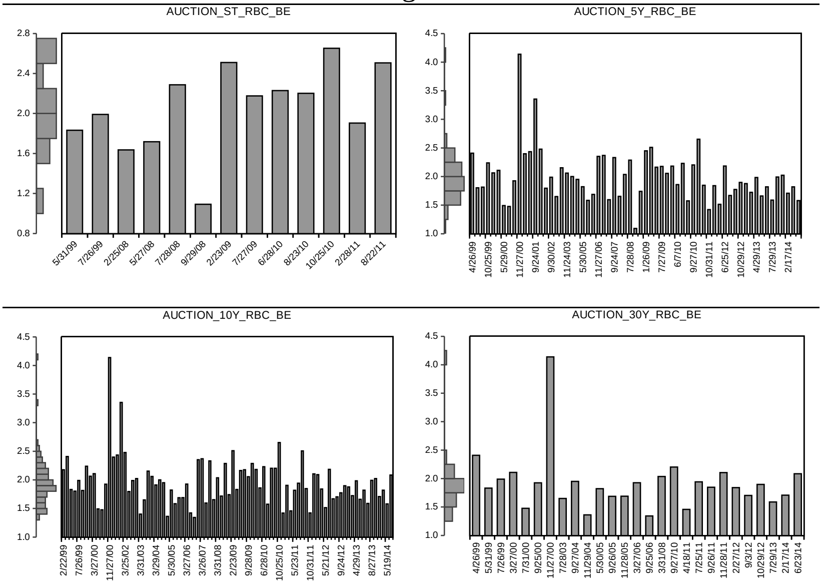


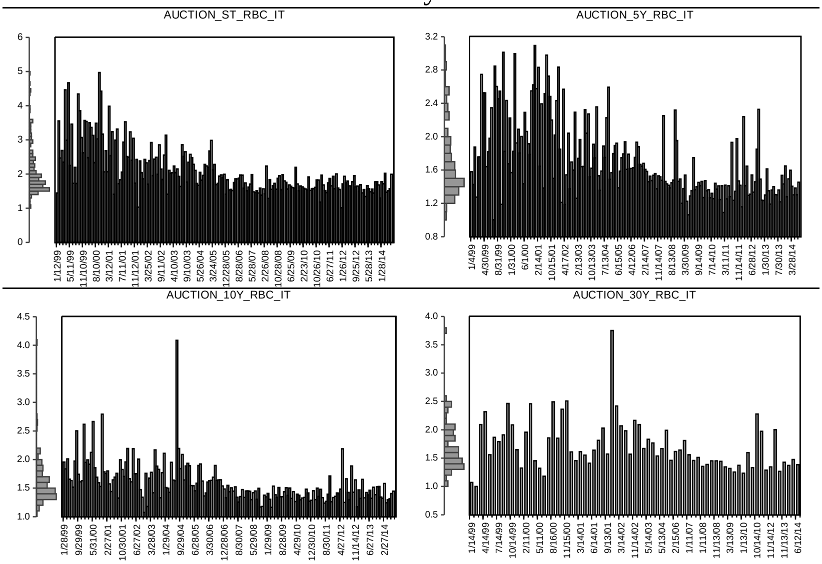
Figure 3.2: Bid-to-cover ratios



Belgium

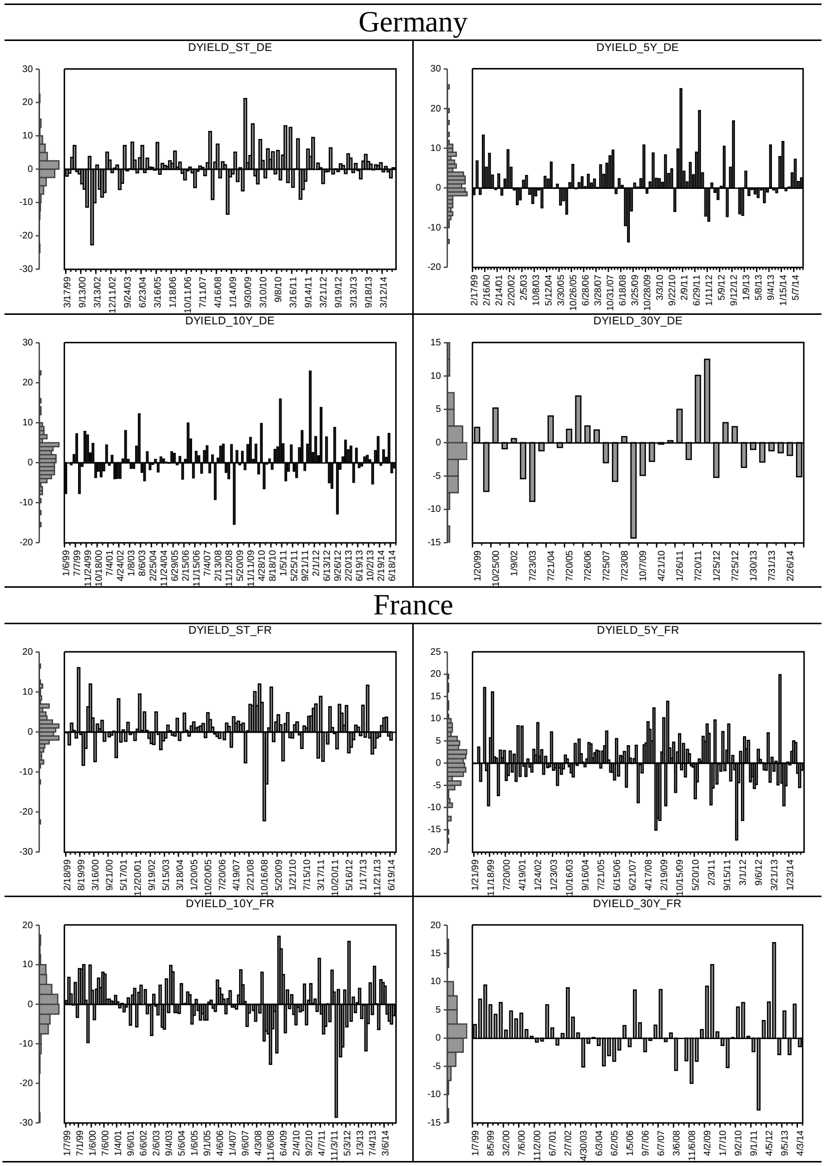


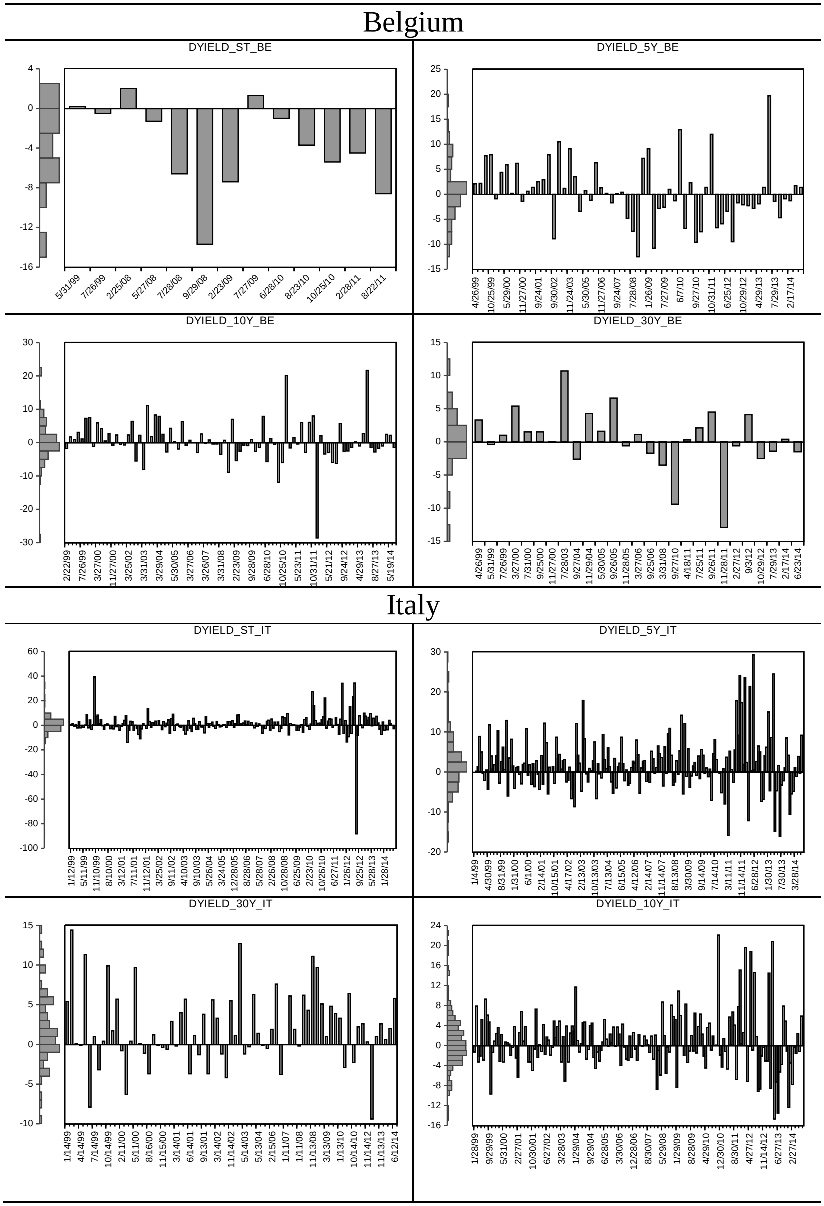
Italy



Notes: this figure shows the realizations of the bid-to-cover ratios on the horizontal axis and the histograms of their frequency distributions on the vertical axis. From left-to-right and from above to below the charts are based on the 2-year (3-year for Belgium), 5-year, 10-year and 30-year auctions, respectively.

Figure 3.3: Secondary market yield changes on auction days



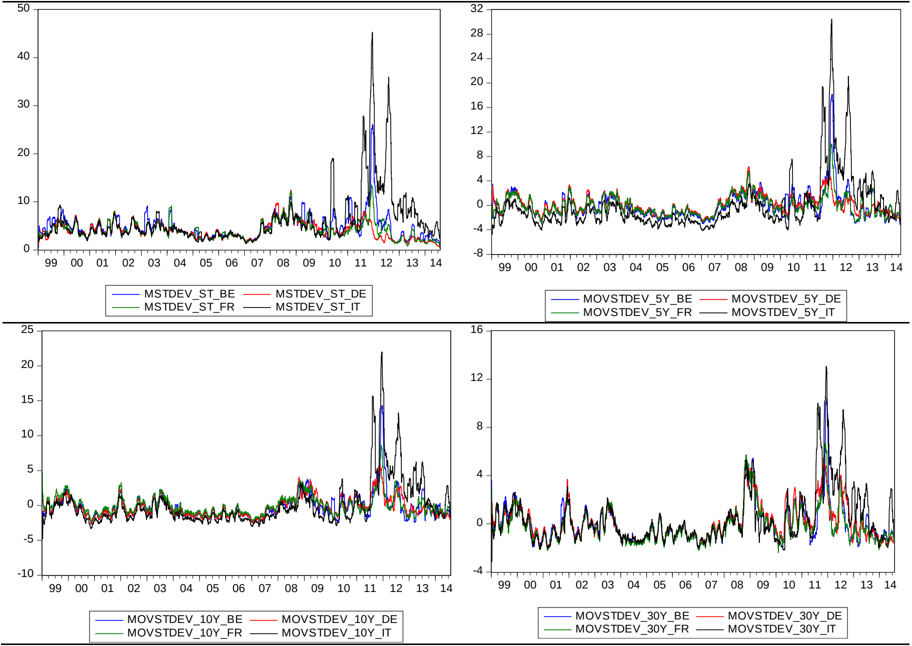


Notes: this figure shows the realizations of secondary-market yield changes on auction days on the horizontal axis and the histograms of their frequency distributions on the vertical axis. The unit is basis points.

Figure 3.4: Volatility of daily yield changes

The charts show $VOL_{t+l}^{j} = StDev_{t+l}^{j} - \overline{StDev}^{j}$, which is the deviation of the 30-day moving standard deviation of secondary market yield changes from its average over all auction days.

2-year maturity	5-year maturity



Appendix 3.A: Elastic supply

The relevant expressions to be used are:

$$p_1^a = \bar{v}_1 + \frac{Cov(v_1, \bar{s}_1)}{Var(\bar{s}_1)}\bar{s}_1 - \tilde{A}\tilde{\sigma}_{11}Q_1^s ,$$

$$p_1^R = \bar{v}_1 + \frac{Cov(v_1, \bar{s}_1)}{Var(\bar{s}_1)}\bar{s}_1 - \tilde{A}\tilde{\sigma}_{11}\tilde{Q}_1 ,$$

$$Q_1^s = \bar{Q}_1 + \theta(p_1^a - p_1^R).$$

Combining these expressions yields after a little algebra:

$$p_1^a = p_1^R + \left(\frac{\tilde{A}\tilde{\sigma}_{11}}{1 + \theta\tilde{A}\tilde{\sigma}_{11}}\right)\left(\tilde{Q}_1 - \bar{Q}_1\right).$$

Using the expression for p_1^R, we can write $\frac{Cov(v_1,\bar{s}_1)}{Var(\bar{s}_1)}\bar{s}_1 = p_1^R - \bar{v}_1 + \tilde{A}\tilde{\sigma}_{11}\tilde{Q}_1$.

Substituting into

$$p_2^a = \bar{v}_2 + \frac{Cov(v_2,\bar{s}_1)}{Var(\bar{s}_1)}\bar{s}_1 - \tilde{A}\sigma_{21}Q_1^s = \bar{v}_2 + \frac{Cov(v_2,\bar{s}_1)}{Cov(v_1,\bar{s}_1)}\frac{Cov(v_1,\bar{s}_1)}{Var(\bar{s}_1)}\bar{s}_1 - \tilde{A}\sigma_{21}Q_1^s$$

yields

$$p_2^a = \bar{v}_2 + \frac{\sigma_{21}}{\sigma_{11}}\left(p_1^R - \bar{v}_1 + \tilde{A}\tilde{\sigma}_{11}\tilde{Q}_1\right) - \tilde{A}\sigma_{21}Q_1^s$$

having used that $Cov(v_1, \bar{s}_1) = Var(v_1)$, $Cov(v_2, \bar{s}_1) = Cov(v_2, v_1)$ and that $\frac{\sigma_{21}}{\sigma_{11}} = \frac{Cov(v_2,v_1)}{Var(v_1)}$. Substituting into this expression for p_2^a the supply equation, we obtain:

$$p_2^a = \bar{v}_2 + \frac{\sigma_{21}}{\sigma_{11}}\left(p_1^R - \bar{v}_1 + \tilde{A}\tilde{\sigma}_{11}\tilde{Q}_1\right) - \tilde{A}\sigma_{21}\left(\bar{Q}_1 + \theta(p_1^a - p_1^R)\right)$$

Substituting out $p_1^a - p_1^R$, we obtain

$$p_2^a = \bar{v}_2 + \frac{\sigma_{21}}{\sigma_{11}}\left(p_1^R - \bar{v}_1 + \tilde{A}\tilde{\sigma}_{11}\tilde{Q}_1\right) - \tilde{A}\sigma_{21}\left(\bar{Q}_1 + \left(\frac{\theta\tilde{A}\tilde{\sigma}_{11}}{1+\theta\tilde{A}\tilde{\sigma}_{11}}\right)\left(\tilde{Q}_1 - \bar{Q}_1\right)\right)$$

$$\Longrightarrow p_2^a = \bar{v}_2 + \frac{\sigma_{21}}{\sigma_{11}}\left(p_1^R - \bar{v}_1 + \tilde{A}\tilde{\sigma}_{11}\tilde{Q}_1\right) - \tilde{A}\sigma_{21}\left(\frac{1}{1+\theta\tilde{A}\tilde{\sigma}_{11}}\bar{Q}_1 + \left(\frac{\theta\tilde{A}\tilde{\sigma}_{11}}{1+\theta\tilde{A}\tilde{\sigma}_{11}}\right)\tilde{Q}_1\right)$$

$$\Longrightarrow p_2^a = \bar{v}_2 + \frac{\sigma_{21}}{\sigma_{11}}\left(p_1^R - \bar{v}_1 + \tilde{A}\tilde{\sigma}_{11}\tilde{Q}_1\right) - \frac{\bar{A}\sigma_{21}}{1+\theta\tilde{A}\tilde{\sigma}_{11}} - \tilde{A}\sigma_{21}\left(\frac{\theta\tilde{A}\tilde{\sigma}_{11}}{1+\theta\tilde{A}\tilde{\sigma}_{11}}\right)\tilde{Q}_1$$

$$\Longrightarrow p_2^a = \bar{v}_2 + \frac{\sigma_{21}}{\sigma_{11}}\left(p_1^R - \bar{v}_1\right) - \frac{\bar{A}\sigma_{21}}{1+\theta\tilde{A}\tilde{\sigma}_{11}} + \frac{\sigma_{21}}{\sigma_{11}}\tilde{A}\tilde{\sigma}_{11}\tilde{Q}_1 - \tilde{A}\sigma_{21}\left(\frac{\theta\tilde{A}\tilde{\sigma}_{11}}{1+\theta\tilde{A}\tilde{\sigma}_{11}}\right)\tilde{Q}_1$$

$$\Longrightarrow p_2^a = \bar{v}_2 + \frac{\sigma_{21}}{\sigma_{11}}\left(p_1^R - \bar{v}_1\right) - \frac{\bar{A}\sigma_{21}}{1+\theta\tilde{A}\tilde{\sigma}_{11}} + \frac{\sigma_{21}}{\sigma_{11}}\tilde{A}\tilde{\sigma}_{11}\tilde{Q}_1\left(1 - \frac{\theta\tilde{A}\sigma_{11}}{1+\theta\tilde{A}\tilde{\sigma}_{11}}\right)$$

$$\Longrightarrow p_2^a = \bar{v}_2 + \frac{\sigma_{21}}{\sigma_{11}}\left(p_1^R - \bar{v}_1\right) - \frac{\bar{A}\sigma_{21}}{1+\theta\tilde{A}\tilde{\sigma}_{11}} + \frac{\sigma_{21}}{\sigma_{11}}\tilde{A}\tilde{\sigma}_{11}\tilde{Q}_1\left(\frac{1+\theta\tilde{A}\frac{MN-1}{NN-2}\sigma_{11}^*}{1+\theta\tilde{A}\tilde{\sigma}_{11}}\right)$$

where we have used that $\tilde{\sigma}_{11} = \sigma_{11} + \left(\frac{M}{N}\right)\left(\frac{N-1}{N-2}\right)\sigma_{11}^*$. This last expression can be rewritten further into equation (5) in the main text.

Appendix 3.B: Individual country estimates of (3.6)

Table 3.A.1: Bid-to-cover ratio and changes in secondary market yields

$\Delta y_t^j = c_0^j + AUC_t^j(\alpha + \beta \widetilde{BC}_t^j) + \varepsilon_t^j$, estimated for a panel consisting of Germany, Belgium, France and Italy.				
Full sample period (January 1,1999 - July 31, 2014)				
	Deviation BC from sample average	Deviation BC from previous auction	Deviation BC from average over previous 4 auctions	Deviation BC from average over preceding year
Germany				
2-year α	0.66*	0.65*	0.58	0.60
2-year β	-1.70***	-1.73***	-1.51	-1.35*
5-year α	2.11***	2.12***	1.96***	2.07***
5-year β	-2.47**	-3.11***	-3.01***	-3.11***
10-year α	1.23***	1.25***	1.19***	1.10***
10-year β	-2.81***	-3.34***	-3.30***	-3.27***
30-year α	-0.51	-0.63	-0.65	-0.49
30-year β	-4.48**	-1.52	-4.35**	-2.06
France				
2-year α	0.88**	0.88**	0.85**	0.83**
2-year β	-0.60	-0.96	-2.01***	-1.55**
5-year α	0.63	0.63	0.59	0.61
5-year β	-0.86*	-1.19**	-2.15***	-2.06***
10-year α	0.17	0.17	0.11	0.16
10-year β	-0.01	-1.10*	-0.84	-0.05
30-year α	1.53***	1.50***	1.22**	1.53***
30-year β	-0.24	-1.48*	-0.21	-0.81
Belgium				
2-year α	-3.72**	-4.05**	-5.99***	-4.89***
2-year β	0.44	-0.12	3.46	2.27
5-year α	0.52	0.48	0.19	0.46
5-year β	-1.09	-0.46	-1.79	-2.18
10-year α	0.58	0.59	0.55	0.59
10-year β	-3.13**	-3.29***	-2.93**	-3.67***
30-year α	0.49	0.34	0.10	0.66
30-year β	-1.54	-2.43**	-2.58*	-1.09
Italy				
2-year α	1.14*	1.15*	1.13*	1.08*
2-year β	-1.25	-2.07**	-2.15**	-1.72
5-year α	2.18***	2.18***	2.15***	2.17***
5-year β	-1.38	-0.27	-2.07	-1.32
10-year α	0.87*	0.88*	0.88*	0.87*
10-year β	-0.76	-0.70	-0.07	-0.25
30-year α	2.05***	2.02***	1.83***	2.28***
30-year β	-4.46***	-3.66***	-3.05**	-3.58***

Notes: See Table 3.4.

Appendix 3.C: Expanding the pre-auction window

Table 3.C.1: Bid-to-cover ratio – expanding the window to y_{t-2}

$y_t^j - y_{t-2}^j = c_0^j + AUC_t^j(\alpha + \beta \widetilde{BC}_t^j) + \varepsilon_t^j$, estimated for a panel consisting of Germany, Belgium, France and Italy.				
	Deviation BC from sample average	Deviation BC from previous auction	Deviation BC from average over previous 4 auctions	Deviation BC from average over preceding year
2-year α	1.55***	1.54***	1.53***	1.49***
2-year β	-1.56***	-1.36**	-1.95**	-1.57**
5-year α	2.03***	2.04***	1.96***	2.02***
5-year β	-1.34**	-1.23**	-2.61***	-2.60***
10-year α	1.51***	1.52***	1.47***	1.51***
10-year β	-1.81***	-1.98***	-2.20***	-1.96***
30-year α	2.38***	2.36***	2.18***	2.62***
30-year β	-3.02***	-3.05***	-2.38**	-2.83***

Notes: See Table 3.4.

Table 3.C.2: Bid-to-cover ratio – expanding the window to y_{t-3}

$y_t^j - y_{t-3}^j = c_0^j + AUC_t^j(\alpha + \beta \widetilde{BC}_t^j) + \varepsilon_t^j$, estimated for a panel consisting of Germany, Belgium, France and Italy.				
	Deviation BC from sample average	Deviation BC from previous auction	Deviation BC from average over previous 4 auctions	Deviation BC from average over preceding year
2-year α	2.04***	2.03***	1.98***	1.96***
2-year β	-1.70**	-1.63**	-1.72*	-1.56*
5-year α	2.22***	2.21***	2.09***	2.19***
5-year β	-0.92	-0.40	-2.28**	-2.54***
10-year α	1.60***	1.62***	1.51***	1.60***
10-year β	-1.82**	-1.99**	-2.65***	-2.27**
30-year α	2.97***	2.99***	2.88***	3.23***
30-year β	-4.25***	-3.82***	-3.15***	-3.44***

Notes: See Table 3.4.