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## Cross-Border Auction Cycle Effects of Sovereign Bond Issuance in the Euro Area

We provide evidence for the euro area of spillovers from foreign public debt auctions into domestic secondary-market auction cycles. We also confirm existing evidence of such spillovers from domestic issues into the domestic secondary market. Consistent with a theory of primary dealers' limited risk-bearing capacity, we find that auction cycles from domestic issues are stronger during the recent crisis period, whereas cross-border effects are stronger in the precrisis period, but this evidence is not strong. This finding likely reflects the opposing effects of reduced sovereign bond market integration during the crisis and higher yield covariances caused by more market volatility.

*JEL* codes: G12, G18

Keywords: auctions, auction cycles, cross-border effects, public debt, crisis, primary dealers, limited risk-bearing capacity, primary markets, secondary markets.

**BUDGETARY POLICY IN THE EURO AREA FACED severe challenges during the sovereign debt crisis. Fiscal stimulus and interventions in the financial sector caused high budget deficits, resulting in large amounts of newly issued debt.**

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In turn, these deteriorating fiscal positions, in combination with weak growth, caused risk premia on sovereign debt to rise to dangerously high levels in some instances. Further challenges were posed by fears of cross-country contagion of the financial market reactions to the budgetary difficulties plaguing euro area member states.

In this paper, we study how secondary markets for sovereign debt react to domestic and foreign issues of new public debt in the euro area. In particular, we are interested whether primary issues cause “auction cycles,” whereby secondary market yields rise in anticipation of the auction and fall thereafter. Studying potential auction cycles is important, because they affect the cost of the auctions in the primary market and they may provide an indication of the potential roll-over risk associated with the public debt. Moreover, such a study may provide leads for improvements in the design of the auction mechanism and the timing of auctions. For example, if auction cycles are larger in more turbulent periods, governments may want to consider increasing the flexibility of auction calendars to be able to concentrate new debt issues in tranquil periods, when the upward pressure on yields in anticipation of the auction is smaller. The possibility of spillovers of domestic debt issues into foreign auction cycles raises a set of policy issues, such as the potential needs to coordinate auction activity at the euro area level in such a way that auction moments are spread sufficiently in time. A step has already been taken toward enhanced coordination with the EU’s fiscal compact, which “aims at increasing coordination in debt issuance, and commits signatories to report on their public debt issuance plans to the Council and Commission on an ex-ante basis” (European Commission 2013).<sup>1</sup>

The specific contributions of the current paper are the following. First, we explore the presence of domestic auction cycles for a new and broader country sample than studied before in the literature. We perform this analysis for the full sample period since the inception of the euro in 1999 and the precrisis and crisis subperiods. Second, and more importantly, due to this broader country sample, this is (to the best of our knowledge) the first paper to explicitly address the cross-country spillover effects of domestic debt issues on foreign auction cycles. Third, this is also the first paper to explore how these spillover effects differ in the periods before and during the recent financial crisis.

It is not *a priori* clear whether the spillovers should have increased or decreased as a result of the crisis. We therefore develop a new theoretical model of the primary market for sovereign bonds in an international setting. The model features partially segmented markets where primary dealers with limited risk-bearing capacity initially buy all the bonds in the auction. These dealers may be active in several countries, or active only in the market for domestic debt. An auction in one country may, via hedging demands, affect the prices of bonds in other countries, as well as the prices of already traded domestic bonds. Our model predicts that increased risk

1. EU Debt management officers cooperate through the Economic and Financial Committee Sub-Committee on EU Sovereign Debt Markets. One of its tasks is to promote the integration and a better functioning of EU government debt markets. The Sub-Committee publishes an indicative quarterly calendar for sovereign bond issuance in the EU Member States. See [http://europa.eu/efc/content/efc-sub-committee-eu-sovereign-debt-markets\\_en](http://europa.eu/efc/content/efc-sub-committee-eu-sovereign-debt-markets_en).

aversion and market volatility lead to a strengthening of these spillovers. Indeed, we have witnessed a number of occasions when unrest in the financial markets spread across large parts of the euro area, suggesting that uncertainty about the success of a debt auction in one country could spill over into nervousness about sovereign debt market conditions of other countries. But, on the other hand, a crisis may undermine financial market integration, as captured by the extent to which primary dealers are active internationally. Diminished sovereign bond market integration during the crisis would therefore *ceteris paribus* reduce the cross-border spillovers from auctions.

Our main results are in line with the theoretical framework. First, we find systematic evidence of a domestic auction cycle in response to new debt issues. Second, the domestic auction cycle tends to be larger during the crisis than before the crisis. The sum of the up and down movements in the secondary market over the full cycle can be quite substantial and exceed 20 basis points during the crisis period. Third, we find systematic evidence of foreign secondary market yield responses to new domestic debt issues. While the cycle associated with foreign auctions tends to be smaller than that associated with domestic auctions, it can still be quite substantial and reach a size of around 5 basis points. Fourth, the strong evidence for spillovers from foreign auctions remains present if we make those spillovers functions of the overlap in the primary dealerships among the countries, thus providing further support for our theoretical framework. Fifth, we find limited evidence that the spillover effects of auctions are more prevalent before the crisis than during the crisis, consistent with a reduction in the integration of euro area sovereign debt markets during the crisis. This may not be surprising, because our theoretical framework shows that a crisis affects the strength of cross-border auction spillovers via channels that may work in opposite directions. In particular, evidence reviewed in the next section suggests a reduction in (cross-border) primary dealer activity, which would weaken auction spillovers, while most cross-border covariances of yield changes are higher during the crisis than before, which would strengthen auction spillovers. Finally, we find evidence that the cycles associated with domestic and foreign auctions are larger when market volatility is higher.

The analysis in this paper connects to different strands in the literature. First, there is a small literature that has explored the interplay between domestic primary and secondary public debt markets. Fleming and Rosenberg (2007) and Lou, Yan, and Zhang (2013) find evidence of an auction cycle for the U.S., while Beetsma et al. (2016) find similar evidence for Italian public debt auctions, but only limited evidence for German debt auctions.<sup>2</sup> Moreover, they find that the Italian auction cycle is larger in the period since the onset of the crisis in 2007 than before the crisis.

Second, a substantial literature has emerged on sovereign bond markets in the euro area. Several studies analyze the determinants of sovereign yields in the euro area during the crisis, with a particular focus on country risk and liquidity. Examples are Beber, Brandt, and Kavayecz (2009), Favero, Pagano, and von Thadden (2010),

2. These types of auction cycles may also occur in other markets, such as in equity markets and corporate debt markets (see, e.g., Duffie 2012).

Von Hagen, Schuknecht, and Wolswijk (2011), Mohl and Sondermann (2013), Monfort and Renne (2014), De Santis (2014), and Ejsing, Grothe, and Grothe (2015). Other papers, such as Pozzi and Wolswijk (2012), Christiansen (2014), and Cipollini, Coakley, and Lee (2015), study the integration of these markets after the introduction of the euro in 1999. The increased divergence in sovereign spreads reported in these papers indicates a reversal of the high degree of integration of euro area sovereign bond markets after the onset of the financial crisis in 2007.

A third strand of the literature focuses on the consequences for the risk of contagion in euro area sovereign bond markets. Several articles, such as Ang and Longstaff (2013) and Battistini, Pagano, and Simonelli (2014), explore the relationship between sovereign risk and common risk factors in the euro area. Linkages between sovereigns and the banking sector are seen as an important source of cross-country contagion effects—see De Bruyckere et al. (2013), Acharya, Drechsler, and Schnabl (2014), Claeys and Vašíček (2014), Brutti and Sauré (2015), and Kallestrup, Lando, and Murgoci (2016). Several papers investigate the role of news in generating spillover effects. Examples are Beetsma et al. (2013) and Bhanot et al. (2014). The latter paper demonstrates the adverse spillover effects of negative domestic news on sovereign interest spreads among the crisis countries. It finds that those effects are stronger when foreign banks have a larger stake in the domestic economy. By contrast, as Baele et al. (2013) demonstrate, countries with solid macroeconomic fundamentals appeared to benefit from “flight-to-safety” effects. While these papers investigate the presence of contagion in the levels of sovereign bond yields, our study takes a different approach by exploring spillovers to foreign secondary markets around the time of domestic public debt auctions.

The remainder of this article is structured as follows. Section 1 provides some institutional background information on the auction mechanisms employed in our sample countries. This section also presents a simple model of the price-setting behavior of primary dealers with limited risk-bearing capacity and limited market segmentation between domestic and foreign bond markets. Section 2 describes the data set and discusses some key summary statistics of the data. This section also analyses the presence of domestic auction cycles using an event study in the vein of Lou, Yan, and Zhang (2013) and Beetsma et al. (2016). Section 3 uses regression analysis to estimate the magnitude of the auction cycles caused by the domestic and foreign auctions. The section also investigates whether the auction cycles differ for the precrisis and the crisis period. Section 4 concludes the main body of this paper. The Appendix contains derivations for the theoretical model. The Web Appendices contain robustness results and are available via Internet or upon request from the authors.

## 1. INSTITUTIONAL BACKGROUND, THE CRISIS, AND THEORETICAL FRAMEWORK

In this section, we first provide some institutional background information for public debt auctions of the countries in our sample, Belgium, France, Germany, Italy,

the Netherlands, and Spain. These are the six countries with the largest nominal stock of general government debt in the euro area. Together these countries accounted for almost 90% of the total stock of outstanding euro area sovereign debt in 2014.<sup>3</sup> Because primary dealers play a key role during auctions, we formulate a simple theoretical model of both domestic and foreign price formation around auction dates in which the behavior of primary dealers with limited risk-bearing capacity features prominently.

### *1.1 Auction Mechanisms for Euro Area Public Debt*

Euro area treasuries fulfill the largest part of their annual debt issuance requirements through public auctions. Auctions are announced in an annual auction calendar. Germany, the Netherlands, and Italy also publish a quarterly calendar in which they provide more information about the bonds to be issued at each auction in the upcoming quarter.<sup>4</sup> Details of an upcoming auction, such as the maturity and an indication of the targeted volume, are typically announced in a press statement some working days before the auction takes place. In other words, market participants know the auction date and typically also have more detailed auction information before the start of the relevant (for our analysis) event window around the auction.<sup>5</sup>

Participation in public debt auctions is largely limited to designated banks, the so-called primary dealers.<sup>6</sup> They absorb the debt issuance on the day of a public debt auction, while they sell the newly issued bonds to end users mostly in the days after an auction. Primary dealers are typically bound to a minimum participation requirement on the primary market. Primary dealers are also required to provide liquidity on secondary markets, except in Germany. The minimum participation requirement on the primary market varies across countries from a minimum purchase requirement of 0.05% of the total amount issued in Germany to a minimum bidding requirement of 3% of all bids per auction in Spain.

3. The total stock of government debt in the euro area amounted to 9,326.3 billion euros in 2014, of which 2,188.7 billion euros consisted of debt from Germany (23.5%), 2,137.1 billion euros from Italy (22.9%), 2,038.4 billion euros from France (21.9%), 1,040.9 billion euros from Spain (11.2%), 450.5 billion euros from the Netherlands (4.8%), and 426.7 billion euros from Belgium (4.6%) (see, e.g., Eurostat 2015).

4. Concretely, France publishes a monthly calendar that only states dates; Italy publishes quarterly updates of minimum amounts for reopenings and coupons for new issues; the Netherlands and Germany mention the specific bond, the date, and an indicative amount; Belgium and Spain only publish an annual calendar. These calendars are published on the websites of the treasury agencies.

5. The auctions of our sample countries share many features. However, there are also some differences. For example, 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 cutoff price. Given the limited number of cross-sectional units, we do not attempt to link differences in the outcomes across the countries to differences in auction types. Moreover, the commonalities in the outcomes seem more pervasive than the differences.

6. Strictly speaking Germany does not use a primary dealer system, but has a “Bund Issues Auction Group” of banks that are allowed to participate in its auctions. Credit institutions domiciled in a member state of the European Union can join this group if they fulfill certain requirements, such as a minimum purchase requirement (see, e.g., Finanzagentur 2017). With some abuse of terminology, we will refer to these institutions as the “primary dealers” for Germany. France, Spain, and Italy currently allow investors who are not primary dealer to participate in auctions. In practice, direct bidders are not active in the French and Italian bond auctions, while they are somewhat more active in Spain (see, e.g., OECD 2014).

TABLE 1  
OVERVIEW OF PRIMARY DEALERS IN 2014

	Germany	Netherlands	France	Belgium <sup>a</sup>	Italy	Spain <sup>b</sup>
ABN AMRO	X	X		X <sup>r</sup>		
Bankinter						X
Banca IMI	X				X	
Bankhaus Lampe KG	X					
Bankia						X
Bank of America Merrill Lynch	X		X		X	
Barclays	X	X	X: 2	X	X: 5	X: 2
Bayerische Landesbank	X					
BBVA	X			X <sup>r</sup>		X: 3
Belfius				X <sup>r</sup>		
BHF-Bank Aktiengesellschaft	X					
BNP Paribas	X: 4		X: 1	X	X	X
Caixa Bank						X: 4
Citigroup	X	X	X	X	X: 4	X: 1
Commerzbank	X: 1	X: 2	X	X <sup>r</sup>	X	X
Confederación Esp. De Cajas de Ahorros						X
Crédit Agricole	X: 5		X: 4	X	X	X
Credit Suisse	X		X		X	X
Danske Bank A/S	X					
Dekabank	X					
Deutsche Bank	X: 2	X	X	X	X	X
DZ Bank	X					
Goldman Sachs	X		X	X <sup>r</sup>	X	X
HSBC	X: 3	X: 5	X: 5	X	X	X: 5
ING	X	X: 1		X	X	
Jefferies	X	X		X <sup>r</sup>		
JP Morgan	X		X	X	X: 3	X
KBC				X		
Landesbank Baden-Wurttemberg	X					
Landesbank Hessen-Thuringen Girozentrale	X					
Mizuho	X					
Monte Paschi di Siena					X: 1	
Morgan Stanley	X		X	X	X	X
Natixis	X	X	X	X		X
Nomura	X	X: 4	X	X	X	X
Norddeutsche Landesbank Girozentrale	X					
Nordea	X			X <sup>r</sup>		
Rabobank	X	X: 3				
Royal Bank of Scotland	X	X	X	X	X	
Santander	X	X	X	X		X
Scotiabank Europe	X		X	X <sup>r</sup>		
Société Générale	X	X	X: 3	X	X	X
UBS	X		X	X	X	
Unicredit	X				X: 2	
Total	37	14	19	24	20	20

NOTES: Germany, Italy, Spain, France, and the Netherlands publish primary dealer rankings. The numbers depict the top 5 in the ranking for 2014. For France and Italy, the rankings for 2013 are shown.

<sup>a</sup>Belgium has primary dealers and recognized dealers. Primary dealers have more duties and obligations than recognized dealers, such as access to noncompetitive subscriptions and an obligation to participate in auctions. Recognized dealers are denoted with a superscript r.

<sup>b</sup>Spain has a separate list of primary dealers for T-bills and government bonds. The table shows the list for government bonds.

Table 1 lists the primary dealers for the year 2014. Importantly, we see a high degree of cross-country overlap in primary dealerships. All 14 primary dealers for the Netherlands and all 19 primary dealers for France, for instance, hold a primary dealership for Germany as well. In addition, six banks (Barclays, Commerzbank,

Deutsche Bank, HSBC, Nomura, and Société Générale) hold a primary dealership in all countries in our data set. As the model presented below suggests, this overlap should induce spillovers of auctions in one country on secondary markets of other countries. The reason is that participation in a new debt issue induces the primary dealers to optimally rearrange the remainder of their bond portfolio, which has an effect on the prices of the bonds that are already part of the portfolio.

Germany, the Netherlands, France, Italy, and Spain publish annual rankings of primary dealer performance. Table 1 also shows the top-5 primary dealers for each of these countries in 2014. Five banks hold a top-5 position in two or more countries (Barclays, Citigroup, Commerzbank, Crédit Agricole, and HSBC). The rankings also show the importance of domestic primary dealers. For each country, the top-5 contains at least two domestic banks. Although their relative importance may change over time, generally, the set of primary dealers tends to be stable over time for a given country. Private conversation with primary dealers reveals that they perceive several advantages of being high in the ranking. Examples are enhanced exposure to the outside world, better chances to be selected as a trading partner in other assets, to take part in syndications to place public debt and to carry out government transactions and, due to the signaling value, better opportunities to become a partner to other financial institutions.

### *1.2 Primary Dealer Behavior during the Crisis in Europe*

There are two potentially relevant ways in which the crisis may have affected primary dealer behavior. First, it may have affected overall primary dealer activity. Primary dealer activity depends on their willingness and capacity to build inventories of sovereign bonds around an auction. The BIS (2014) reports a reduction in risk tolerance by market participants after the financial crisis based on a survey of market participants, which is in line with findings by Adrian et al. (2013) for primary dealers in the U.S. In addition, market participants in the BIS survey and a 2013 survey on primary markets developments by the OECD Working Party on Debt Management (see, e.g., OECD 2014) expect that new regulations following the crisis, such as “Basel III” and the EU’s implementation through its “Capital Requirements Directive IV,” may have resulted in a reduction in the amount of capital on balance sheets of primary dealers that can be allocated to absorb new debt issues. The shrinkage of European primary dealers’ trading books is supported by the Bankscope data underlying Figure 1, which depicts a falling volume of trading securities since the start of the global economic and financial crisis of the five primary dealers that held a top-5 position in two or more countries in our sample in 2014. The IMF reports a fall in banks’ trading assets in the euro area from 39% of total assets in 2006 to 24% of total assets in 2013 (IMF 2014, p. 23), while the BIS reports a drop of net trading securities of major European banks from 3 trillion U.S. dollars in 2007 to less than 1.5 trillion dollars (BIS 2014, Graph 7). Obviously, the banking sector is broader than the set of primary dealers, but even so the IMF and BIS figures support the trend exposed in Figure 1.



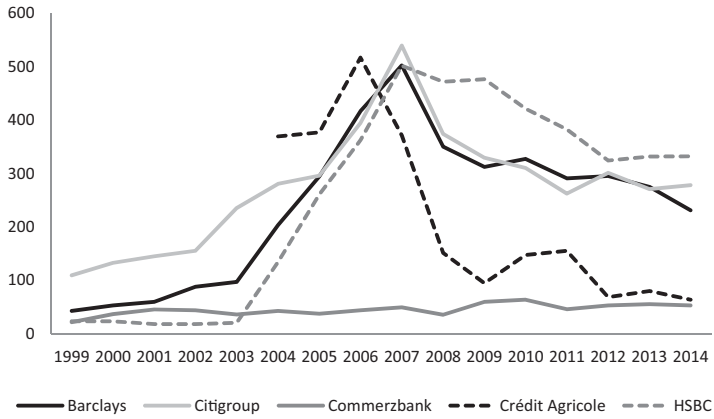


FIG. 1. Trading Securities Major European Primary Dealers (in Billions of U.S. \$).

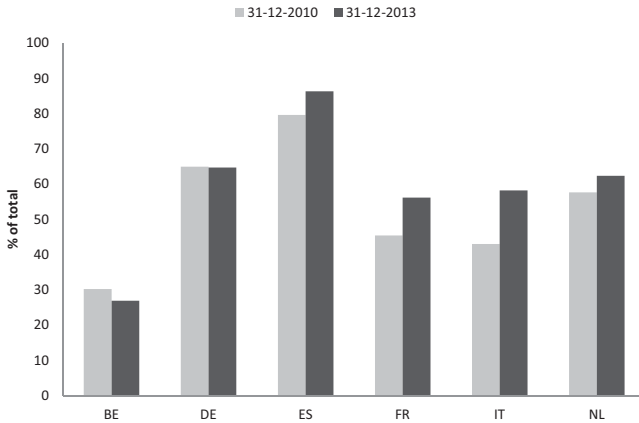


FIG. 2. Share of Domestic Primary Dealer Exposure to Own Sovereign.

NOTES: The bars represent total bond holdings by national primary dealers of their own sovereign included in the EBA-data divided by total bond holdings of the same sovereign by all (domestic and foreign) primary dealers included in the EBA-data.

Second, the crisis may have caused a shift between domestic and foreign primary dealer activity. There is quite substantial evidence from the literature that the European debt crisis has reduced the integration of European bond markets (see, e.g., Pozzi and Wolswijk 2012, Christiansen 2014, and Cipollini, Coakley, and Lee 2015). Using bank-level data on sovereign exposures from the European Banking Authority (EBA) stress tests, Horváth, Huizinga, and Ioannidou (2015) present evidence of an increasing sovereign debt home bias among large European banks between 2010 and 2013. To form an impression of how the crisis may have affected the latter, Figure 2

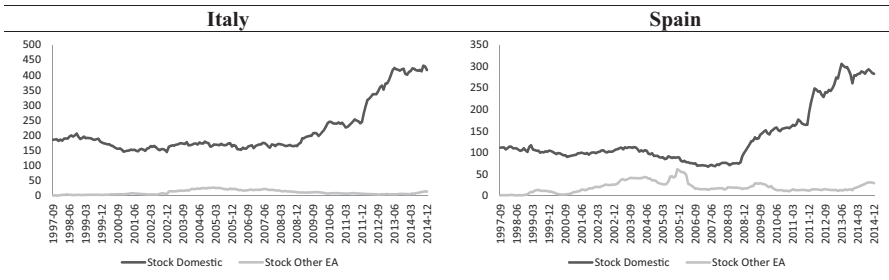


Fig. 3. Domestic and Foreign Sovereign Debt Holdings by the Consolidated Banking Sector.

NOTES: Figures are in billions of euros. The figure depicts the holdings by the consolidated banking sector of domestic sovereign debt and foreign sovereign debt from the rest of the Europe's Economic and Monetary Union (EMU).

SOURCE: ECB (2016).

depicts for the countries in our sample the total exposures of the domestic primary dealers in the EBA data set to their own sovereign, divided by the total exposure of all primary dealers in the EBA data set to the same sovereign.<sup>7</sup> The figure is indicative of a retrenchment of financial integration of the European bond markets as captured by the reduced activity of foreign primary dealers in the domestic markets: four of the six countries exhibit an increase in the relative role of domestic primary dealers, which in the case of Spain rises to well over 80%. Further, based on monthly data from the ECB (2016), Figure 3 shows the substantial expansion of domestic sovereign bond holdings relative to holdings of sovereign bonds from the rest of Europe's Economic and Monetary Union by the banking sectors in Italy and Spain after the onset of the recent crisis.<sup>8</sup>

### 1.3 A Model of Auction Cycles and Cross-Border Auction Spillovers

The description of the auction mechanisms in the previous subsection suggests a key role for the primary dealers in a model describing the price formation of public debt around dates at which new debt is issued. We develop such a model below. New is the international setting combined with the partially segmented markets in which the primary dealers can be active. Our model is, in particular,

7. The EBA defines the total exposures as the gross long positions held in the different books (trading, banking) net of the cash short positions, ordinarily held in the trading book. In the context of our analysis, the figure should be interpreted with some care. Obviously, non-EU primary dealers are not included, because they were not subject to the European stress tests. The exposures are those associated with all the banks in the EBA data set, hence not only those associated with the primary dealers. Moreover, in many instances, domestic primary dealers are also primary dealer for other foreign governments, in contrast to the theoretical model presented below, which makes a sharp distinction between global and local primary dealers. Note also that the first observation moment already falls well into the crisis period. Hence, the figure may lead to an underestimation of the trend toward more sovereign debt being held domestically.

8. Interestingly, evidence provided by Ongena, Popov, and van Horen (2016) suggests that banks' increased exposure to domestic sovereign debt during the euro area sovereign debt crisis is at least partly due to "moral suasion" by fiscally stressed sovereigns putting pressure on domestic banks to take more of their debt on their balance sheets.

also relevant for price formation in the secondary market, as the group of dealers in this market largely coincides with the group of primary dealers and because primary dealers are typically required to provide liquidity on the secondary market.

The key mechanism for the price effects in our model is that an upcoming debt auction induces the primary dealers to make room for the new issue in their asset portfolio, implying selling pressure on closely substitutable assets. Hence, their yield goes up in the run-up to the auction, while yields fall in the days after the auction as the primary dealers unload their inventory of the newly issued asset. The risks that primary dealers run, and which they want to be compensated for, are the fluctuations in the value of the new issue during the period that it is on their books.

In view of the ensuing empirical analysis, we want our model to capture the domestic and cross-border secondary market effects of primary sovereign debt issues. In addition, we want it to account for how these effects change as a result of a crisis like the one that the euro area experienced recently. This can be achieved if we introduce partially segmented markets into our model and allow for the degree of segmentation to change as a result of the crisis. Such partial segmentation is a realistic feature for the euro area. For example, although legally the euro area is characterized by perfect capital mobility and cross-border asset trading is voluminous, there remains a substantial home bias in asset holdings. Figure 2, which showed that disproportionate shares of the public debt are held by domestic primary dealers, is highly suggestive of this bias.

Starting point for the development of our model is Ho and Stoll (1983), as worked out in De Jong and Rindi (2009, Ch. 2). Our model extends Beetsma et al. (2016) into three directions: (i) we allow for primary dealers to hold debt from multiple countries; (ii) we distinguish between local and global primary dealers as investors in sovereign debt; and (iii) we make aggregate risk aversion a function of the size of the market. Local primary dealers trade only in debt issued in their own country, while global primary dealers trade in debt issued by all countries. The market segmentation with global and local dealers, who have access to different segments of the bond market, is related to the setup in the international asset pricing models with partially segmented markets, developed by Errunza and Losq (1985) and De Jong and De Roon (2005). This distinction produces the aforementioned partially segmented market for domestic and foreign public debt. The partial segmentation allows the domestic and cross-border secondary market effects of a new debt issue to differ in size and allows to capture the effects of a change in financial market integration.

We solve for the bond prices in the context of a general model setup with two countries, Home ( $h$ ) and a Foreign ( $f$ ). After this, we will consider two specific cases that are relevant for our analysis.

There is a risk-free asset against which primary dealers can borrow and lend without any restriction. Without loss of generality, we assume that the risk-free asset carries an interest rate of zero. Further, Home and Foreign feature vectors of bonds with

normally distributed payoff values  $\tilde{F}_h$ , respectively,  $\tilde{F}_f$ . The variance–covariance matrix of the payoff vector  $\tilde{F} \equiv (\tilde{F}'_h, \tilde{F}'_f)'$  is

$$\Sigma = \begin{bmatrix} \Sigma_{h,h} & \Sigma_{h,f} \\ \Sigma_{f,h} & \Sigma_{f,f} \end{bmatrix},$$

where  $\Sigma_{h,h}$  and  $\Sigma_{f,f}$  are the variance–covariance matrices of  $\tilde{F}_h$  and  $\tilde{F}_f$ , respectively, and  $\Sigma_{h,f}$  and  $\Sigma_{f,h}$  contain the (suitably organized) covariances of the elements of  $\tilde{F}_h$  with those of  $\tilde{F}_f$ . Later, we will specialize the setup to some specific cases that fit our empirical setup.

We also allow for two types of primary dealers, purely local dealers who only trade in the bonds of their own country and global dealers who trade in the bonds of both countries. Under the assumption that all primary dealers feature exponential (i.e., constant absolute risk aversion) utility and identical relative risk aversion  $\eta$ , the demand functions of the local and global primary dealers are given by their respective first-order conditions (De Jong and Rindi 2009, Ch. 2):

$$P_c = E[\tilde{F}_c] - \eta W_c^{-1} \Sigma_{c,c} x_c, \quad \text{where } c \in \{h, f\}$$

$$P = E[\tilde{F}] - \eta W_g^{-1} \Sigma x_g,$$

where  $P = (P_h', P_f)'$  is the vector of prices of all bonds,  $P_h$  and  $P_f$  are the vectors of prices of the Home and Foreign bonds, respectively,  $x_g$  and  $x_c$  are the amounts demanded by the global primary dealers and the local primary dealers of country  $c$ , respectively, and  $W_g$  and  $W_c$  are aggregate wealth of the global and local primary dealers of country  $c$ , respectively. Aggregating the demands, equalizing them to the aggregate supply  $X = (X_h', X_f)'$ , and solving yields the following price formula for Home bonds:<sup>9</sup>

$$P_h = E[\tilde{F}_h] - \eta[W_g I + W_h(I - \theta_f R)]^{-1} [(I - \theta_f R) \Sigma_{h,h} X_h + (I - \theta_f) \Sigma_{h,f} X_f], \quad (1)$$

where  $I$  is the identity matrix (of appropriate dimensions),  $\theta_f = W_f/(W_f + W_g)$ , and  $R \equiv (\Sigma_{h,f} \Sigma_{f,f}^{-1} \Sigma_{f,h}) \Sigma_{h,h}^{-1}$  is the multivariate  $R^2$  of a regression of  $\tilde{F}_h$  on  $\tilde{F}_f$ . Next, we derive a set of insightful analytical results for two special cases that fit our empirical setup.

*Two home bonds and no foreign bonds.* The special case of only two Home bonds and no Foreign bonds allows us to establish the effect of the issuance of a new Home

9. The algebra is a bit cumbersome (see the Appendix). Of course, a “symmetric” expression is obtained for Foreign’s price vector. However, we present only Home’s price vector, because this suffices for our exposition below.

bond, denoted by subscript “n,” on the secondary market price of an existing (“old”) Home bond, denoted by subscript “o”.<sup>10</sup>

$$\frac{\partial P_{h,o}}{\partial X_{h,n}} = -\eta \frac{1}{W_h + W_g} \text{Cov}(\tilde{F}_{h,o}, \tilde{F}_{h,n}) = -\eta \frac{1}{W_h + W_g} \rho_{o,n} \sigma_{h,o} \sigma_{h,n}, \quad (2)$$

where  $\sigma_{h,o}$  and  $\sigma_{h,n}$  are the standard deviations of the payoffs  $\tilde{F}_{h,o}$  and  $\tilde{F}_{h,n}$  of the old, respectively, new, bond, and  $\rho_{o,n}$  is the correlation between  $\tilde{F}_{h,o}$  and  $\tilde{F}_{h,n}$ . If the auctioned bond is a reopening of an existing series, the new Home bond coincides with the existing Home bond and  $\partial P_h / \partial X_h = -\eta(W_h + W_g)^{-1} \text{Var}(\tilde{F}_h)$ . Equation (2) shows that assuming a positive covariance between the payoffs, an upcoming auction pushes down the price of the existing bond. This is the hypothesis of the domestic auction cycle. This effect is larger, the larger is the size of the auction, the more closely substitutable the two assets are in terms of their payoff correlation and the smaller is the aggregate amount of primary dealer wealth  $W_h + W_g$  to absorb Home debt. A higher payoff correlation requires an increase in the expected return on the existing bond to keep it in the portfolio when the new bond is issued. If  $W_h + W_g$  falls, there is less capital available to bear the additional risks associated with absorbing the new issue.

We are also interested in the likely effects of a financial crisis on the domestic auction cycle. First, a crisis may suppress the risk tolerance of the primary dealers, that is,  $\eta/(W_h + W_g)$  rises, implying a stronger negative response of the price of the old bond to the new debt issue. A reduction in risk tolerance can be the result of a fundamental increase in risk aversion  $\eta$  or a fall in the amount of capital allocated to primary dealer activity shrinks.<sup>11</sup> Second, the crisis may raise the uncertainty  $\sigma_{h,o}$  and  $\sigma_{h,n}$  about the payoffs of the instruments, thereby amplifying the price effect of the new debt issue. The various channels all work in the same direction, suggesting that the negative price effect of an auction of given size is larger during a crisis than outside a crisis.

*One Home and one Foreign Bond.* The focus of this paper concerns the analysis of the spillovers of a Foreign bond issue on Home secondary bond market prices. Hence, we now explore the case of a single Home and a single Foreign bond. In this case, the formula for the Home bond price simplifies to:

$$P_h = E[\tilde{F}_h] - \eta[W_g + W_h(1 - \theta_f \rho_{h,f}^2)]^{-1} [(1 - \theta_f \rho_{h,f}^2) \sigma_h^2 X_h + (1 - \theta_f) \sigma_{h,f} X_f], \quad (3)$$

10. This formula can be derived easily from equation (1) by setting  $\theta_f = 0$ . The resulting model is equivalent to the one presented in Beetsma et al. (2016).

11. The reduction in primary dealer capital can be the direct consequence of a tightening of the capital requirements for European primary dealers during the crisis, as the anecdotal documentation in the previous subsection suggested, or the indirect consequence of a fundamental increase in risk aversion  $\eta$ , leading to less capital being allocated to dealer activities, as suggested by Adrian et al. for the U.S. primary dealer market. Hence, the effect of a higher fundamental risk aversion  $\eta$  on primary dealer risk tolerance can be both direct and indirect through the capital they allocate to their activity.

where  $\rho_{h,f}$  is the correlation between  $\tilde{F}_h$  and  $\tilde{F}_f$ . Substituting  $1 - \theta_f = W_g/(W_g + W_f)$ , we obtain the domestic price effect of a Foreign auction:

$$\frac{\partial P_h}{\partial X_f} = -\frac{\eta}{\hat{W}} \left( \frac{W_g}{W_g + W_f} \right) \rho_{h,f} \sigma_h \sigma_f, \quad \text{where } \hat{W} \equiv W_g + W_h (1 - \theta_f \rho_{h,f}^2). \quad (4)$$

Analogous to the predictions of a new Home bond issue studied above, we obtain predictions for the effect of a Foreign debt issue on the Home bond price:

- (i) If the payoffs between the Home and Foreign bonds have a positive covariance, a new Foreign bond issue pushes down the price of the Home bond.
- (ii) The price effect of a Foreign auction will be larger, the larger is the size of the auction.
- (iii) The price effect of a Foreign auction will be larger, the more closely substitutable the Home and Foreign bonds are as measured by their correlation.
- (iv) Finally, the price effect of a Foreign auction will be larger, the more global Foreign's dealership base is, as measured  $W_g/(W_g + W_f)$ .

This intuition for this last effect is that if Foreign's primary dealers are more global, there is a larger overlap in the relevant primary dealership bases of Home and Foreign, and hence, Home faces stronger hedging effects from Foreign auctions in the portfolios of its primary dealers.

We are also interested in how the financial crisis may affect the spillover. We can distinguish the following possible effects of the crisis:

- (i) A reduction in risk tolerance, as captured by an increase in  $\eta/\hat{W}$ , which strengthens the spillover. Here,  $\hat{W}$  is an adjusted measure of primary dealer wealth available in the market for Home debt.
- (ii) For given correlation between the yields  $\rho_{h,f}$ , an increase in the market volatilities  $\sigma_h$  and  $\sigma_f$  raises the covariance between the yields and strengthens the price spillover.
- (iii) A fall in the degree of financial market integration, as captured by  $W_g/(W_g + W_f)$ , that is, global primary dealer capital as a share of total available primary dealer capital for Foreign, holding constant  $\hat{W}$ . This dampens the price spillover of a foreign debt auction.

*Partially segmented home bond markets.* The case in the previous subsection with one Home and one Foreign bond with partially segmented dealerships can be directly relabeled to a setting of partially segmented Home bond markets. This translation is relevant, because there is empirical evidence that debt of different maturities tends to attract different clienteles (see, e.g., Greenwood and Vayanos 2010, 2014). Some primary dealers may cater to some clienteles more than to others, and therefore, trade more in some maturities than in others, while other primary dealers have no preference for trading one maturity or another. In terms of the model specialization in the previous subsection, the Home and Foreign bonds now become Home bonds of different maturities, while the "local" primary dealers become primary dealers

who tend to specialize in bonds of a specific maturity. The “global” primary dealers are unspecialized primary dealers. From the price formula (4), we observe that if the market for some specific maturity is smaller, as captured by a reduction in  $\hat{W}$ , then the price effect of a new issue of this maturity is larger. From the ensuing empirical analysis, we can see whether this prediction is borne out by the data.

#### *1.4 Alternative Explanations for Secondary Market Effects of Auctions*

Below, we will report empirical results that are in line with the theoretical model just presented. Beetsma et al. (2016) discuss a number of alternative hypotheses for yield movements in the secondary market around primary issues and provide references to the relevant literature. One alternative is that new debt issues affect the outstanding amount of debt. However, to the extent that the new debt issue replaces debt that is redeemed, the outstanding debt stock is unaffected, while insofar the outstanding stock of debt is affected, we expect the effect of the new issue to be small relative to the existing stock of debt. Hence, abstracting from potential “local supply effects” relevant for specific maturities, if changes in the outstanding debt are the supposed source of the movements in the secondary market yields, we expect these yields either not to move at all, or to exhibit a limited rise before the auction and to stay at this higher level after the auction since the outstanding debt stock remains (at least for some time) higher than before the auction. We have tested for asymmetry in secondary market price movements before and after the auctions and found that in an overwhelming majority of the cases, the symmetry hypothesis was not rejected. A second alternative concerns the possibility that on the issuance date, the current “on-the-run” issue switches to “off-the-run” status, which makes it less attractive for repo transactions (see, e.g., Sundaresan 1994), thereby suppressing its price. For the U.S., Krishnamurthy (2002) shows that the on-the-run premium is highest directly after the auction of a new instrument and falls in the run-up to a new auction. However, the “on-the-run/off-the-run” spread seems less relevant here, as most of the countries in our sample use auctions to reopen previously issued series. Moreover, the dissipation of repo specialness implies a cheapening of the instrument before but not after an auction. It cannot explain the strong yield reversals observed after an auction.

## 2. DATA

In this section, we describe the data and present some first indicative results using a simple event study approach. Formal econometric evidence of auction cycles is provided in the next section.

### *2.1 Data Description and Key Statistics*

We use data from the primary and secondary markets for sovereign bonds of Belgium, France, Germany, Italy, the Netherlands, and Spain in the period from

January 1, 1999 until July 31, 2014. Our analysis will consider both the full sample period and a sample split into the precrisis period, defined as the period January 1, 1999–June 30, 2007, and the crisis period, defined as the period July 1, 2007–July 31, 2014. We collect primary market data from Bloomberg for the 5-, 10-, and 30-year maturity segment. These are the only three maturities for which all the countries in our sample performed auctions during both subperiods. For each auction, Bloomberg reports 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 data from Bloomberg with data from the countries' debt management agencies. We also retrieve end-of-day secondary market yields from Bloomberg and calculate the daily yield changes in basis points for the 5-, 10-, and 30-year maturity segment.

Table 2 reports summary statistics for the secondary market yields. The table shows the means and standard deviations for both the precrisis and crisis period. Generally, the standard deviation of daily yield changes is inversely related to the length of the maturity. The precrisis period shows limited cross-country variation in standard deviations. In the crisis period, we see an increase in the standard deviation for each country-maturity combination. For Belgium, France, Germany, and the Netherlands, the average increase equals 1 basis point, whereas Italy and Spain witness an average rise of, respectively, 4 and 5 basis points. As a result, the cross-country variation in the standard deviations increases in the crisis period compared to the precrisis period.

Table 3 reports the matrices of covariances (lower triangle) and correlations (upper triangle) of the secondary market yields between each country pair in the 5-, 10-, and 30-year maturity segment for both the precrisis and the crisis period. All entries in the table are positive. Our model of primary dealers' limited risk-bearing capacity and partial segmentation suggests that the cross-country spillovers of auctions are stronger when the covariances between the yields of different countries are higher. The covariances of Dutch and German yields with yields of Italy and Spain exhibit a substantial fall when going from the precrisis to crisis period, while the other covariances do not change materially or even increase. In fact, the covariance between Italian and Spanish yields increases very substantially. Correlations exhibit a much more consistent pattern of change. While correlations are always 0.9 or higher before the crisis, going from the precrisis to the crisis period, each correlation, except for one, falls. In some instances, such as between Germany and the Netherlands and between Italy and Spain, the fall is only limited, while in other instances, in particular between Germany or the Netherlands, on the one hand, and Italy or Spain, on the other hand, the fall is very substantial. Hence, the rise in the covariances that we observe in a number of instances can be attributed to an increase in market volatility going from the precrisis to the crisis period.

Table 4 reports key statistics for the sovereign bond auctions. For each country, the frequency of auctions with a 5-year and 10-year maturity is higher than that of 30-year auctions. For example, Germany records 107 five-year auctions and 122 ten-year auctions, versus only 36 thirty-year auctions. The table also shows that the size is, on average, larger for the 5- and 10-year auctions than for the 30-year auctions. The



TABLE 2  
MEANS AND STANDARD DEVIATIONS OF DAILY YIELD CHANGES

			5-Year	10-Year	30-Year
Belgium	Mean (in basis points)	Full sample	-0.08	-0.06	-0.07
		Precrisis	0.04	0.03	-0.02
		Crisis	-0.23	-0.17	-0.12
	Standard deviation (in basis points)	Full sample	5.44	4.65	4.31
		Precrisis	4.57	3.94	3.77
		Crisis	6.32	5.39	4.88
Italy	Mean (in basis points)	Full sample	-0.05	-0.03	-0.02
		Precrisis	0.07	0.05	0.02
		Crisis	-0.18	-0.11	-0.06
	Standard deviation (in basis points)	Full sample	7.37	5.95	4.82
		Precrisis	4.36	3.90	3.64
		Crisis	9.83	7.72	5.93
France	Mean (in basis points)	Full sample	-0.07	-0.06	-0.05
		Precrisis	0.06	0.03	0.00
		Crisis	-0.22	-0.17	-0.12
	Standard deviation (in basis points)	Full sample	4.92	4.37	4.18
		Precrisis	4.39	3.99	3.70
		Crisis	5.48	4.79	4.71
Spain	Mean (in basis points)	Full sample	-0.10	-0.07	-0.05
		Precrisis	-0.01	-0.03	-0.05
		Crisis	-0.19	-0.12	-0.05
	Standard deviation (in basis points)	Full sample	7.65	6.38	5.58
		Precrisis	4.35	3.77	3.57
		Crisis	10.07	8.32	7.14
Germany	Mean (in basis points)	Full sample	-0.07	-0.07	-0.07
		Precrisis	0.05	0.03	0.00
		Crisis	-0.23	-0.18	-0.14
	Standard deviation (in basis points)	Full sample	4.85	4.41	4.26
		Precrisis	4.37	3.85	3.70
		Crisis	5.37	5.01	4.85
Netherlands	Mean (in basis points)	Full sample	-0.08	-0.06	-0.07
		Precrisis	0.05	0.03	0.00
		Precrisis	-0.23	-0.18	-0.14
	Standard deviation (in basis points)	Full sample	4.83	4.31	4.21
		Precrisis	4.48	3.93	3.69
		Crisis	5.21	4.72	4.76

NOTES: Subperiod "Precrisis" ranges from January 1, 1999 until June 31, 2007, while subperiod "Crisis" ranges from July 1, 2007 until July 31, 2014.

total amount of 30-year debt issued over all auctions in our data set equals 397 billion euro, while the total amounts of 5- and 10-year debt issued are 1,778 and 2,050 billion euros, respectively. For all countries, except Spain, the size of the average allotment is highest for auctions of 10-year bonds.

Comparing across countries, we observe that the frequency of auctions is highest for Italy, France, and Spain. Germany issues new debt at a lower frequency, but the size of its auctions is largest, ranging between 3.1 and 5.0 billion euros, whereas the average auction size is lowest in Spain and Belgium, with a range between 0.7 and 1.6 billion euros. Belgium and the Netherlands have comparable nominal stocks of general government debt, which are the lowest in the sample. However, their auction practices differ. The Netherlands issues relatively large amounts per auction at a low frequency of auctions, whereas Belgium issues smaller amounts at a higher frequency.

**TABLE 3**  
**COVARIANCES AND CORRELATIONS OF DAILY YIELD CHANGES**

$i \downarrow j \rightarrow$		Precrisis (1-1-1999-31-6-2007)					Crisis (1-7-2007-31-7-2014)					
		Germany	Netherlands	France	Belgium	Spain	Germany	Netherlands	France	Belgium	Spain	
Germany												
Netherlands		0.94			0.93					0.89		
France		18.44		0.96	0.91					24.80		0.76
Belgium		18.33	18.61	0.95	0.92					22.50		0.83
Italy		18.05	18.75	18.53	0.93					16.64		25.40
Spain		17.62	17.99	17.82	0.90					9.85		18.07
		17.17	17.66	17.41	17.61	17.04	5.31	18.39	31.51	77.47		
10-Year maturity												
$i \downarrow j \rightarrow$		Precrisis (1-1-1999-31-6-2007)					Crisis (1-7-2007-31-7-2014)					
		Germany	Netherlands	France	Belgium	Spain	Germany	Netherlands	France	Belgium	Italy	Spain
Germany												
Netherlands		0.98			0.95					0.91		
France		14.85		0.98	0.96					21.52		0.75
Belgium		15.02	15.32	0.98	0.96					17.95		0.82
Italy		14.47	14.73	15.01	0.96	0.94				13.50		19.66
Spain		14.26	14.54	14.75	14.47	13.73	0.89	13.59	22.33	5.36		5.36
		13.79	14.03	14.22	14.04		2.45	13.54	22.91	6.75		51.02
30-Year maturity												
$i \downarrow j \rightarrow$		Precrisis (1-1-1999-31-6-2007)					Crisis (1-7-2007-31-7-2014)					
		Germany	Netherlands	France	Belgium	Spain	Germany	Netherlands	France	Belgium	Italy	Spain
Germany												
Netherlands		0.98			0.92					0.98		
France		13.35		0.98	0.95					22.54		0.82
Belgium		13.38	13.35	0.96	0.96					18.70		0.84
Italy		13.28	13.31	13.41	0.93	0.91				16.09		19.97
Spain		12.40	12.36	12.44	12.48	11.90	3.03	10.08	14.57	4.25		4.25
		12.58	12.56	12.63	12.58		5.04	12.76	17.64	6.13		32.77

NOTE: Lower diagonal entries are covariances  $Cov(R_i, R_j)$ , and upper diagonal entries are correlations  $\rho_{i,j}$ .

TABLE 4  
SUMMARY STATISTICS OF AUCTIONS

	Full sample						Precrisis period			Crisis period									
	5-Year		10-Year		30-Year		5-Year	10-Year	30-Year	5-Year	10-Year	30-Year							
	Number of auctions	Average amount allotted (million euro)	Average accepted yield (%)	Number of auctions	Average amount allotted (million euro)	Average accepted yield (%)	Number of auctions	Average amount allotted (million euro)	Average accepted yield (%)	Number of auctions	Average amount allotted (million euro)	Average accepted yield (%)							
Belgium	63	87	27	26	38	15	37	49	12	887	1,188	714	886	1,208	589	888	1,172	872	
	3.2	3.9	4.5	4.2	4.5	4.9	4.2	3.4	4.1	163	151	63	81	83	37	82	68	26	
France	2,918	3,459	1,433	2,694	3,115	1,385	3,140	3,880	1,502	2.8	3.9	4.6	3.9	4.3	5.0	1.6	3.3	4.0	
	107	122	36	43	52	14	64	70	22	4,571	5,032	3,094	5,353	6,208	4,450	4,045	4,157	2,231	
Germany	2.5	3.3	3.8	3.7	4.3	4.7	1.6	2.5	3.2	197	182	73	109	95	51	88	87	22	
	2,471	2,753	1,549	2,148	2,490	1,539	2,872	3,041	1,570	3.8	4.6	5.4	4.0	4.6	5.5	3.6	4.6	5.1	
Italy	29	57	11	6	30	4	23	27	7	1,808	2,245	1,603	1,915	2,393	2,013	1,781	2,081	1,369	
	2.0	3.8	3.6	3.3	4.5	4.7	1.7	2.9	3.0	133	123	57	60	69	37	73	54	22	
Netherlands	1,643	1,479	787	1,206	1,104	599	2,002	1,960	1,086	3.8	4.7	5.1	4.1	4.7	5.1	3.5	4.7	5.1	
Spain																			

NOTES: See Notes to Table 2.

TABLE 5  
NUMBER OF AUCTIONS ON THE SAME DATE AND WITHIN A 10-DAY WINDOW

	5-Year						10-Year						30-Year							
	DE	NL	FR	BE	IT	ES	DE	NL	FR	BE	IT	ES	DE	NL	FR	BE	IT	ES		
DE		16	48	15	60	46	DE		12	47	32	61	49	DE		2	1	5	4	3
NL	0		13	4	17	15	NL	0		34	5	8	27	NL	0		3	3	5	1
FR	0	1		20	126	30	FR	0	0		22	119	54	FR	0	0		3	14	9
BE	0	0	0		23	20	BE	0	1	0		71	20	BE	0	0	0		1	3
IT	8	1	0	2		78	IT	1	0	0	10		49	IT	0	0	0	0		22
ES	1	0	22	0	3		ES	1	0	43	0	0		ES	0	0	1	0	0	

NOTE: Lower diagonal entries are auctions on the same date, and upper diagonal entries are auctions within a 10-day window from each other.

These patterns may be interesting in and of themselves, because it suggests that the traditionally “more vulnerable” countries tend to opt for more frequent, but smaller, auctions, possibly as a way to reduce the risk of an auction going awry and/or to reduce the magnitude of the auction cycle.

Table 5 shows that the number of auctions of different countries coinciding on the same day is limited. France and Spain are the exception to this regularity. Our data set contains 22 cases of coinciding 5-year auctions in France and Spain (respectively, 13.5% and 16.5% of the total numbers of auctions) and 43 cases of coinciding 10-year auctions (respectively, 28.5% and 34.6% of the total numbers of auctions). However, the number of auctions of different countries within a 10-day window (5 days before and after an auction) is substantial. The upper diagonal of Table 5, for instance, shows 126 instances of 5-year auctions in Italy and France within a 10-day window from each other (respectively, 64.0% and 77.3% of the total number of auctions).

We also collect detailed data on the primary dealers in our sample. We gather the annual primary dealer lists and primary dealer rankings from the countries’ debt management agencies, while we obtain annual data on book equity and trading assets for the top-5 primary dealers in Germany, the Netherlands, France, Italy, and Spain from Bankscope. Belgium does not rank its primary dealers.

## 2.2 An Event Study of Auction Cycles

The methodology of our event study is similar to that in Lou, Yan, and Zhang (2013) and Beetsma et al. (2016). Lou, Yan, and Zhang (2013) find evidence for the United States that secondary market yields tend to increase in the run-up to an auction and fall back once the auction has taken place. Beetsma et al. (2016) find similar auction cycles for Germany and Italy, with the cycle being more significant and larger for the latter country. For the five trading days before and after an auction of a particular maturity, we show the development of the average secondary market yields of the same maturity. In particular, we report the average of the yield movement between the end of day  $t$  and the end of the auction day (indicated by subscript 0),  $y_t - y_0$ , together with the 90% confidence band around this movement.

We consider the 5-, 10-, and 30-year auctions of the six countries in our sample, resulting in 18 country-maturity pairs. Figure 4 shows the secondary-market yield movements around domestic auction dates in basis points for all country-maturity pairs in our sample. In line with the results of Beetsma et al. (2016), the figure shows clear and highly significant auction cycles for Italy and smaller and less significant cycles for Germany. Belgium has somewhat smaller auction cycles than Italy and the confidence bands are wider. France also exhibits some indications of auction cycles, with a particularly pronounced yield increase in the 5 days before a 30-year auction. For Spain, we can only detect a significant auction cycle around issues of 30-year debt. This auction cycle is of the order of magnitude of that for Italy. Finally, there is not much indication of auction cycles for the Netherlands, although secondary market yields on 5- and 30-year auctions exhibit some upward movement prior to an auction.

Next, we are interested in the effect of a foreign public debt auction of a particular maturity in one of the other countries in our sample on domestic secondary market yields. For example, we are interested in how the 5-year secondary market yield for German debt moves around 5-year auctions in any of the other countries in our sample. For each country  $i$ , Figure 5 reports the average of  $y_{it} - y_{i,0}$ , where  $y_{it}$  and  $y_{i,0}$  are the end-of-day secondary market yields on the country  $i$ 's debt, while time subscript 0 refers to the auction dates of the other countries in the sample. We average over all foreign auctions of the same maturity. Overall, the figure is strongly suggestive of the presence of auction cycles around foreign auctions. The evidence is particularly suggestive for 30-year foreign auctions. For Germany, the Netherlands, Belgium, and France, we find an increase in the secondary-market yield by 2 basis points or more in the 5 days before an auction, as well as a consistent, though somewhat smaller, decline in the yield after the auction. Also, for the other two countries, this event study suggests evidence of domestic cycles around foreign auctions, in particular, in the 30-year segment. This evidence is consistent with our theoretical framework and the positive covariances between the pairs of same-maturity debt instruments reported in Table 3.

### 3. REGRESSION EVIDENCE OF AUCTION CYCLES

We now turn to our regression analysis in which we link secondary-market yield movements around auction dates to both domestic and foreign auctions. This allows us to estimate the size and the significance of potential auction cycles. We use a new specification to estimate the cycles associated with both domestic and foreign auctions in a single regression. Hence, if the timing of the domestic and foreign auctions is correlated, including foreign auctions in the regressions allows us to avoid potential biases due to overlapping windows around auction dates in the estimates of the cycles. A second advantage of the single regression framework is that it allows us to compare the sizes of the cycles associated with foreign and domestic auctions.

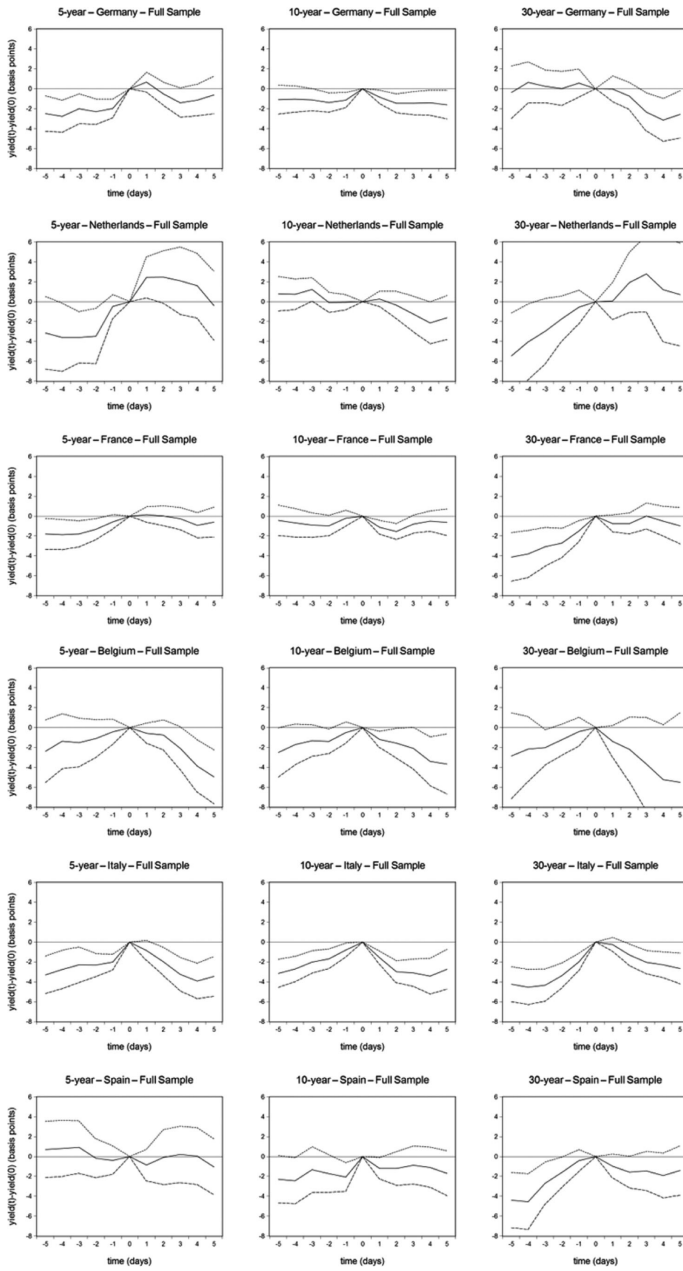


FIG. 4. Average Yield Movement before and after a Domestic Auction.

NOTES: The figure reports the average of  $y_t - y_0$ , where  $y_t$  is the end-of-day yield of the bond on day  $t$  and  $y_0$  is the end-of-day yield on the same maturity bond on the auction day 0. All yields are expressed in basis points. The dotted lines are the 90% confidence intervals obtained with Newey–West adjusted standard errors.

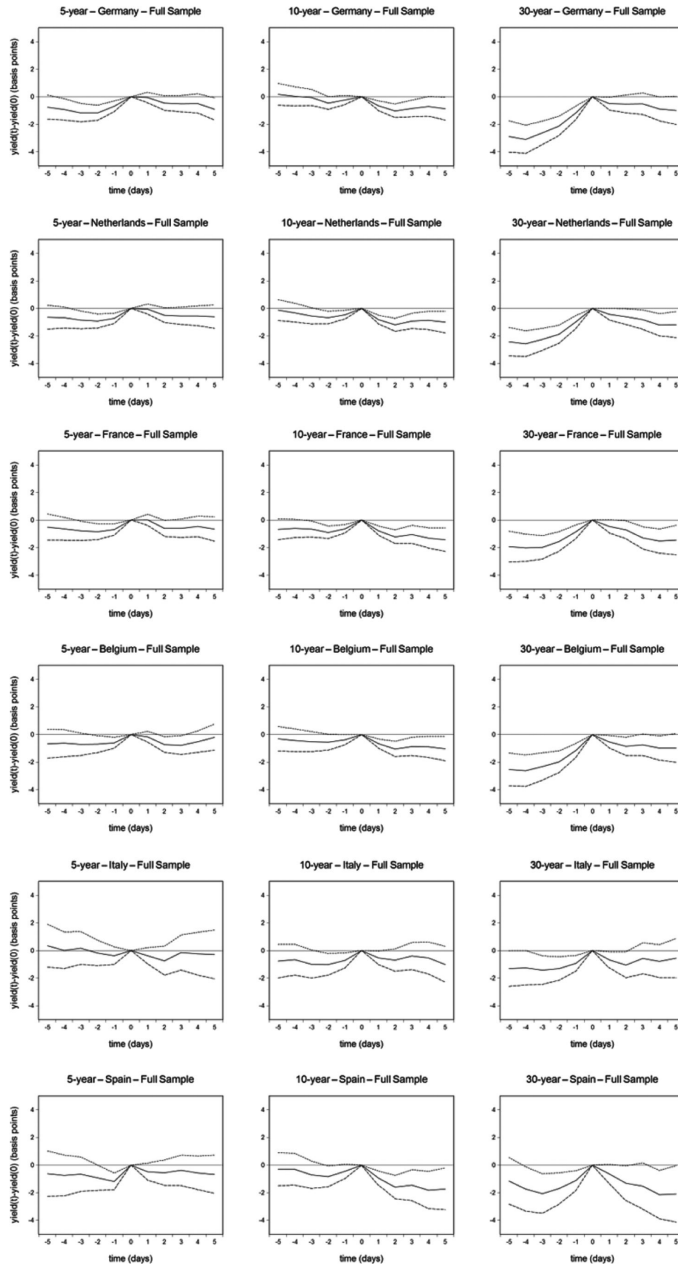


FIG. 5. Average Yield Movements before and after a Foreign Auction.

NOTES: The figure reports the average of the domestic end-of-day yield difference  $y_t - y_0$ , where 0 refers to the day a foreign auction of the same maturity takes place, and the average is taken over all foreign auctions of the same maturity. Further, see *Notes* to Figure 4.

We will perform regressions for the full sample period as well as separately for the precrisis and crisis subperiods.

### 3.1 Baseline Regression

For each country  $i$  and each maturity  $m$ , we estimate separately the following regression equation for the daily yield change:<sup>12</sup>

$$\Delta y_{it} = c_i + \sum_{l=4}^{-5} \alpha_{il} AUC_{i,t+l} + \sum_{l=4}^{-5} \gamma_{il} \sum_{j(\neq i)} AUC_{j,t+l} + \varepsilon_{it}, \quad (5)$$

where  $c_i$  is a constant and  $AUC_{it}$  is a dummy that takes a value of 1 if an auction of a bond with maturity  $m$  takes place in country  $i$  at date  $t$ , and a value of zero otherwise.<sup>13</sup> Further,  $\varepsilon_{it}$  is a disturbance term. The term  $\sum_{j(\neq i)} AUC_{j,t+l}$  is the number of maturity  $m$  auctions by all countries in our sample other than  $i$  on date  $t$ . Hence, equation (5) estimates the effect of a domestic auction or the sum of all foreign auctions on a given date on the secondary market yield for that particular maturity in the 4 days before the auction ( $4 \geq l > 0$ ), the day of the auction ( $l = 0$ ), and the five days after an auction ( $-5 \leq l < 0$ ). We estimate this equation for each of our six countries for 5-year, 10-year, and 30-year maturities.

There is evidence of a cycle associated with domestic auctions if the secondary market yield increases in the 5 days prior to (and including) the auction day ( $\sum_{l=4}^0 \alpha_{il} > 0$ ) and decreases in the 5 days after an auction ( $\sum_{l=-1}^{-5} \alpha_{il} < 0$ ).<sup>14</sup> Likewise, there is evidence of a cycle associated with foreign auctions if  $\sum_{l=4}^0 \gamma_{il} > 0$  and  $\sum_{l=-1}^{-5} \gamma_{il} < 0$ . The formal null hypothesis of no cycle associated with domestic, respectively foreign, auctions is formulated as:

$$H_0^a : AC \equiv \left( \sum_{l=4}^0 a_{il} \right) - \left( \sum_{l=-1}^{-5} a_{il} \right) = 0,$$

$$H_0^y : ACF \equiv \left( \sum_{l=4}^0 y_{il} \right) - \left( \sum_{l=-1}^{-5} y_{il} \right) = 0,$$

for which we use an  $F$ -test.

Table 6 reports the ordinary least squares (OLS) estimates of  $AC$  and  $ACF$  for the full sample period in basis points. The standard errors are Newey–West

12. We suppress the maturity index, but include the country index, because later we need to distinguish between the country that issues a new bond and the country for which we take the secondary market yield.

13. Although information on the auction size is available, in the sequel, we choose to use only dummy variables for the auctions. The reason is that while the auction dates are fixed in advance and thus can be taken as exogenous, the auction size may be endogenous. In particular, prior to the auction, the debt management agency announces a target volume or a target range for the volume. However, if demand at the auction turns out to be lower than anticipated, it may choose to issue at the lower end of this target range, because issuing a higher volume would require a higher auction yield.

14. Note that  $(\sum_{l=4}^0 \alpha_{il} > 0)$  also includes the movement of the yield during the auction day. If anything, this biases the results against finding an auction cycle, because it is possible that primary dealers have already started off-loading their inventory of the new debt issue between the end of the auction itself and the end of the trading day on which it takes place.



TABLE 6  
TESTING FOR AUCTION CYCLES

$$\Delta y_{it} = c_i + \sum_{l=4}^{-5} \alpha_{il} AUC_{i,t+l} + \sum_{l=4}^{-5} \gamma_{il} \sum_{j(\neq i)} AUC_{j,t+l} + \varepsilon_{it}$$

$$AC = \left( \sum_{l=4}^0 a_{il} \right) - \left( \sum_{l=-1}^{-5} a_{il} \right) \quad \text{and} \quad ACF = \left( \sum_{l=4}^0 \gamma_{il} \right) - \left( \sum_{l=-1}^{-5} \gamma_{il} \right)$$

	Germany	Netherlands	France	Belgium	Italy	Spain	Panel
5-year debt							
AC	3.05*	3.12	2.18	6.96**	6.95***	0.19	3.99***
ACF	1.85***	1.39**	1.61**	0.94	-0.08	1.46	1.06***
Adjusted R <sup>2</sup>	0.01	0.01	0.00	0.00	0.01	0.00	0.00
DW	1.93	1.90	1.90	1.72	1.73	1.67	1.78
10-year debt							
AC	2.76**	0.63	1.13	6.06**	6.94***	3.61	3.66***
ACF	1.03	1.43***	2.35***	1.71***	2.54***	2.40**	1.79***
Adjusted R <sup>2</sup>	0.01	0.01	0.01	0.01	0.01	0.01	0.01
DW	1.94	1.93	1.94	1.71	1.82	1.71	1.82
30-year debt							
AC	2.96	4.99	6.07***	7.92	7.21***	5.77**	6.10***
ACF	4.45***	4.04***	3.71***	3.95***	2.63**	3.65**	3.79***
Adjusted R <sup>2</sup>	0.01	0.01	0.01	0.01	0.01	0.00	0.01
DW	1.90	1.90	1.86	1.76	1.84	1.75	1.83

NOTES: Estimation is for the full sample period January 1, 1999–July 31, 2014. Estimation method is ordinary least squares (OLS) with Newey–West adjusted standard errors. The column under the header “Panel” reports panel OLS regressions estimated with country-fixed effects. Further, \*, \*\*, and \*\*\* denote significance at the 10%, 5%, and 1% levels, respectively. Finally, DW is the Durbin–Watson test statistic.

adjusted, hence robust against serial correlation and heteroscedasticity. In line with the literature, the adjusted  $R^2$  is low. We also report the Durbin–Watson test for autocorrelation in the residuals. Because the DW statistic is always quite close to 2, which is its value under the null of no autocorrelation, there is only very limited autocorrelation, consistent with our robustness analysis below. We discuss first the evidence of domestic auction cycles. The estimates are consistent with the results from the event study, while, moreover, for Germany and Italy, they are consistent with Beetsma et al. (2016). For Italy, in line with our theoretical model, we find a highly significant auction cycle for all three maturities. For Germany and Belgium, we find evidence of an auction cycle for the 5- and 10-year maturities and for France and Spain for the 30-year maturity. No evidence of auction cycles is found for the Netherlands.

There is rather substantial cross-country variation in the magnitude of the domestic auction cycles. The size of the Italian cycle is around 7 basis points, more than double that of Germany in the 5- and 10-year segment, while the sizes of the Belgian auction cycles in those segments are comparable to those for Italy. The sizes of the French and Spanish auction cycles in the 30-year segment are also broadly comparable to those for Italy in this segment.

In line with our theory, we find strong evidence of auction cycles arising from foreign auction activity. We observe a (highly) significant auction cycle in each country in the 30-year segment in response to foreign auction activity, while for the 10-year segment, we find the same result for all countries except Germany. The evidence of cross-border spillovers is slightly weaker for the 5-year markets. Still, also in this segment, foreign auction activity generates auction cycles in the secondary debt markets of Germany, France, and the Netherlands, despite the absence of cycles in response to domestic auctions for the latter two countries. The maximum cycle in response to foreign auctions is about 4.5 basis points, smaller than the maximum cycle of about 7 basis points in response to domestic auctions.<sup>15</sup> For each country, the maximum spillover effect is always found for the 30-year auctions. This result is even more salient, because the issue sizes of the 30-year auctions are systematically smaller than those of the other two maturities and because the standard deviations of the daily yield changes on 30-year debt tend to be smaller than those on 5- and 10-year debt (see Table 2). Our finding can be explained in the context of our model (see specifically Subsection 2.3.3) if the market for 30-year bonds is partially segmented from the markets for the other maturities. If primary dealers allocate less capital to the 30-year maturity auctions, the price effects of these auctions can be larger than of the auctions of the other maturities, despite the smaller issue sizes and the lower volatility in the yield changes.

While the estimates of the auction cycles differ across the countries, *a priori* the observed differences may not be too surprising due to the limited size of the samples at the individual country level. For this reason, Table 6 also reports the results of estimating (5) as a panel (with country-fixed effects), hence for given maturity forcing the cycles in response to domestic and foreign debt issues to be the same across the countries. Now, the estimates of *AC* and *ACF* are highly significant in all instances. They are largest for 30-year debt. Further, the responses to domestic auctions are on the order of two to four times as large as the responses to foreign auctions.

A potential concern with the panel approach is that in the estimation, it forces the cycles to be the same across the countries, while, in fact, they are different. The third column of Table 7 reports the unweighted averages of the country-specific cycle estimates for a system estimation of country-specific OLS-regressions. We observe that the estimates are always highly significant and very close to those for the panel regression (repeated for convenience in the second column of Table 7). Therefore, no system estimates will be reported in the sequel.

Our data also allow us to explore the strength of bilateral spillovers, that is, to estimate for country *i*'s yields a separate auction cycle associated with each other country *j*. Because there are only a relatively limited number of auctions for each

15. For the comparison of the magnitudes of the cycles associated with domestic and foreign auctions, it is useful to notice that there may be more than one foreign auction on days that foreign auctions take place. This would push down the estimate of the auction cycle associated with a single foreign auction. However, the average number of foreign auctions on days that foreign auctions take place is always less than 1.10, and for most country-maturity combinations, it is even substantially closer to one.

TABLE 7  
SYSTEM ESTIMATION

$$\Delta y_{it} = c_i + \sum_{l=4}^{-5} \alpha_{il} AUC_{i,t+l} + \sum_{l=4}^{-5} \gamma_{il} \sum_{j(\neq i)} AUC_{j,t+l} + \varepsilon_{it}$$

$$AC = \left( \sum_{l=4}^0 a_{il} \right) - \left( \sum_{l=-1}^{-5} a_{il} \right) \quad \text{and} \quad ACF = \left( \sum_{l=4}^0 \gamma_{il} \right) - \left( \sum_{l=-1}^{-5} \gamma_{il} \right)$$

	Panel	System	Eq. test
5-year debt			
AC	3.99***	3.74***	9.94*
ACF	1.06***	1.19***	2.71
10-year debt			
AC	3.66***	3.52***	15.03**
ACF	1.79***	1.91***	4.12
30-year debt			
AC	6.10***	5.82***	2.90
ACF	3.79***	3.74***	1.68

NOTES: Estimation is for the full sample period January 1, 1999–July 31, 2014. Estimation method is ordinary least squares (OLS) with Newey–West adjusted standard errors. The column under the header “Panel” reports panel OLS regressions estimated with country-fixed effects, while the column under the header “System” reports the unweighted averages of the country-specific cycle estimates when the country-specific OLS regression equations are estimated as a system. The column “Eq. test” tests whether the AC and ACF estimates are equal across the countries for given maturity issued. Further, see Notes to Table 6.

bilateral spillover, the share of significantly estimated cycles associated with foreign auctions is smaller than before (27 out of 90 possible combinations). Estimation as a panel, so estimating the effect of country  $j$ 's auctions on each other country  $i$ 's yields, while imposing that the effect is the same for each  $i$ , yields in most instances (highly) significant cycle estimates. The estimates are reported in Table A.1 in Web Appendix A (not for publication).

The yield increase in the days before an auction raises debt issuance costs for the government. Following Lou, Yan, and Zhang (2013) and Beetsma et al. (2016), we can use our estimates to calculate the additional costs associated with issuing domestic debt within the event window of a foreign issue. If such costs are substantial, then this suggests that it might be financially beneficial for treasury agencies to coordinate their auction calendars, so that auctions of different countries that take place close in time are avoided as much as possible. As an indicative calculation, we focus on 30-year debt issues for Italy and Spain and use the panel estimates in the final column of Table 6 to calculate the average yield increase, which is 1.90 basis points, that is, half the estimate of  $(\sum_{l=4}^0 \gamma_l) - (\sum_{l=-1}^{-5} \gamma_l)$ . Associated with an average-size issue for Italy, which is around 1.5 billion euros, this results in an additional interest payment resulting from a foreign auction of about 290,000 euros annually and a loss in present value terms of about 4.8 million over the life of the issue.<sup>16</sup> The

16. To compute the latter number, we use the average duration of 16.36 years over three randomly chosen 30-year auctions in 2006 and three randomly chosen 30-year auctions in 2013.

TABLE 8  
CONTROLLING FOR MARKET CONDITIONS

$$\Delta y_{it} = c_i + \sum_{l=4}^{-5} \alpha_{il} AUC_{i,t+l} + \sum_{l=4}^{-5} \gamma_{il} \sum_{j(\neq i)} AUC_{j,t+l} + \delta \Delta X_{t-1} + \varepsilon_{it},$$

$$AC = \left( \sum_{l=4}^0 a_{il} \right) - \left( \sum_{l=-1}^{-5} a_{il} \right) \quad \text{and} \quad ACF = \left( \sum_{l=4}^0 \gamma_{il} \right) - \left( \sum_{l=-1}^{-5} \gamma_{il} \right),$$

is a Vector Containing Variables Measuring Market Conditions: the Euro Stoxx Bank Index, the Euro Stoxx Index, the CBOE Volatility Index (VIX), and the Euro Overnight Index Average (EONIA)

	Germany	Netherlands	France	Belgium	Italy	Spain	Panel
5-year debt							
AC	2.40	3.28	2.72*	6.36**	6.71***	0.45	3.95***
ACF	1.88**	1.20*	1.34*	0.84	-0.04	1.33	0.96***
Adjusted R <sup>2</sup>	0.02	0.01	0.01	0.01	0.01	0.01	0.01
DW	1.92	1.88	1.86	1.68	1.75	1.70	1.77
10-year debt							
AC	2.80**	0.28	1.03	5.62**	6.04***	3.58	3.43***
ACF	0.90	1.36**	2.23***	1.55**	2.45***	2.04*	1.66***
Adjusted R <sup>2</sup>	0.01	0.01	0.01	0.01	0.02	0.01	0.01
DW	1.94	1.92	1.93	1.68	1.86	1.76	1.83
30-year debt							
AC	3.01	3.49	5.66***	8.01	7.43***	5.55**	6.06***
ACF	4.13***	3.97***	3.50***	3.97***	2.45**	3.14*	3.59***
Adjusted R <sup>2</sup>	0.01	0.01	0.01	0.01	0.01	0.01	0.01
DW	1.91	1.92	1.86	1.75	1.86	1.78	1.84

NOTES: Estimation is for the full sample period January 1, 1999 – July 31, 2014. Further, see Notes to Table 6.

corresponding numbers for Spain are approximately 200,000 euros and 3.1 million euros.

### 3.2 Robustness

The previous subsection presented evidence of auction cycles arising from domestic and foreign public debt auctions. In this subsection, we explore the robustness of the evidence.

As a first robustness test, we add control variables to equation (6) to test whether our results are driven by confounding factors. In particular, we want to exclude the possibility of yield movements around auctions being driven by fluctuations in market conditions around the auction dates. In Table 8, we therefore control for the lagged first differences of the Euro Stoxx Bank Index to measure developments in the European banking sector, the Euro Stoxx Index to capture developments in the European equity markets, the CBOE volatility index (VIX) to control for market volatility, and the Euro Overnight Index Average (EONIA) to control for interbank funding conditions. As before, we include lags to rule out feedback effects, although using contemporaneous values would again yield very similar results. The results are similar to those in Table 6, providing further support for the hypothesis that the

strong evidence of cycles associated with both domestic and foreign auctions is the result of the auctions themselves and not of confounding factors.

Although our standard errors are Newey–West corrected, hence robust against autocorrelation, in our second robustness test, we explore whether expanding our specification by including as an explanatory variable  $y_{i,t-1}$  or  $\Delta y_{i,t-1}$  affects the estimates. The results are reported in Web Appendix B (not for publication) in Tables B.1a and B.1b, which correspond to Table 6, and Tables B.1c and B.1d, which correspond to Table 8. The estimates of  $AC$  and  $ACF$  are always close or even extremely close to their original values and they are significant or not significant, whenever they were so before. The only exception is the loss of significance of  $AC$  at the 10% level for 10-year Spanish debt when the lagged yield is added. Still, in this case, the point estimate is almost unchanged. In the estimates with the lagged change  $\Delta y_{i,t-1}$ , the latter is always significant, but its value is always small (between 0.06 and 0.14). Again, the estimates of  $AC$  and  $ACF$  are very close to the original estimates.

Our third robustness test excludes those *individual* auctions that cause an exceptionally large (in absolute magnitude) domestic cycle  $(y_{i,0} - y_{i,5}) - (y_{i,5} - y_{i,0})$ , where, again,  $y_{it}$  is the end-of-day  $t$  secondary market yield on a country  $i$  bond of given maturity, where  $t = 0$  refers to the day of the individual auction by country  $i$ . The idea is that those exceptional cases may have been caused by extreme events that are not captured by our theoretical framework. Examples might be the sudden loss of confidence in the survival of the euro or an unexpected downgrade by a credit rating agency. To determine the set of auctions to be excluded, we compare the magnitudes of the individual domestic cycles with the distribution of the other domestic cycles for the same country-maturity combination. There are 10 such cases in which specific individual cycles are far larger in size than the other individual cycles. In some instances, but not in all, we can detect the likely reason for the extreme yield movements in the secondary market. Reassuringly, the estimates (and their significance) of the domestic and foreign cycles associated with the “nonextreme” auctions tend to be close to the corresponding estimates in Table 6 (see Table C.1 in Web Appendix C—not for publication). In view of this finding, we do not pursue other, more formal strategies for the exclusion of observations.

### 3.3 Accounting for the Overlap in the Primary Dealer Base

The theoretical model presented in Section 2 assigns a key role to primary dealer behavior in producing auction cycles. Therefore, in this subsection, we extend the baseline regression model (5) to take explicit account of the potential role of the overlap of the primary dealer base between countries for the cross-border spillover effects of auctions. While the theoretical model features a sharp distinction between local and global primary dealers, in reality, the distinction will be less clear cut. Some primary dealers may serve a limited number of treasuries, while others may serve most or all of them. Therefore, we construct a bilateral “globalness” index that measures the degree to which the primary dealers of a given country overlap with the

primary dealers of another country, as well as an aggregate “globalness” index that measures to what extent the primary dealers of a given country overlap with those in the remainder of the country sample. For date  $t$  in year  $y$ , the bilateral index is

$$G_{ij,t} = \sum_{r=1}^5 I_j(PD_{ir}^y) w_{ir}^y / \sum_{r=1}^5 w_{ir}^y,$$

where  $PD_{ir}^y$  is the  $r$ th-ranked primary dealer of country  $i$  in year  $y$ ,  $I_j(PD_{ir}^y)$  is an indicator function that takes on a value of 1 if  $PD_{ir}^y$  is in the full list of primary dealers of country  $j$ , and zero otherwise, and  $w_{ir}^y$  is some weight, to be further specified below. Hence, the index is the same for any date  $t$  in the same year. Analogously, for date  $t$  in year  $y$ , the aggregate index of the “globalness” of country  $i$ ’s primary dealers is obtained by summing over all the other countries:

$$G_{i,t} = \sum_{j \neq i} \sum_{r=1}^5 I_j(PD_{ir}^y) w_{ir}^y / \sum_{j \neq i} \sum_{r=1}^5 w_{ir}^y.$$

The new regression equation becomes:

$$\Delta y_{it} = c_i + \sum_{l=4}^{-5} \alpha_l AUC_{i,t+l} + \sum_{j \neq i} \sum_{l=4}^{-5} \gamma_l G_{ij,t+l} AUC_{j,t+l} + \varepsilon_{it}, \tag{6a}$$

or

$$\Delta y_{it} = c_i + \sum_{l=4}^{-5} \alpha_l AUC_{i,t+l} + \sum_{j \neq i} \sum_{l=4}^{-5} \gamma_l G_{i,t+l} AUC_{j,t+l} + \varepsilon_{it}. \tag{6b}$$

*A priori*, it is not clear what would be the ideal set of weights in the indices. Therefore, we apply different weights. The simplest is when we set all  $w_{ir}^y$  equal to one. However, we also consider the cases in which  $w_{ir}^y$  is the value of the book equity or the amount of trading assets of the  $r$ th-ranked primary dealer of country  $i$  in year  $y$ . We estimate equations(6a) and (6b) as a panel for various weighting schemes and for the baseline in which  $G_{ij,t+l} = 1$ . However, because there are no primary dealer rankings for Belgium, we drop Belgium from the sample. We have annual data on primary dealer rankings from 2000 onward, except for Spain, for which these data are available from 2001 onward. We use the rankings for 2000 to calculate the index for 1999, while for Spain, we use the ranking for 2001 to calculate the index for 1999 and 2000. Table 9 reports the estimates for the bilateral and the aggregate index and for the three possible weighting schemes ( $w_{ir}^y$  equal to one, equal to book equity, and equal to trading assets). To avoid an explosion of the numbers to be reported, we only report the panel estimates. Further, to ensure comparability of the magnitudes of our estimates with those for the baseline specification, we divide the explanatory variables  $G_{ij,t} AUC_{j,t}$  and  $G_{i,t} AUC_{j,t}$  by their averages across the sample on days that

TABLE 9  
GLOBALNESS AND STRENGTH OF AUCTION SPILLOVERS

	Baseline	BU	BB	BT	AU	AB	AT
	$\Delta y_{it} = c_i + \sum_{l=4}^{-5} \alpha_l AUC_{i,t+l} + \sum_{j \neq i} \sum_{l=4}^{-5} \gamma_l G_{ij,t+l} AUC_{j,t+l} + \varepsilon_{it}$						
5-year debt							
AC	3.62***	3.64***	3.66***	3.65***	3.61***	3.67***	3.71***
ACF	1.23***	0.51*	0.72**	0.69***	0.49	0.85**	0.96***
10-year debt							
AC	3.34***	3.35***	3.33***	3.30***	3.35***	3.35***	3.33***
ACF	2.16***	1.00***	1.07***	1.06***	1.24***	1.47***	1.50***
30-year debt							
AC	5.88***	5.74***	5.77***	5.77***	5.76***	5.80***	5.74***
ACF	3.77***	1.72***	1.89***	1.69***	2.70***	3.10***	2.86***

NOTES: (i) Estimation is for the full sample period January 1, 1999–July 31, 2014. (ii) Model is estimated as a panel for Germany, The Netherlands, France, Italy, and Spain. (iii) Data on primary dealer rankings are available from 2000 and onward. We use the rankings from 2000 to calculate the index for 1999. For Spain, the rankings are available from 2001 onward, so we use the ranking from 2001 to calculate the index for 1999 and 2000. (iv) Baseline:  $G_{ij,t+l} = 1$ . The column under “Baseline” is comparable to the final column in Table 6, except that Belgium is no longer in the sample and the sample starts in 2000. AU: Aggregate un-weighted index; AB: Aggregate index weighted by book equity; AT: Aggregate index weighted by trading assets; BU: Bilateral unweighted index; BB: Bilateral index weighted by book equity; BT: Bilateral index weighted by trading assets. Further, see Notes to Table 6.

there is an auction in at least one of the countries other than  $i$ . Evidence of spillovers of foreign auctions into domestic cycles remains very strong. This result is found for all combinations of the bilateral or the aggregate index and the various weighting schemes. Also, the magnitudes of the new auction cycle estimates tend to be quite well in line with the figures reported for the baseline in the final column of Table 6.

### 3.4 Splitting between the Precrisis and the Crisis Periods

We now allow for the possibility of the size of the auction cycles to differ for the precrisis and the crisis periods. In order to formally test the difference in the responses of the yield changes for the two subperiods, we estimate the parameters for both subperiods in a single regression:

$$\Delta y_{it} = c_i + DPRE * \left( \sum_{l=4}^{-5} \alpha_{il} AUC_{i,t+l} + \sum_{l=4}^{-5} \gamma_{il} \sum_{j(\neq i)} AUC_{j,t+l} \right) + (1 - DPRE) * \left( \sum_{l=4}^{-5} \beta_{il} AUC_{i,t+l} + \sum_{l=4}^{-5} \delta_{il} \sum_{j(\neq i)} AUC_{j,t+l} \right) + \varepsilon_{it}, \quad (7)$$

where the precrisis dummy  $DPRE$  equals 1 during the period January 1, 1999–June 30, 2007, and zero otherwise. Hence, we have returned to the baseline regression framework. Alternatively, we could estimate (6a) or (6b) allowing for coefficients to vary between both subperiods. However, the results tend to be similar to those based on (7); hence, we stick to this simpler setup. Table 10 reports the results.

TABLE 10  
SPLIT INTO PRECRISIS AND CRISIS PERIOD

$$\Delta y_{it} = c_i + DPRE * \left( \sum_{l=4}^{-5} \alpha_{il} AUC_{i,t+l} + \sum_{l=4}^{-5} \gamma_{il} \sum_{j(\neq i)} AUC_{j,t+l} \right) + (1 - DPRE) * \left( \sum_{l=4}^{-5} \beta_{il} AUC_{i,t+l} + \sum_{l=4}^{-5} \delta_{il} \sum_{j(\neq i)} AUC_{j,t+l} \right) + \varepsilon_{it},$$

where the Precrisis Dummy *DPRE* Equals 1 during the Period January 1, 1999–June 30, 2007, and zero otherwise

$$AC\_PRE = \left( \sum_{l=4}^0 \alpha_{il} \right) - \left( \sum_{l=-1}^{-5} \alpha_{il} \right), ACF\_PRE = \left( \sum_{l=4}^0 \gamma_{il} \right) - \left( \sum_{l=-1}^{-5} \gamma_{il} \right), AC\_POST = \left( \sum_{l=4}^0 \beta_{il} \right) - \left( \sum_{l=-1}^{-5} \beta_{il} \right), ACF\_POST = \left( \sum_{l=4}^0 \delta_{il} \right) - \left( \sum_{l=-1}^{-5} \delta_{il} \right).$$

	Germany	Netherlands	France	Belgium	Italy	Spain	Panel
<b>5-year debt</b>							
<i>AC_PRE</i>	-0.67	5.60**	2.47*	5.31*	1.96	1.67	2.33**
<i>AC_CRISIS</i>	5.44***	2.63	1.17	8.18**	12.93***	-0.60	5.34***
<i>ACF_PRE</i>	3.20***	2.07**	2.23**	2.02**	1.96**	1.81**	2.20***
<i>ACF_CRISIS</i>	0.78	0.82	0.91	-0.24	-0.64	1.04	0.04
Wald test <i>AC</i>	3.63*	0.54	0.22	0.31	7.96***	0.24	4.30**
Wald test <i>ACF</i>	3.08*	0.99	0.84	1.84	0.96	0.08	9.92***
Wald test joint	3.11**	0.74	0.47	1.07	5.42***	0.16	7.54***
Adjusted <i>R</i> <sup>2</sup>	0.02	0.01	0.01	0.01	0.01	0.00	0.01
DW	1.93	1.90	1.90	1.72	1.74	1.67	1.78
<b>10-year debt</b>							
<i>AC_PRE</i>	4.91***	1.66	2.57*	-0.27	1.51	1.99	2.15**
<i>AC_CRISIS</i>	1.34	-0.85	-0.74	11.19***	12.30***	4.91	5.14***
<i>ACF_PRE</i>	1.86**	2.13***	2.32**	2.40***	1.95**	1.87**	2.14***
<i>ACF_CRISIS</i>	0.11	0.69	2.12**	0.82	2.77*	2.80	1.44***
Wald test <i>AC</i>	2.24	0.53	1.63	5.98**	11.19***	0.39	6.20**
Wald test <i>ACF</i>	1.79	1.67	0.02	1.41	0.22	0.19	1.59
Wald test joint	2.07	1.05	0.81	3.74**	5.77***	0.28	4.01**
Adjusted <i>R</i> <sup>2</sup>	0.01	0.01	0.01	0.01	0.02	0.01	0.01
DW	1.94	1.93	1.94	1.71	1.83	1.71	1.82
<b>30-year debt</b>							
<i>AC_PRE</i>	1.54	5.77	5.47***	-2.34	5.60***	0.78	3.56***
<i>AC_CRISIS</i>	3.87	4.59	6.75*	20.40*	10.20***	13.67***	9.61***
<i>ACF_PRE</i>	3.87***	3.32***	3.06***	4.18***	2.71**	3.43***	3.47***
<i>ACF_CRISIS</i>	5.37***	5.17***	4.59**	3.03	2.54	4.77	4.29***
Wald test <i>AC</i>	0.32	0.03	0.10	4.02**	1.59	6.48**	11.19***
Wald test <i>ACF</i>	0.44	0.81	0.52	0.26	0.01	0.16	0.92
Wald test joint	0.35	0.42	0.30	2.01	0.87	3.26**	5.89***
Adjusted <i>R</i> <sup>2</sup>	0.01	0.01	0.01	0.01	0.00	0.00	0.01
DW	1.89	1.90	1.86	1.77	1.84	1.75	1.83

NOTES: Estimation is for the full sample period January 1, 1999–July 31, 2014. “Wald test *AC*” tests the null hypothesis *AC\_PRE* = *AC\_CRISIS*. “Wald test *ACF*” tests the null hypothesis *ACF\_PRE* = *ACF\_CRISIS*, and “Wald test joint” tests the joint hypothesis *AC\_PRE* = *AC\_CRISIS* and *ACF\_PRE* = *ACF\_CRISIS*. Further, see Notes to Table 6.



First, we discuss the differences in the cycles caused by domestic auctions for the two subperiods. We start with the individual country estimates. Beetsma et al. (2016) find that Italian auction cycles are more significant and larger during the crisis than in the period before. Here, we study a broader set of euro area countries. Indeed, for Italy, before the crisis, there is only evidence of an auction cycle in the 30-year segment, but not in the 5- and 10-year segment, while during the crisis, there is highly significant evidence for all maturities. For Belgium, there is only precrisis evidence in the 5-year segment, while during the crisis, all three maturities exhibit evidence of an auction cycle. For Spain, we find only evidence of a (highly significant) cycle for 30-year debt during the crisis period. These findings can be seen as broadly consistent with the predictions that our theoretical framework would make on the basis of the higher market volatility (see Table 2) during the crisis period for all three countries and the reduction in primary dealer activity as suggested by the anecdotal evidence reported in Subsection 1.2. The pattern for the other countries is more diffuse. France exhibits evidence of cycles for all maturities in the precrisis period, while for the crisis period, evidence of a cycle is confined to 30-year debt. Germany exhibits precrisis evidence for 10-year debt and crisis evidence for 5-year debt, while the Netherlands only exhibits evidence for 5-year debt for the precrisis period. In particular, for the Belgian 30-year segment, we estimate an auction cycle of over 20 basis points. Table 10 also reports formal tests of the differences in the sizes of the auction cycles between the two periods. The tests are only in a limited number of cases significant. The strongest evidence is found for Belgium, Italy, and Spain. The final column in Table 10 reports the estimates and Wald tests when (7) is estimated as a panel, hence forcing the auction cycles to be identical for all countries. Now, the evidence appears to be more clear-cut. In line with the theory, we observe that the auction cycles are significantly larger for all three maturities during the crisis.

We turn now to the discussion of the differences in the cross-border spillover effects of auctions between the precrisis and the crisis period. The precrisis cycle associated with foreign auction activity is (highly) significant for all country—maturity combinations in our sample. In fact, except in one instance for the 30-year maturity, significance is always at the 1%-level. By contrast, for the crisis period, there is much less evidence of cross-border spillovers and, in particular, we observe no cross-border spillovers to Belgium, Italy, and Spain of foreign 30-year debt auctions, though there are still spillovers to the other three countries. Evidence of spillovers is completely absent for the 5-year segment and in the 10-year segment only present for France and Italy. Despite the difference between the precrisis and the crisis period in terms of the significance of the spillovers, the formal Wald test for the difference in the sizes of the cycles caused by foreign auctions is significant only for German 5-year debt and only at the 10% level. The lack of formal statistical difference may be attributable to the fact that the crisis-period estimates of the cycles associated with foreign auctions are less precisely estimated due to the higher yield volatility. (In all instances, we find that the standard deviation of the estimated spillovers has become higher than in the first subperiod.) Moreover, in most instances, the cycle estimates remain positive during the crisis period. Hence, although overall the preceding results are suggestive

of a reduction in the auction spillovers going from the precrisis to the crisis period, it is difficult to draw statistically firm conclusions in this regard. In fact, both reduced and increased spillovers can be consistent with the theoretical model. On the one hand, we expect the increases in the yield covariances that occurred in a majority of the cases (see Table 3) to strengthen the spillovers, while, on the other hand, we expect the suggested reduction in European bond market integration associated with a relative increase in domestic primary dealer activity to weaken spillovers (see Section 1). The final column of Table 10 reports the estimated spillovers when we estimate the model as a panel. The 5-year debt exhibits a significant reduction in spillovers going from the precrisis to the crisis period. We also observe a reduction for 10-year debt, but a slight increase for 30-year debt. However, in both cases, the change is not significant.

Our estimates are based on the crisis period starting in July 2007. However, some might argue that in the euro area, the main crisis, or a second crisis, started when the Greek debt was downgraded to junk status by Standard & Poor's on April 27, 2010, signaling the beginning of the euro-area debt crisis. As an alternative to the current sample split, we also estimate (7) starting the second subsample on April 27, 2010. The results are reported in Table D.1 in Web Appendix D (not for publication). Between the two sample splits, there is a substantial overlap of the instances in which the estimated auction cycles are significant. This is, in particular, the case for the panel estimates, for which the estimated sizes of the auction cycles are very similar to the original ones. The exception is the estimate of the auction cycle associated with foreign five-year debt issuance, which is now significantly negative during the crisis sample.

### 3.5 Linking Auction Cycles to Market Volatility

The final column of Table 7 tests whether the auction cycles are equal across the countries when the individual country equations are estimated as a system. Equality of cycles resulting from domestic auctions is rejected in two out of three cases, while equality of the cycles resulting from foreign auctions is never rejected. Nevertheless, to allow for potential differences in the sizes of the auctions cycles across the countries, and motivated by the theory results in Section 1, we make the coefficients on the auction cycle dummies a linear function of market volatility. To the extent that market volatility is affected by the crisis, this also provides an alternative way to assess the effects of the crisis for the auction cycles.

Market volatility is based on the (rolling) 30-day backward-looking standard deviation of daily yield changes. The foreign auction dummies are interacted either with the domestic or foreign market volatility measure. We interact the domestic auction dummy  $AUC_{i,t}$  with our volatility measure  $VOL_{i,t-5}$ , which is the standard deviation of changes in the daily yield of country  $i$  over the past 30 days. We use the fifth lag of this standard deviation. This way we avoid that our volatility measure is affected by the outcome of the auction, which would violate the exogeneity of the explanatory variables. The variable is demeaned by its average value over all country- $i$  auction days

TABLE 11  
INTERACTING DOMESTIC AND FOREIGN AUCTIONS WITH DOMESTIC VOLATILITY

$$\begin{aligned} \Delta y_{it} &= c_i + \sum_{l=4}^{-5} AUC_{i,t+l}(\alpha_{il} + \beta_{il}VOL_{i,t+l-5}) + \sum_{l=4}^{-5} \gamma_{il} \sum_{j(\neq i)} AUC_{j,t+l} \\ &+ \sum_{l=4}^{-5} \delta_{il} \sum_{j(\neq i)} AUC_{j,t+l} * VOL_{i,t+l-5} + \varepsilon_{it} AC = \left( \sum_{l=4}^0 \gamma_{il} \right) - \left( \sum_{l=-1}^{-5} a_{il} \right) . AC\_INT \\ &= \left( \sum_{l=4}^0 \beta_{il} \right) - \left( \sum_{l=-1}^{-5} \beta_{il} \right) , ACF = \left( \sum_{l=4}^0 \gamma_{il} \right) - \left( \sum_{l=-1}^{-5} \gamma_{il} \right) \text{ and } ACF\_INT \\ &= \left( \sum_{l=4}^0 \delta_{il} \right) - \left( \sum_{l=-1}^{-5} \delta_{il} \right) \end{aligned}$$

	Germany	Netherlands	France	Belgium	Italy	Spain	Panel
5-year AC	3.07**	3.14	2.30	6.35**	7.14***	0.03	4.02***
5-year AC_INT	0.71	5.04**	-0.94	0.80	2.87***	-0.87	1.13***
5-year ACF	1.94***	1.42**	1.61**	0.93	0.84	1.60	1.09***
5-year ACF_INT	-0.32	-0.01	-0.29	-1.09	-0.82	-0.38	-0.75***
Adjusted R <sup>2</sup>	0.01	0.01	0.01	0.02	0.05	0.03	0.02
DW	1.92	1.91	1.89	1.72	1.75	1.69	1.78
10-year AC	2.83**	0.45	1.02	6.25**	7.09***	3.55	3.69***
10-year AC_INT	0.01	0.01	-0.83	4.93*	2.64**	-0.09	1.32***
10-year ACF	1.02	1.40**	2.33***	1.67***	2.69***	2.36**	1.81***
10-year ACF_INT	0.83*	0.55	0.80	0.48	0.57	0.16	0.44***
Adjusted R <sup>2</sup>	0.01	0.01	0.01	0.02	0.03	0.02	0.01
DW	1.94	1.93	1.94	1.72	1.83	1.70	1.82
30-year AC	2.70	4.81	6.17***	7.74*	6.58***	6.49***	6.00***
30-year AC_INT	4.56**	0.04	1.37	12.90*	2.03*	2.68	3.02***
30-year ACF	4.32***	3.93***	3.62***	3.88***	2.49**	3.33**	3.67***
30-year ACF_INT	1.00	1.64*	1.14	0.99	1.03	2.22**	1.48***
Adjusted R <sup>2</sup>	0.01	0.01	0.01	0.02	0.01	0.01	0.01
DW	1.90	1.90	1.86	1.78	1.84	1.76	1.83

Notes: Estimation is for the full sample period January 1, 1999–July 31, 2014. Further, see Notes to Table 6.

(i.e., by the mean over all  $t$  of  $AUC_{i,t} * VOL_{i,t-5}$  if  $AUC_{i,t} > 0$ ). We interact the sum of foreign auction dummies  $\sum_{j(\neq i)} AUC_{j,t}$  with two possible volatility measures:

- (1.) Domestic volatility:  $\sum_{j(\neq i)} AUC_{j,t} * VOL_{i,t-5}$ . This variable is demeaned by its average over all foreign auction days (i.e., the mean over all  $t$  of  $\sum_{j(\neq i)} AUC_{j,t} * VOL_{i,t-5}$  if  $\sum_{j(\neq i)} AUC_{j,t} > 0$ ).
- (2.) Foreign volatility:  $\sum_{j(\neq i)} AUC_{j,t} * VOL_{j,t-5}$ . This variable is demeaned by its average over all foreign auction days (i.e., the mean over all  $t$  of  $\sum_{j(\neq i)} AUC_{j,t} * VOL_{j,t-5}$  if  $\sum_{j(\neq i)} AUC_{j,t} > 0$ ).

The results are reported in Tables 11 and 12, respectively. With the additional parameters to be estimated, the number of degrees of freedom at the individual country level shrinks further. Still, the signs of the estimated coefficient sums are generally consistent with each other, while the panel generally yields (highly) significant estimates. In all instances, the size of the cycle associated with domestic auction activity

TABLE 12  
 INTERACTING DOMESTIC AND FOREIGN AUCTIONS WITH DOMESTIC VOLATILITY, RESPECTIVELY, FOREIGN VOLATILITY

$$\begin{aligned} \Delta y_{it} &= c_i + \sum_{l=4}^{-5} AUC_{i,t+l}(\alpha_{il} + \beta_{il}VOL_{i,t+l-5}) + \sum_{l=4}^{-5} \gamma_{il} \sum_{j(\neq i)} AUC_{j,t+l} \\ &+ \sum_{l=4}^{-5} \delta_{il} \sum_{j(\neq i)} AUC_{j,t+l} * VOL_{j,t+l-5} + \varepsilon_{it}AC = \left( \sum_{l=4}^0 a_{il} \right) - \left( \sum_{l=-1}^{-5} a_{il} \right), AC-INT \\ &= \left( \sum_{l=4}^0 \beta_{il} \right) - \left( \sum_{l=-1}^{-5} \beta_{il} \right), ACF = \left( \sum_{l=4}^0 \gamma_{il} \right) - \left( \sum_{l=-1}^{-5} \gamma_{il} \right) \text{ and } ACF-INT \\ &= \left( \sum_{l=4}^0 \delta_{il} \right) - \left( \sum_{l=-1}^{-5} \delta_{il} \right) \end{aligned}$$

	Germany	Netherlands	France	Belgium	Italy	Spain	Panel
5-year AC	3.00*	3.62	2.51*	5.78**	7.13***	0.50	3.94***
5-year AC_INT	1.16	4.93**	-0.86	0.94	2.90***	-0.40	1.11***
5-year ACF	3.55***	3.71***	3.71**	3.99**	3.42	-0.32	3.04***
5-year ACF_INT	-0.37*	-0.48**	-0.45*	-0.61	-0.61	0.36	-0.42***
Adjusted R <sup>2</sup>	0.01	0.01	0.01	0.02	0.05	0.03	0.02
DW	1.92	1.91	1.89	1.72	1.75	1.69	1.78
10-year AC	2.84**	0.07	0.72	6.02**	7.15***	3.88*	3.75***
10-year AC_INT	0.19	-0.70	-0.66	4.16	2.56**	0.14	1.30***
10-year ACF	-0.86	1.10	1.74	0.94	-0.06	0.39	0.64
10-year ACF_INT	0.36	0.04	0.09	0.13	0.52	0.46	0.22*
Adjusted R <sup>2</sup>	0.01	0.01	0.01	0.02	0.03	0.02	0.01
DW	1.94	1.93	1.94	1.72	1.83	1.70	1.82
30-year AC	2.69	4.88	6.10***	11.15**	5.59***	6.69**	5.97***
30-year AC_INT	4.61**	-0.12	1.47	15.07**	1.58	3.07*	3.15***
30-year ACF	-1.92	-4.19	-1.18	0.41	0.71	-0.20	-1.08
30-year ACF_INT	1.40*	1.87**	1.05	0.65	0.40	1.00	1.07***
Adjusted R <sup>2</sup>	0.01	0.01	0.01	0.02	0.01	0.01	0.01
DW	1.90	1.90	1.86	1.78	1.84	1.76	1.83

NOTES: Estimation is for the full sample period January 1, 1999–July 31, 2014. Further, see Notes to Table 6.

increases with market volatility. Also, the spillovers from foreign auction activity are significantly affected by both domestic and foreign volatility. However, the effect of volatility is smaller than in the case of domestic auctions, and for 5-year auctions, it is negative.

#### 4. CONCLUDING REMARKS

This paper has provided evidence of auction cycles in secondary public debt markets of the euro area in response to domestic and foreign primary debt auctions. To this end, we constructed a unique data set of sovereign bond auctions covering Belgium, France, Germany, Italy, the Netherlands, and Spain. Together, these countries account for around 90% of the outstanding public debt of the euro area. We focused on the period since the inception of the euro area and study both the full sample

period and the precrisis and crisis subperiods. To the best of our knowledge, this is the first paper to study the domestic and cross-border spillover effects of sovereign bond auctions.

Except for the Netherlands, for the full sample, all the countries exhibit an auction cycle in response to domestic debt issues. The evidence is strongest for the crisis period and for the 30-year maturity, for which we find a cycle of up to 20 basis points during the crisis period. All these results are in line with our theoretical framework, which emphasizes the role of the primary dealers with limited risk-bearing capacity. Also, in line with our theoretical framework, we find strong evidence of a transmission of foreign auctions into domestic cycles for domestic auctions that take place within the event windows of a foreign auction. These spillovers can amount to a cycle of about 5 basis points. The evidence remains as strong if we make the spillovers a function of the overlap of the primary dealerships across the countries, providing further support for the theoretical framework. The evidence for spillovers appears to be somewhat stronger during the precrisis than during the crisis period. In combination with the theoretical predictions of our model and the tendency of cross-border yield covariances to increase during the crisis, this suggests a reduction in sovereign bond market integration during the crisis in line with the primary dealer activity data presented in this paper. We find that foreign debt issues occurring close in time to a domestic issue may seriously impact the cost of the latter. For example, over the full period until maturity for an average-size domestic 30-year issue, this cost is estimated at 5 and 3 million euros for Italy and Spain, respectively.

Our results are relevant for Treasuries issuing new debt. The observed sensitivity of the auction cycles to turbulence in the financial markets suggests that retaining sufficient flexibility by the issuers could limit debt issuance costs and reduce the risk of roll-over crises. Obviously, increased flexibility should not come at the cost of reduced predictability of the debt issuance plans of the authorities. Issuers could vary the issuance amounts in a systematic way with market volatility, thereby assuring that market participants understand their reaction function. Moreover, the finding of, sometimes strong, spillovers of foreign auctions indicates that proper coordination of the auction calendars (i.e., sufficient time between auctions of different countries) among euro area countries may also limit issuance costs. One step has already been taken into this direction with the EU's fiscal compact (European Commission 2013). In view of the evidence consistent with primary dealer behavior as the source of the auction cycles, an alternative channel to limit these auction cycles might be to open the sovereign bond auctions to a wider range of institutional investors or to stimulate these to take up a larger role. However, a drawback of reducing the role of the primary dealers is that, because of the long-term relationship they have with the debt agencies, they provide a steady demand for newly issued debt also under unfavorable circumstances and often act as market makers in the secondary market for Treasury bonds.

The analysis and results in this paper suggest a number of avenues for further research. One concerns the investigation of the role of the auction design and the macroeconomic fundamentals for the emergence of auction cycles. Another avenue for further research would be to investigate the spillovers from U.S. Treasury auctions

on sovereign bonds yields in the Eurozone. *A priori*, the strength of the expected spillovers is unclear. On the one hand, the U.S. seems to be further segmented from euro area markets than other euro area markets, while, on the other hand, the U.S. Treasury issues larger amounts of debt, and many primary dealers operating in the euro area also operate in the U.S.

#### APPENDIX: DERIVATIONS OF THEORETICAL MODEL

The equilibrium price satisfies

$$P = E[\tilde{F}] - \eta \left[ \begin{bmatrix} W_h \Sigma_h^{-1} & 0 \\ 0 & W_f \Sigma_f^{-1} \end{bmatrix} + W_g \Sigma^{-1} \right]^{-1} X.$$

Taking  $\Sigma$  out of the matrix inverse gives:

$$P = E[\tilde{F}] - \eta \left[ \begin{bmatrix} \Sigma_{h,h} & \Sigma_{h,f} \\ \Sigma_{f,h} & \Sigma_{f,f} \end{bmatrix} \begin{bmatrix} W_h \Sigma_{h,h}^{-1} & 0 \\ 0 & W_f \Sigma_{f,f}^{-1} \end{bmatrix} + W_g I \right]^{-1} \Sigma X,$$

which can be written as:

$$P = E[\tilde{F}] - \eta A^{-1} \Sigma X,$$

where

$$A \equiv \begin{bmatrix} (W_h + W_g) I & W_f \beta_{h,f} \\ W_h \beta_{f,h} & (W_f + W_g) I \end{bmatrix},$$

and where  $\beta_{h,f} = \Sigma_{h,f} \Sigma_{f,f}^{-1}$  and  $\beta_{f,h} = \Sigma_{f,h} \Sigma_{h,h}^{-1}$ . Using the partitioned matrix inverse formulas of Bierens (2014), we can write the elements of  $A^{-1}$  as

$$A^{11} = (A_{11} - A_{12} A_{22}^{-1} A_{21})^{-1} = \left[ (W_h + W_g) I - \frac{W_h W_f}{W_f + W_g} \beta_{h,f} \beta_{f,h} \right]^{-1},$$

$$A^{12} = -A^{11} A_{12} A_{22}^{-1} = -A^{11} \frac{W_f}{W_f + W_g} \beta_{h,f}.$$

Notice that we can also write:

$$\Sigma X = \begin{bmatrix} \Sigma_{h,h} & \Sigma_{h,f} \\ \Sigma_{f,h} & \Sigma_{f,f} \end{bmatrix} \begin{bmatrix} X_h \\ X_f \end{bmatrix} = \begin{bmatrix} \Sigma_{h,h} X_h + \Sigma_{h,f} X_f \\ \Sigma_{f,h} X_h + \Sigma_{f,f} X_f \end{bmatrix}.$$

Adding it all together, Home bond prices are given by  $P_h = E[\tilde{F}_h] - \eta A^{11} [\Sigma_{h,h} X_h - \frac{W_f}{W_f + W_g} \beta_{h,f} \Sigma_{f,h} X_h + \Sigma_{h,f} X_f - \frac{W_f}{W_f + W_g} \beta_{h,f} \Sigma_{f,f} X_f]$ .

Substituting the definitions of  $\beta_{h,f}$  and  $\beta_{f,h}$ , and collecting terms, we find:

$$P_h = E[\tilde{F}_h] - \eta A^{11} \left[ \left( \Sigma_{h,h} - \frac{W_f}{W_f + W_g} \Sigma_{h,f} \Sigma_{f,f}^{-1} \Sigma_{f,h} \right) X_h + \frac{W_g}{W_f + W_g} \Sigma_{h,f} X_f \right],$$

where  $\Sigma_{h,f} \Sigma_{f,f}^{-1} \Sigma_{f,h}$  is the variance of the portfolio of Foreign bonds that best replicates the Home bonds. Going back to the definition of  $A^{11}$ , define

$$R = \beta_{h,f} \beta_{f,h} = \Sigma_{h,f} \Sigma_{f,f}^{-1} \Sigma_{f,h} \Sigma_{h,h}^{-1}.$$

Using this in the preceding expression, we obtain equation (1).

In the special case of two Home bonds only, an old and a new one, we can use  $\theta_f = 0$  in (1), and hence, the second element of the two-element vector  $P_h$  simplifies to:

$$P_{h,o} = E[\tilde{F}_{h,o}] - \frac{\eta}{W_h + W_g} [\text{Cov}(\tilde{F}_{h,o}, \tilde{F}_{h,n}) X_{h,n} + \text{Var}(\tilde{F}_{h,o}) X_{h,o}],$$

from which the derivative in equation (2) follows immediately.

In the special case of one Home bond and one Foreign bond, we have that  $R = (\text{Cov}(\tilde{F}_h, \tilde{F}_f) / (\text{Var}(\tilde{F}_h) \text{Var}(\tilde{F}_f)))^2 = \rho_{h,f}^2$ .

Substituting this into equation (1), which is now a scalar expression, we obtain equation (3).

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## SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.