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Monetary and Economic Department

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Intraday dynamics of euro area sovereign CDS and bonds*

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Abstract

The recent sovereign debt crisis in the euro area has seen credit spreads on sovereign bonds and credit default swaps (CDS) surge for a number of member states. While these events have increased interest in understanding the dynamics of sovereign spreads in bond and CDS markets, there is little agreement in the literature as to whether one of the two markets is more important than the other in terms of price discovery of sovereign credit risk. In this paper we reexamine this issue using intraday data for both market segments and employing carefully constructed cash (bond) spreads to ensure proper comparability with CDS spreads. This enables us to obtain much sharper estimates in our empirical analysis, and hence substantially clearer results with respect to price discovery. We find that the pricing of sovereign credit risk in the bond and in the CDS market converges over time, and that deviations between the two market segments do not persist for long. A key result is that the CDS market dominates the bond market in terms of price discovery in the vast majority of cases we examine. That is, CDS premia in many cases adjust more quickly to reflect new information than bonds spreads. This result holds also when taking into account transaction costs in the analysis.

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1 Introduction

In the aftermath of the 2008-09 financial crisis investors became increasingly concerned about the fiscal outlook in a number of countries, including several of those in the euro area. As a result, sovereign credit spreads began rising sharply for a number of euro area countries. At their peak, yield spreads on sovereign bonds relative to German bonds reached several hundred basis points. These spreads had averaged only a few basis points in the years between the introduction of the euro and the start of the global financial crisis. As sovereign bond yields rose during the recent sovereign debt crisis, the interest in trading credit risk protection on euro sovereign borrowers via credit default swaps (CDS) grew substantially and spreads on such instruments also surged. These developments sparked strong interest in the market for sovereign CDS among policy makers and regulators. Of particular interest has been the interplay between the pricing of sovereign credit risk in CDS and in bond markets, and the possibility that one market could be systematically leading the other.

In this paper we analyse the intraday dynamics of euro area sovereign credits spreads in CDS and bond markets, focusing in particular on the price discovery process - the efficient and timely incorporation of the information implicit in investor trading into market prices.[1] To investigate the price discovery process for euro area sovereign credit markets, we rely on the fact that a credit risky sovereign bond can be viewed as a combination of a risk free bond and a CDS contract providing credit protection on the risky bond. Under certain conditions (see discussion below), the yield spread of the risky bond over the risk free bond should therefore be equal to the premium (usually called "spread") of the CDS contract. In particular, CDS and (par floating rate) bond credit spreads will be equal if financial markets are frictionless and complete (Duffie (1999)). Otherwise, investors would be able to make arbitrage profits. In practice, frictions and imperfections often make such arbitrage trades difficult and costly to varying degree. These imperfections include limited and time-varying liquidity in some or all market segments, unavailability of instruments with identical maturity and payout structures, and the fact that some arbitrage trades require tying up large amounts of capital for extended periods of time. As a result, the difference between the credit spreads in the two market segments - often denoted the "basis" - is typically not zero. However, we would expect to see arbitrage forces come into play if the basis becomes too wide, pushing it back towards zero.

Using a vector error correction (VECM) approach, we analyse the extent to which spreads adjust in response to a widening of the basis. We also examine whether the adjustment takes place predominantly in one of the two market segments, and how fast the adjustment process is. Our main finding is that for most countries the CDS market

[1] See Lehmann (2002) for a general discussion of price discovery in financial markets.

leads the bond market in terms of credit risk price discovery. In other words, CDS prices tend to move first in response to news, and bond prices tend to adjust towards the pricing in the CDS market. Hence, credit spreads in the two markets tend to converge over time as suggested by theory. We also find that deviations do not persist for long. The estimated half lives of a shock to the basis range from around half a day to 12 days across the countries in our sample. A key contribution of this paper is that - via the use of intraday price data from both markets - we are able to estimate the spread dynamics and the price discovery implications much more accurately than in existing studies on sovereign credit markets. To our knowledge, no other empirical work has tested the intraday patterns of sovereign CDS and bond market credit spreads.

As discussed above, the liquidity situation in sovereign CDS and bond markets varies over time and this will affect the ability of investors to implement trades aimed at exploiting apparent arbitrage opportunities related to a non-zero basis. We check to which extent liquidity or transaction cost considerations might affect our baseline results by reestimating the model for data that includes a proxy for transaction costs, namely the observed bid-ask spreads in the two market segments. By selecting the bid or ask prices that would be relevant for arbitrageurs given the observed basis, we aim to better capture the market environment that investors would face at each point in time. We find that our baseline results hold up very well, even when including this proxy for transaction costs.

1.1 Related literature

One of the first studies to test the no-arbitrage relationship between CDS and bond credit premia discussed above is Blanco et al. (2005), who use a VECM methodology to study corporate bond and CDS markets. For a sample of 33 investment grade U.S. and European firms, they find an equilibrium long-run relation between the pricing in the two markets for the majority of firms. They also find that in most cases price discovery takes place in the CDS market. In another early paper, Zhu (2006) uses a similar approach to study a sample of 24 large (mainly U.S.) investment grade firms and confirms the existence of a long-term equilibrium relation as well as the result that the CDS market tends to lead the bond market. Using a substantially larger dataset that includes 1599 entities (mostly corporations), Hull et al. (2004) find that the theoretical relationship between CDS spreads and bond yield spreads holds fairly well. Mayordomo et al. (2011) analyse European corporate credit markets, focusing on the role of liquidity in the price discovery process during the financial crisis. Defining liquidity as the relative number of participants in a given market, they find evidence that relative liquidity affects the price discovery process. Moreover, their results vary between the pre-crisis and the crisis periods. Before the crisis, CDS lead the bond market (asset swap spreads) while during the crisis leadership is reversed. Upper and Werner (2007) analyse the price discovery process in a sovereign bond market by comparing the pricing in the cash and in a derivatives market. Specifically, they consider the information content of trades in Bund futures and German government bonds before and during the 1998 financial market turbulences. They find that under normal market conditions prevailing in the first half of the year, between 19 and 33 per cent of the variation in the price was due to trading in the bond market. By contrast, during turbulent conditions the bond market's share in price discovery dropped to zero, with information becoming incorporated into prices only in the futures market. They attribute this to an unusually high proportion of large client trades that were executed against dealer inventory, which suggests that these trades were motivated by liquidity rather than by information.

In an interesting recent paper Giannikos et al. (2013) examine the dynamics of price discovery using daily stock prices, CDS spreads, and bond spreads over a four-year period before and during the crisis (2005-2008) for 10 US financial firms. They find that throughout the sample period, CDS and bond spreads are clearly cointegrated and that the CDS market dominates in terms of price discovery. They also find that the role of the stock market changed when the crisis hit. Before the crisis, the stock market played a dominant role in price discovery while during the financial crisis, the role of the stock market weakened, and the CDS market became dominant.

There are a few studies available that focus on sovereign credit markets and that compare bond and CDS markets. Ammer and Cai (2011) examine emerging market sovereign borrowers and find a stable long-term relationship between cash and CDS markets for most countries based on VECM estimates. On the issue of price discovery, their findings are mixed, with CDS markets leading bond markets for some countries and the opposite relation for others. They also conclude that the relative liquidity of the two markets is a key determinant of where price discovery occurs. Levy (2009) regresses sovereign CDS spreads on corresponding bond spreads for a range of emerging markets and finds large deviations from parity, a result that is largely explained by liquidity effects.

The sovereign debt crisis in the euro area has resulted in a few recent papers focusing on euro sovereigns. Arce et al. (2012) examine 11 EMU countries and find persistent deviations from the theoretical CDS-bond parity during the sovereign crisis that were absent prior to the crisis. Moreover, they find that some of the variation in the price discovery process can be explained by a number of risk sources and market frictions, including counterparty risk, funding costs, a global risk indicator and ECB interventions in sovereign bond markets. Using a sample of six euro area countries, Palladini and Portes (2011) find a more stable price discovery process where CDS markets generally lead bond markets, although in contrast to our results they find that the adjustment towards equilibrium is very slow. Fontana and Scheicher (2010) study ten euro sovereigns and find that price discovery is evenly split between CDS and bond markets. O'Kane (2012) reports similar results by only using Granger-Causalities on daily data.

The differences in results reported in these studies could be due to sample differences or to differences in how bond spreads are calculated. For example, Arce et al. (2012) use the 5-year yield to maturity difference relative to German Bunds, Palladini and Portes (2011) use 5-year "constant maturity" bond yield differences (again relative to Germany), while Fontana and Scheicher (2010) use 10-year yield to maturity minus the 10-year euro swap rate. Moreover, these studies use daily or weekly data for the empirical analysis, which may lead to inaccurate matching of CDS and bond spread observations, especially in periods when activity in one or both of the markets is low and trades occur infrequently.

In this paper, we try to be as careful as possible to avoid such problems by using intraday data for both CDS spreads and for government bond prices. In addition, instead of using simple yield differences as our measure of cash spreads, we use carefully constructed asset swap spreads based on estimated zero-coupon government bond prices. This ensures that we are comparing "apples with apples" in our empirical analysis, by matching exactly the maturities and the cash flow structures of the CDS and the cash components. The use of asset swap spreads is also in line with the practice used in commercial banks when trading the CDS-cash basis.

The remainder of the paper is structured as follows. In Section 2, we discuss characteristics of sovereign credit markets and describe the theoretical relation between CDS and cash spreads. Section 3 describes our intraday data and provides measures of market activity during our sample period. In this section, we also describe how we construct our measure of the sovereign credit basis using asset swap spreads. In Section 4 we describe properties of our CDS and asset swap spread data and report results from stationarity and cointegration tests. Further we introduce the standard vector error correction model (VECM). Section 5 presents the main empirical results of our analysis of the CDS-cash basis, including price discovery measures and the impact of market liquidity conditions. In Section 6 we provide a number of robustness checks. Section 7 concludes.

2 Sovereign CDS and bond markets

2.1 Sovereign CDS

Sovereign CDS are financial contracts offering protection against potential losses from credit events on debt issued by a sovereign borrower for a given time period. The protection buyer pays a regular (usually quarterly) premium - also known as the CDS spread - expressed in (annual) basis points per notional amount of the contract, in exchange for a one-off contingent payment if any of a set of pre-specified credit events occurs. The CDS can therefore be viewed as an insurance contract where the buyer of protection pays a premium to the seller in order to receive protection against a set of credit events. Unlike an insurance contract, however, the buyer of protection does not necessarily have to suffer any actual losses to receive payment when a credit event occurs. As CDS are over-the-counter (OTC) instruments, the terms of a transaction can in principle be negotiated. In practice, however, these transactions have become increasingly standardised.

CDS contracts for sovereign as well as other reference entities are generally documented under a legal agreement called a Master Agreement from the International Swaps and Derivatives Association (ISDA). Sovereign CDS can be triggered by a range of credit events, including the failure to pay coupon or principal, repudiation or moratorium of existing obligations, or restructuring (Willeman et al. (2010)). Restructuring, in turn, has to be considered binding on all investors and may be due to a reduction or postponement of payment of interest or principal, a change in seniority, or redenomination into a currency other than a "Permitted Currency".[2]

If the contract is triggered by a credit event, it is settled either via physical delivery of bonds or via cash settlement. In the first case, the buyer of protection may sell any acceptable deliverable obligation to the seller of protection for a price of par. In the second case, the protection seller pays an amount corresponding to par minus a pre-specified recovery rate (percentage of notional repaid in the event of a default) to the buyer. Cash settlement has gradually replaced physical settlement as the most popular settlement method. In addition, most sovereign CDS trade with auction settlement, meaning that following a credit event there will be an auction to determine the final recovery rate. In the auction, investors who wish to do so can deliver (or receive) underlying debt whereas investors who do not participate will settle only in cash using the final recovery rate from the auction.

Finally, sovereign CDS contracts are nowadays typically denominated in a currency different from the main currency of the deliverable obligations. CDS on euro area sovereigns therefore tend to be denominated in US dollars (whereas US sovereign CDS tend to be denominated in euros). The main reason for this is that faced with a credit event, it is assumed that the local currency will come under considerable pressure.

2.2 Relation between sovereign CDS and bonds

Bonds issued by countries associated with non-negligible credit risk are priced to compensate investors for this risk. Hence, by subtracting the yield of a comparable bond (in terms of maturity, currency, etc.) that is considered free of credit risk from the yield on the credit risky bond, we can isolate the credit risk component, also called the credit spread. Intuitively, then, the CDS spread and the bond credit spread of a particular

[2] "Permitted Currency" is defined as Euros, legal tender in a G7 country or legal tender in an OECD country with at least one AAA rating from Moody's, S&P or Fitch (Willeman et al. (2010)).

sovereign should be closely linked, as they both measure credit risk compensation for that sovereign.

More formally, no-arbitrage arguments can be invoked to show that the CDS spread must equal the spread between the payments of a par floating-rate note issued by the reference entity of the CDS and the payments of a floating-rate credit risk free note (Duffie (1999)). However, for this parity to hold, a number of specific conditions must be met, including that markets are perfect and frictionless, that bonds can be shorted without restrictions or cost, there are no tax effects, etc. Moreover, floating rate notes are relatively uncommon, in particular for sovereigns. And to the extent that fixed-rate bonds are used as substitutes, it is unlikely that the maturity of these exactly match that of standard CDS contracts. This means that the difference between the CDS premium and the bond spread, the so-called basis, is typically not zero. In fact, if market imperfections grow - as they tend to do during times of stress - the basis can become both sizeable (positive or negative) and very persistent.

There are, however, limits to how much the basis can widen. At some point, arbitrage strategies will become feasible, even in stressed market conditions. One would therefore expect to find that, although the basis can deviate from zero significantly and persistently, it would tend to revert back towards zero in the long run. This is one of the main issues we will be examining in the empirical analysis below.

3 Data

The core data we use in the empirical analysis consists of intraday quotes on CDS contracts and government bonds for France, Germany, Greece, Ireland, Italy, Portugal and Spain for the period October 2008 to end-May 2011. We choose this group of countries as it includes the countries that have been most affected by the euro sovereign debt crisis, as well as Germany which will serve as a near-risk free reference country, and France which we consider as a low-risk control country. The beginning of the sample period is chosen in order to allow us to focus on the sovereign crisis, while trying to avoid the most extreme market turbulence in the immediate aftermath of the Lehman Brothers collapse. In addition, euro area sovereign CDS markets were very thin prior to 2008 (Figure A.1), making any type of intraday analysis during this period almost impossible. While we have access to data through all of 2011, the quality of the data clearly deteriorates from around mid-2011. This reflects that liquidity dried up in an environment of rapidly worsening conditions in euro area sovereign debt markets. As a result, we set the end of our sample to end-May 2011. We describe our data sources in more detail below.

3.1 Euro area sovereign bond data

Our intraday sovereign bond price data comes from MTS (Mercato Telematico dei Titoli di Stato), the most important electronic platform for euro-denominated government bonds, consisting of a number of domestic markets and a centralized European marketplace. Persaud (2006) reports that in 2006 the MTS platform had a market share of just over 70% of the electronic trading of European government bonds. The MTS data consists of both actual transaction prices and binding bid/offer quotes. The number of transactions of sovereign bonds on the MTS platform is however not sufficient to allow us to undertake any meaningful intraday analysis, except for Italian bonds.[3] In the subsequent analysis we therefore use the trading book or 'best proposal' quotes from the respective domestic MTS markets.[4] The MTS market is open from 8:15 to 17:30 local Milan time (during summer CEST and during winter CET), with a pre-market phase from 7.30 to 8.00 and an offer-market phase from 8:00 to 8:15. We use data from 8:30 to 17:30.

3.2 Euro area sovereign CDS data

Our sovereign CDS data consists of intraday price quotes provided by CMA (Credit Market Analysis Ltd.) Datavision. CMA continuously gathers information on executable and indicative CDS prices directly from the largest and most active credit investors. After cleaning and checking the individual quotes, CMA applies a time and liquidity weighted aggregation so that each reported bid and offer price is based on the most recent and liquid quotes. In the subsequent empirical analysis, we use 5- and 10-year USD-denominated sovereign CDS quotes for the seven countries in our sample. Looking at the number of quotes in Figures A.1 and A.2 in Appendix A, the 5-year segment appears more liquid than the 10-year segment - in particular as of 2010. There is some data on 2-year CDS too, but the number of observations for such contracts is very small and we therefore exclude these observations.

Being an OTC market, the CDS market is in principle open 24 hours a day. In practice, however, most of the activity in the CMA database is concentrated between around 7:00 and 17:00 London time. As we want to match the CDS data with the bond market data, we restrict our attention to the period from 8:30 to 17:30 CET/CEST.

3.3 Sampling frequency

Our empirical analysis of the intraday CDS and bond spread dynamics will be based on a time-series methodology, which means that we need to construct equally-spaced time

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[3] Figure A.3 in Appendix A shows the number of trades on the MTS platform for the countries in our sample from 2006-2011.

[4] We ignore quotes from the centralized European platform (market code: EBM), as quotes for government bonds on the centralised platform are duplicates of quotes on the domestic platforms.

series of spreads. After extensive initial analysis of the amount and distribution of our intraday quotes, both for sovereign CDS and bonds, we conclude that a 30-minute time interval gives us a satisfactory trade-off between data frequency and the occurrence of missing observations. In practice, this means that we use the average of the mid-quotes reported for both bonds and CDS within each half-hour interval. Figure A.2 shows that using a 30-minute sampling frequency, between 75% and 90% of the half hour intervals contain a price for 5-year CDS from 2009 onwards. The proportion of non-empty intervals is somewhat lower for the 10-year contracts, in particular towards the end of the sample. Figure A.5 shows that using a 30-minute sampling interval for bonds we have in almost all cases more than 90% non-empty time intervals.

Microstructure noise effects may come into effect when high frequency data is used (Fulop and Lescourret (2007)). However, this is unlikely to play any significant role for our data based on a 30-minute sampling frequency because we average the reported quotes over each 30 minute interval. Moreover, robustness checks using 1- and 2-hour sampling frequencies provide similar results as our 30-minute data (see Section 6).

3.4 Estimating the intraday CDS-bond basis

In order to construct the CDS-bond basis, we need to specify an appropriate measure for the cash (bond) leg of the basis. We choose to rely on sovereign asset swap spreads for this. An asset swap is a financial instrument that exchanges the cash flows from a given security - e.g. a particular government bond - for a floating market rate[5]. This floating rate is typically a reference rate such as Libor for a given maturity plus or minus a fixed spread, the so-called "asset swap spread". The spread is determined such that the net value of the transaction is zero at inception.

By swapping fixed payments for floating, an investor who owns a fixed-rate bond can therefore hedge out the interest rate risk using an asset swap. As a result, the investor can maintain the original credit exposure to the fixed rate bond without being exposed to interest rate risk. Hence, an asset swap on a credit risky bond is similar to a floating rate note with identical credit exposure. The asset swap spread is therefore similar to the CDS spread on the reference entity, and consequently it is a natural candidate for the cash leg when analysing the CDS-bond basis.

There are various types of asset swaps, but the most common is the so-called par asset swap, in which the swap buyer purchases a bond from the seller in return for a full price of par. Until the bond matures, the swap buyer pays the fixed coupons to the seller and receives Libor plus or minus the asset swap spread. The asset swap buyer is therefore exposed to the credit risk of the bond in case the issuer defaults on future coupon or

[5] See O'Kane (2000) or Gale (2006) for detailed discussions of the mechanics and pricing of asset swaps.

principal payments. The par asset swap spread agreed at the time of inception equates the value of the initial bond purchase with the present value of the net floating payments during the life of the bond. Specifically, the asset swap spread is the fixed value A required for the following equation to hold[6] (O'Kane (2000))

$$\underbrace{100 - P}_{\substack{\text{Upfront payment for bond} \\ \text{asset in return for par}}} + \overbrace{C \cdot \underbrace{\sum_{i=1}^{N_{\text{fixed}}} d(t_i)}_{\text{Fixed payments}} = \underbrace{\sum_{i=1}^{N_{\text{float}}} \big(L_i + A\big) \cdot d(t_i)}_{\text{Floating payments}}}^{\text{Interest rate swap}}, \tag{1}$$

where P is the full (dirty) price of the bond, C is the bond coupon, L_i is the floating reference rate (e.g. Libor) at time t_i, and $d(t_i)$ is the discount factor applicable to the corresponding cash flow at time t_i. Hence, we need four variables to calculate our asset swap spreads: the bond price and coupon, the reference rate, and the discount factor. The specifics of how we choose these variables is described in detail below.

3.4.1 Bond price and coupon

It is generally not possible to find bonds outstanding with maturities that exactly match those of the CDS contracts we use. Moreover, the cash-flows of the bonds and the CDS will not coincide, further complicating a comparison. To overcome these issues, in what follows we use synthetic asset swap spreads based on estimated intraday zero-coupon sovereign bond prices. Specifically, for each 30-minute interval and each country, we estimate a zero-coupon curve based on all available bond price quotes during that time interval using the Nelson-Siegel (1997) method. This involves fitting a discount function to market bond price quotes observable during that half hour interval according to

$$d_t(m) = \exp(-y(t,m) \cdot m), \tag{2}$$

where m denotes time to maturity in years and $y(t,m)$ is the corresponding zero-coupon yield:

$$y(t,m) = \beta_{(t,0)} + \big(\beta_{(t,1)} + \beta_{(t,2)}\big) \cdot \frac{\tau_t}{m}\left[1 - \exp\left(\frac{-m}{\tau_t}\right)\right] - \beta_{(t,2)} \cdot \exp\left(\frac{-m}{\tau_t}\right), \tag{3}$$

where the four Nelson-Siegel parameters $\beta_{(t,i)}$, $i = 0, 1, 2$ and τ_t are estimated for each half hour interval t. We remove estimation results which imply that any segment of the zero curve differs by more than 10% from one 30 minutes interval to the next (less than 0.1% of all 30 minutes intervals). We also exclude results that imply negative instantaneous zero

[6] This assumes that there is no accrued coupon payment due at the time of the trade; otherwise, an adjustment factor would need to be added to the floating payment component.

rates as well as negative or unreasonably large (greater than 50% per annum) asymptotic yields.

With sufficient quotes in each 30-minute interval, we end up with 18 half-hourly estimated zero coupon curves for each trading day and each country. This allows us to price synthetic bonds with maturities that exactly match those of the CDS contracts we study, and we can use these bond prices to back out the corresponding asset swap spreads. To be specific, consider a CDS contract with a maturity of m years for a particular country j, with a spread $S_j(t_k, m)$ observed at time (interval) k on day t. The corresponding cash spread is then given by the asset swap spread $A_j(t_k, m)$, obtained from

$$100 - P_j(t_k, m) = \sum_{i=1}^{N_m} \big(L_i(t_k) + A_j(t_k, m)\big) \cdot d(t_k, t_i), \tag{4}$$

where $N_m = 4 \cdot m$ and $P_j(t_k, m)$ is the m-year maturity zero-coupon bond price at t_k for country j,

$$P_j(t_k, m) = 100 \cdot \exp(-y_j(t_k, m) \cdot m). \tag{5}$$

$y_j(t_k, m)$ is the zero-coupon yield given by the Nelson-Siegel expression and $L_i(t_k)$ is a 3-month forward Libor rate at time t_k. Note that equation (4) is identical to equation (1) for C set to zero as we are now considering (synthetic) zero-coupon bonds.

3.4.2 The reference rate

For the reference rate $L_i(t_k)$ in (4), we use the 3-month Euribor forward curve to match as closely as possible the quarterly cash flows of sovereign CDS contracts. We construct the forward curve using available rates on forward rate agreements (FRAs) and euro interest rate swaps. Here, we only use FRAs for 3-month rates and swaps with quarterly floating-rate payments. Since the financial crisis, interest rates based on different underlying rate tenors have not implied identical forward curves, reflecting higher liquidity and counterparty risk associated with instruments that have longer periods between successive floating payments. Bianchetti (2010) discusses this issue in detail.

We collect the FRA and swap data from Bloomberg, which provides daily (end-of-day) data. 3-month FRAs are available with quarterly settlement dates up to 21 months ahead, i.e. up to 21×24. From two years onwards, we bootstrap zero-coupon swap rates from swap interest rates available on Bloomberg and back out the corresponding implied forward rates. Because the swaps have annual maturities, we use a cubic spline to generate the full implied forward curve, thereby enabling us to obtain the quarterly forward rates needed in (4).

Given our interest in intraday dynamics, we generate estimated intraday Euribor forward rates by assuming that the intraday movements of the Euribor forward curve are proportional to the intraday movements of the German government forward curve.[7] To be precise, for each day, we calculate the difference between our Euribor forward curve and the forward curve implied by the end-of-day Nelson-Siegel curve for Germany.[8] We then keep this difference across the entire curve fixed throughout that same day and add it to the estimated intraday forward curves for Germany earlier on that day to generate the approximate intraday Euribor forward curves. This approach makes the, in our view, reasonable assumption that the intraday variability in Euribor forward rates will largely mirror movements in corresponding German forward rates. We evaluate this as part of our robustness checks in Section 6, and we confirm that the results are robust to this assumption.

3.4.3 The discount rate

Finally, we need to specify the discount rates $d(t_k, t_i)$ in equation (4). Before the financial crisis, market participants tended to use the Libor or Euribor curve for discounting cash flows in swaps and other instruments. In the aftermath of the crisis, however, OTC contracts have become increasingly collateralised using credit support annexes (CSAs) in order to mitigate counterparty risks that became obvious during the crisis. Moreover, central clearing has become more and more widespread, and the collateral posted typically earns a rate linked to the overnight interest rate (Nashikkar (2011)). As a result, the market has increasingly moved to essentially risk-free discounting using the overnight index swap (OIS) curve. We therefore take $d(t_k, t_i)$ in equation (4) to be the euro OIS discount curve.

We construct the OIS discount curve in a way similar to the Euribor forward curve. For OIS contracts with maturities longer than one year, we bootstrap out zero-coupon OIS rates from interest rates on long-term OIS contracts. Thereafter, we construct the entire OIS curve using a cubic spline. Again, we only have access to daily (end-of-day) data for these contracts, so we use the same technique as described above to generate approximate intraday OIS discount curves based on the intraday movements of the German government curve.

3.4.4 The basis

Using the above methodology, we derive the intraday asset swap spreads for each country for the 5- and 10-year maturities (displayed in Appendix B and with descriptive statistics provided in Appendix C) and we calculate the corresponding CDS-bond basis. The

[7] Euribor rates are daily fixing rates, so we are actually approximating the intraday movements of the interbank interest rates for which Euribor serves as a daily benchmark.

[8] Here we use the second to last 30-minute interval, because the last trading interval is occasionally overly volatile.

summary statistics for our 14 basis series for the sample period October 2008 to end of May 2011 are shown in Table D.1 in Appendix D while the series themselves are plotted in Figure 1.

For the theoretical no-arbitrage condition to hold, the basis should be clustered around zero. Instead, we find an average basis for both tenors and all seven sovereigns that is positive over the sample period. The basis spreads vary substantially across countries with means ranging from 74 to 122 bps for 5-year tenors, and from 58 to 175 bps for 10-year tenors (Table D.1). Greece clearly exhibits the highest and most volatile basis.

We have fewer observations in the 10-year segment than for the 5-year horizon. As noted above, this is mainly due to the fact that much of the activity in sovereign CDS markets is concentrated in the 5-year segment. This can be further illustrated by comparing intraday CDS and ASW data points across the two maturity segments.

Figure 2 provides an example, based on an arbitrarily selected week during our sample, which shows that 10-year CDS contracts are quoted less frequently and less 'orderly' than the 5-year contracts. One further aspect stands out in the intraday plots in Figure 2, namely the unusually stable intraday prices for German asset swap spreads. This is an artefact of our assumption that intraday movements in the forward Euribor curve mirror those of the German forward government curve. This assumption results in intraday moves in the right-hand side of the ASW pricing equation (4) essentially cancelling out intraday bond price moves in the left-hand side in the case of German asset swaps.

This may influence the empirical results for Germany, but should not significantly affect the results for other countries (in particular high-spread countries, where bond price movements tend to be substantially larger than any assumed intraday move in the Euribor curve). To verify this, we perform a robustness check and reestimate our model based on an alternative assumption of constant intraday Euribor rates. The results are reported in Section 6.

Figure 1: CDS-asset swap basis

The basis for each reference entity is defined to be the difference between the CDS spread and the ASW spread and is expressed in basis points. The figure shows data with 30 minute sampling frequency.

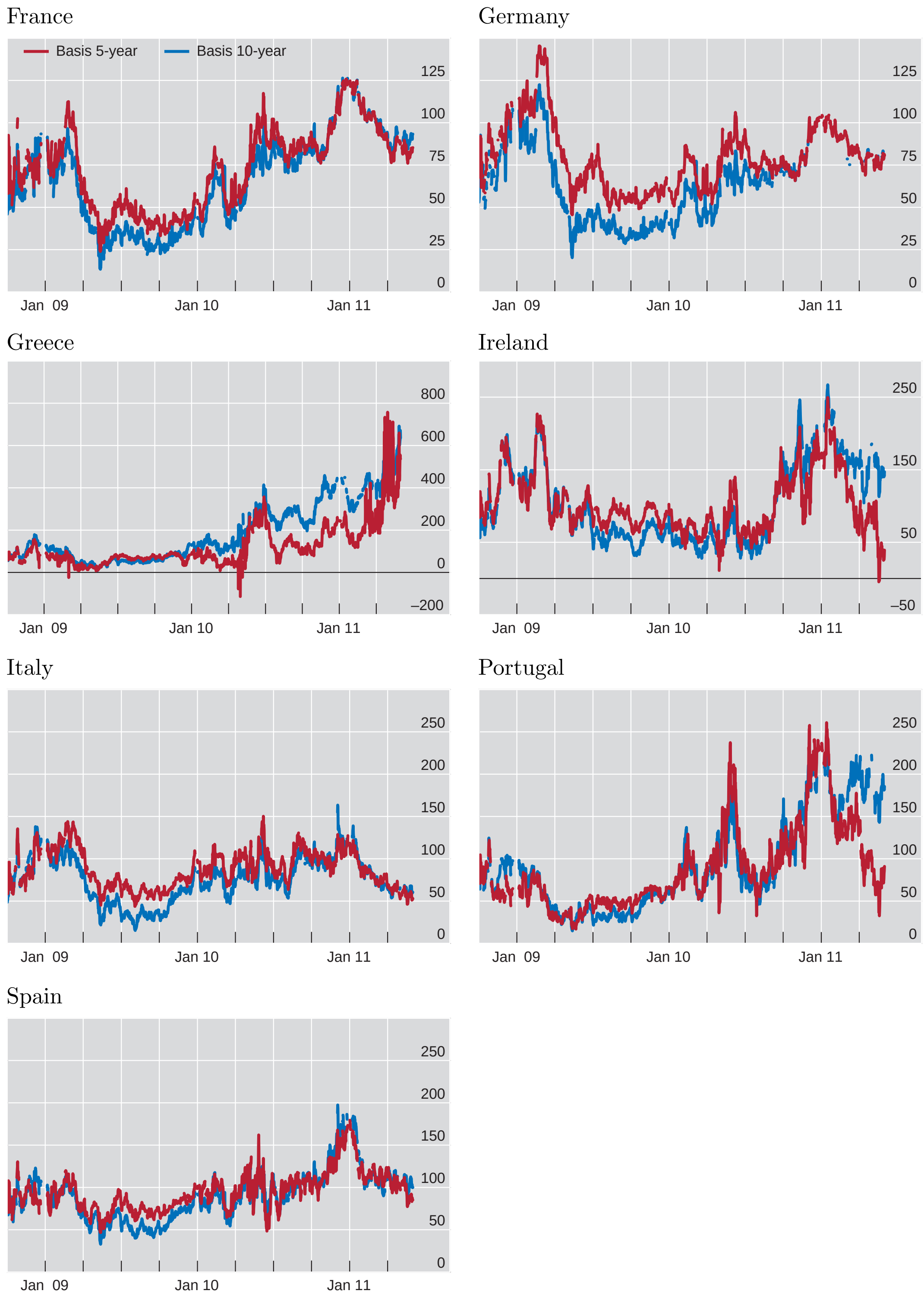


Figure 2: Sample of intraday CDS and ASW spreads

Intraday movements of CDS (right-hand axis) and ASW (left-hand axis) spreads for an arbitrary sampling period (Monday 9th Aug. 2010 to Friday 13th Aug. 2010). The figures show data for a 30 minutes sampling frequency, i.e. 18 time intervals per trading day, starting at 8:30 and ending at 17:30 CET (CEST during summer). The unusually stable intraday prices for German asset swap spreads are an artefact of our assumption that intraday movements in the forward Euribor curve mirror those of the German forward government curve. The data is expressed in basis points.

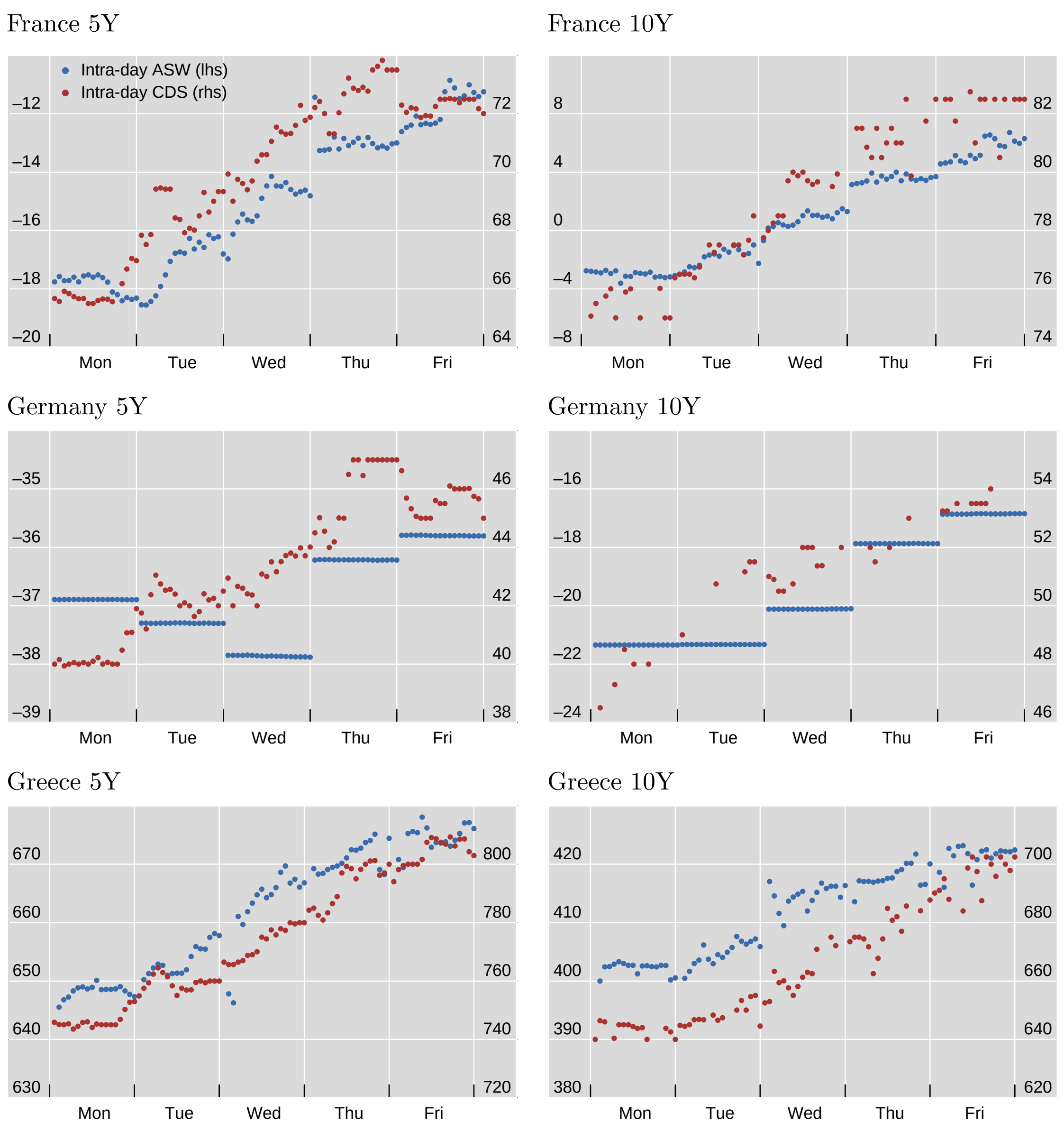
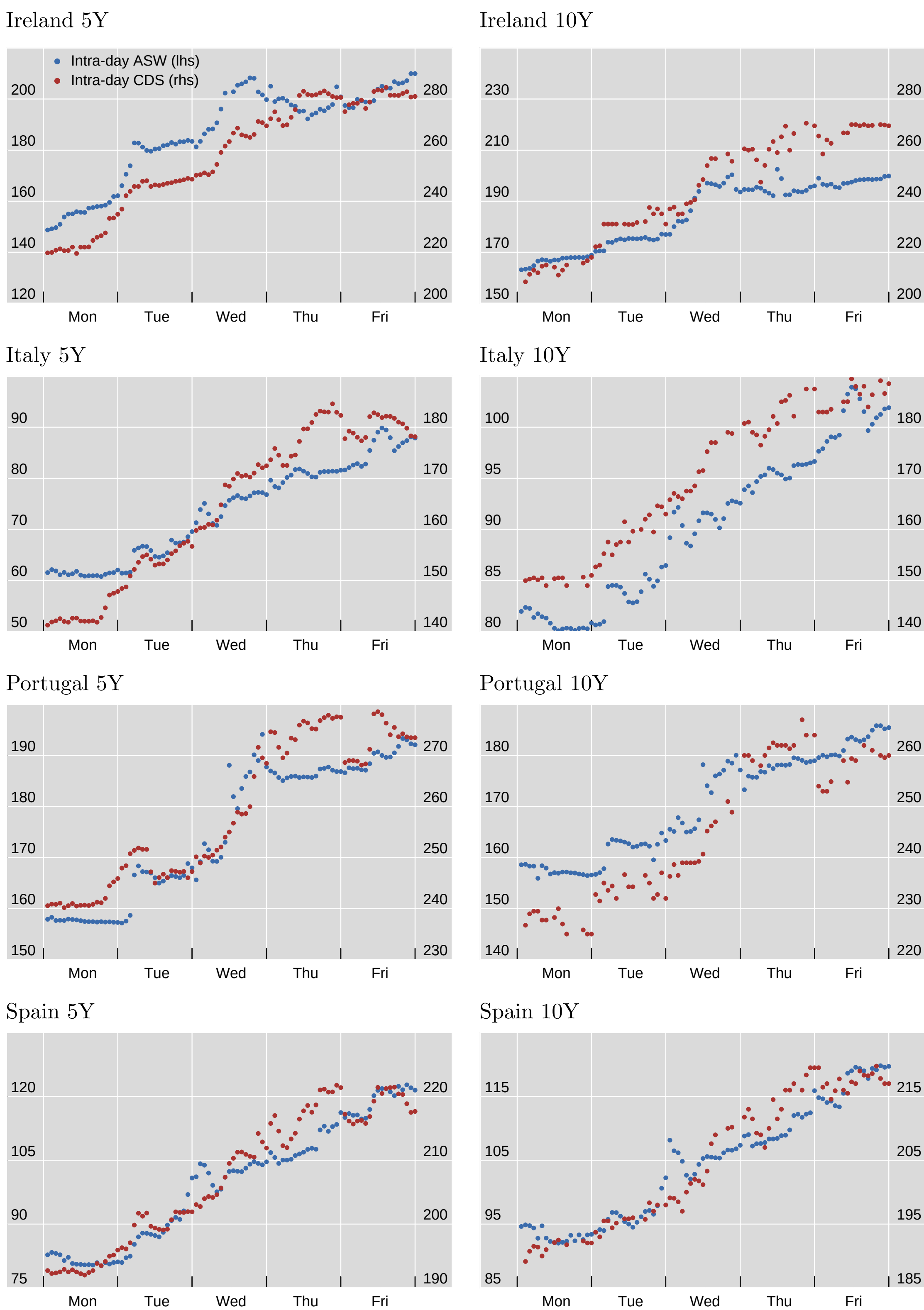


Figure 2: (cont.) Sample of intraday CDS and ASW spreads



4 Modelling the intraday sovereign credit spread dynamics

We are now ready to analyse the intraday CDS and ASW series in order to investigate whether one market is more important for the credit risk price discovery process. The main focus is on our benchmark 30-minute data, but we also present results for other sampling frequencies (1- and 2-hour as well as daily data), and for spreads that have been adjusted for transaction costs. First we perform unit root and stationarity tests to confirm that the spread series contain a unit root. Next, we run cointegration tests, the results of which show that the CDS and the ASW spreads are indeed cointegrated. Given these results, we proceed to estimate VECM models for each sovereign and each maturity in our sample to analyse intraday price discovery.

4.1 Credit spread properties - stationarity, unit root and cointegration

Appendix E contains detailed tables for the unit root and stationarity tests, which show that all our series have a unit root. In general, we find that there is a long-term relationship with a stable basis, indicating that the cash bond market and the CDS market appear to price credit risk similarly in the long run. We consider two time series as cointegrated if the null hypothesis of no cointegration is rejected at the 5 per cent significance level of the Johansen or the Phillips-Ouliaris test. CDS and bond market credit spreads in both the 5- and 10-year segments are found to be cointegrated in all cases, with the exception of the 5-year Irish case for some sampling frequencies. Detailed tables for the cointegration tests can be found in Appendix F.

4.2 Vector error correction model

As our time series are I(1) and the CDS and ASW time series are cointegrated we can employ a VECM model to study the joint price formation process in both markets. From the estimated VECM model one can then calculate measures that indicate which of the two markets is leading the price discovery process. Two standard measures are used to assess the contributions to price discovery: i) the information share or Hasbrouck (1995) measure (HAS) and ii) the common factor component weight or Gonzalo and Granger (1995) measure (GG). We also compute the half-lives of shocks from the VECM model based on the speed of adjustment of the two time-series.

We use the following VECM to estimate the contributions to price discovery from the two markets:

$$\begin{aligned} \Delta CDS_t &= \lambda_1(CDS_{t-1} - \alpha_0 - \alpha_1 ASW_{t-1}) \\ &\quad + \sum_{j=1}^{p} \beta_{1j} \Delta CDS_{t-j} + \sum_{j=1}^{q} \gamma_{1j} \Delta ASW_{t-j} + \varepsilon_t^{CDS} \end{aligned} \tag{6}$$

$$\Delta ASW_t = \lambda_2(CDS_{t-1} - \alpha_0 - \alpha_1 ASW_{t-1}) + \sum_{j=1}^{p} \beta_{2j} \Delta ASW_{t-j} + \sum_{j=1}^{q} \gamma_{2j} \Delta CDS_{t-j} + \varepsilon_t^{ASW} \quad (7)$$

In equations (6) and (7) CDS_t and ASW_t stands for CDS spreads and asset swap spreads at time t for a specific sovereign, while ε_t^{ASW} and ε_t^{CDS} are i.i.d. shocks. The two equations constitute a vector autoregressive model in first-order difference with an additional error correction term. This term would be equal to our CDS-bond basis if $\alpha_0 = 0$ and $\alpha_1 = 1$. The error correction term represents the long-run equilibrium of the two time series and the VAR-term the short-run dynamics coming from market imperfections (Baillie et al. (2002)). We set $p = q$ in the VAR part of equations (6) and (7) and use the lag lengths provided in Table G.1, which are based on the Schwarz information criterion (SIC).

The speed of adjustment parameters λ_1 and λ_2 measure the degree to which prices in a particular market adjust to correct pricing differentials from their long-term relationship. In case price discovery takes place only in the cash bond market we would find a negative and statistically significant λ_1 and a statistically insignificant λ_2, as the CDS market would adjust to correct the pricing differentials from the long-term relationship. In other words, the cash bond market moves ahead of the CDS market as relevant information reaches the market. Conversely, if λ_1 is not statistically significant but λ_2 is positive and statistically significant, the price discovery process takes place in the CDS market only - that is, the CDS market moves ahead of the cash bond market. In cases where both λ's are significant, with λ_1 negative and λ_2 positive, price discovery takes place in both markets.

From the speed of adjustments we can compute the HAS and GG measures of price discovery. As pointed out by de Jong (2002) neither method can be considered universally superior as both measures are closely related by definition. However, only the information share or Hasbrouck measure takes into account the variability of the innovations in each market's price.[9]

[9] See (Man et al.; 2013) for a thorough discussion.

There are four Hasbrouck (HAS) measures, two for each market:

$$\mathrm{HAS}_1^{\mathrm{CDS}} = \frac{\lambda_2^2\left(\sigma_1^2 - \frac{\sigma_{12}^2}{\sigma_2^2}\right)}{\lambda_2^2\sigma_1^2 - 2\lambda_1\lambda_2\sigma_{12} + \lambda_1^2\sigma_2^2} \tag{8}$$

$$\mathrm{HAS}_2^{\mathrm{CDS}} = \frac{\left(\lambda_2\sigma_1 - \lambda_1\frac{\sigma_{12}}{\sigma_1}\right)^2}{\lambda_2^2\sigma_1^2 - 2\lambda_1\lambda_2\sigma_{12} + \lambda_1^2\sigma_2^2} \tag{9}$$

$$\mathrm{HAS}_1^{\mathrm{ASW}} = \frac{\left(\lambda_1\sigma_2 - \lambda_2\frac{\sigma_{12}}{\sigma_2}\right)^2}{\lambda_2^2\sigma_1^2 - 2\lambda_1\lambda_2\sigma_{12} + \lambda_1^2\sigma_2^2} \tag{10}$$

$$\mathrm{HAS}_2^{\mathrm{ASW}} = \frac{\lambda_1^2\left(\sigma_2^2 - \frac{\sigma_{12}^2}{\sigma_1^2}\right)}{\lambda_2^2\sigma_1^2 - 2\lambda_1\lambda_2\sigma_{12} + \lambda_1^2\sigma_2^2}\,, \tag{11}$$

where only two of these measures are independent. Two relationships exist:

$$\mathrm{HAS}_1^{\mathrm{CDS}} + \mathrm{HAS}_1^{\mathrm{ASW}} = 1 \qquad \text{and} \qquad \mathrm{HAS}_2^{\mathrm{CDS}} + \mathrm{HAS}_2^{\mathrm{ASW}} = 1\,.$$

To estimate expressions in equations (8) to (11) we rely on the estimated covariance matrix from the VECM to capture the terms σ_1^2, σ_{12} and σ_2^2.

The Hasbrouck measure is by construction confined to the closed interval [0,1]. This makes an interpretation very straightforward, namely $\min(\mathrm{HAS}_i^{\mathrm{CDS}}) > 0.5$ can be interpreted as the CDS market is contributing more to the price discovery than the cash market. Similarly, $\max(\mathrm{HAS}_i^{\mathrm{CDS}}) < 0.5$ means that the ASW market contributes more to price discovery. By construction of the HAS measure, price volatility reflects new information. Hence, the market that explains most of the variance of innovations is also assumed to contribute most to price discovery.

The GG measure decomposes the common factor itself, but ignores the correlation of the innovations in the two markets. The following two measures exist

$$\mathrm{GG}^{\mathrm{CDS}} = \frac{-\lambda_2}{\lambda_1 - \lambda_2} \tag{12}$$

$$\mathrm{GG}^{\mathrm{ASW}} = \frac{\lambda_1}{\lambda_1 - \lambda_2}\,, \tag{13}$$

whereby it is obvious that $\mathrm{GG}^{\mathrm{CDS}} + \mathrm{GG}^{\mathrm{ASW}} = 1$.[10]

To simplify the notation we only consider the independent set of values $\mathrm{HAS}_1^{\mathrm{CDS}}$, $\mathrm{HAS}_2^{\mathrm{CDS}}$ and $\mathrm{GG}^{\mathrm{CDS}}$ and therefore skip the superscript CDS [11]. In the following we define HAS as the average of HAS_1 and HAS_2. With this convention, HAS and GG measures

[10] Note that when the CDS and ASW spreads are cointegrated the GG measure will be in the interval [0,1].

[11] In the subsequent tables, HAS_1 and HAS_2 are sorted such that HAS_1 is the smaller of the two HAS measures, and HAS_2 the larger.

greater than 0.5 imply that more than 50% of the price discovery occurs in the CDS market. When the measures are close to 0.5 both markets contribute to price discovery without evidence on which market is dominant. GG and HAS below 0.5 suggest price leadership for the cash bond market.

Finally, we are interested in examining the speed of adjustment towards the long-term equilibrium. As the CDS and ASW spreads in the bivariate VECM share a common stochastic trend, the impulse response function for the cointegrating residual can be used to determine the speed of adjustment to long-run equilibrium (Zivot and Wang (2006)). The vector error correction mechanism directly links the speed of adjustment of CDS and ASW spreads to the cointegration residual u_t which follows an implied AR(1) process:

$$u_t = (1 + \lambda_1 - \alpha_1 \lambda_2) u_{t-1} + \varepsilon_t^{CDS} - \alpha_1 \varepsilon_t^{ASW} \equiv \phi u_{t-1} + \varepsilon_t^{CDS} - \alpha_1 \varepsilon_t^{ASW} \,. \qquad (14)$$

The half-life of a shock, n, can now be calculated from the AR(1) coefficient ϕ as:

$$n = \frac{ln(0.5)}{ln(\phi)} \,. \qquad (15)$$

5 Main results

In this section we first present result for the benchmark case, namely the intraday credit spreads with 30 minute sampling frequency. We then present results for intraday spreads after controlling for transaction costs. These are followed by our findings using daily data, which are compared to other findings in the literature. In all cases we find that for most countries the CDS market leads the bond market in terms of credit risk price discovery. After having discussed the main price discovery findings, we calculate the half-life of credit risk shocks given the estimated VECM models to illustrate the economic significance of our findings. We find that in most cases the half-life of any basis-widening is just a few trading days.

5.1 Benchmark case

Here we present our results for the benchmark case, namely the intraday credit spreads with 30 minute sampling frequency. Table 1 provides estimates for the speed-of adjustment parameters λ_1 and λ_2. The majority of the λ_1 parameters have the expected negative sign, consistent with the notion that the bond market contributes to the price discovery process. In other words, the results show that, at least to some extent, CDS spreads adjust to changes in bond (asset swap) prices. This effect is however only statistically significant for Ireland and Portugal and for the Italian 10-year segment.

The results concerning the λ_2 parameter are substantially stronger. Apart from Germany, they have the expected positive sign for all countries, and they are also all statistically significant at the 5% level, except for Ireland where they are significant only at the 10% level. These results indicate strongly that the CDS market contributes importantly to price discovery in euro area sovereign credit markets. Moreover, in most cases the magnitude of λ_2 is larger than λ_1, suggesting that bond spreads adjust stronger than CDS spreads in cases where there are signs of price discovery in both markets.

The result that we obtain a negative and significant λ_2 for Germany is puzzling, as it suggests that a widening of the basis (higher CDS spread or lower cash spread) will tend to result in further declines in the cash spread. This phenomenon is visible in the figures for Germany in Appendix B. We surmise that this behaviour can in part be explained by the presence of periods with flight to safety in our sample, i.e. periods when general widening of CDS spreads in the euro area was met with flight to safe German government bonds, resulting in downward pressure on Bund yields.

The inference above is based on asymptotic standard errors, which should be reliable given that we have approximately 10,000 observations for each time series (Tables C.1 and C.2). Nevertheless, given the high credit spread volatility during our sample period, we also employ a standard bootstrap method as described in Benkwitz et al. (2001), where we use 100,000 Monte-Carlo simulations to generate 95% confidence bands for the λ_i parameters. Figure 3 displays the results which, as expected, are in line with the asymptotic results. The exception is λ_2 for France and Germany, where the bootstrapped confidence bands suggest that this parameter is not significantly different from zero. Hence, the puzzling finding for Germany discussed above appears much weaker in the bootstrapped results.

Our finding that the CDS market has been the main venue for price discovery for most of the euro area sovereign borrowers in our sample is confirmed by the HAS and GG measures in Table 1. In all cases except for Ireland and for the Portuguese 10-year segment, the HAS and GG measures are heavily tilted towards one, indicative of CDS leadership. The bootstrap confidence bands for the HAS and GG price discovery measures displayed in Figure 4 show that in many cases the point values of the measures are not very precisely estimated. Still, most of the confidence bands are tilted towards one, with a number of them (France, Greece, Spain and Germany, 5-years) being significantly higher than 0.5 at the 5% level. In the cases where the HAS and GG measures point towards bond market leadership (Ireland and Portugal, 10-years), the precision of the estimates appears particularly low.

Table 1: Price discovery for the benchmark case

Two measures of price discovery for the period October 2008 to end-May 2011 are reported: the information share or Hasbrouck measure (HAS) and the common factor component weight or Gonzalo-Granger measure (GG), which are based on the system of equations in (6) and (7). The HAS measures in Eqs. (8) to (11) provide upper and lower bounds to the price discovery contribution made in the CDS market. The CDS market is more important in the price discovery process for credit risk whenever GG and HAS are above 0.5, and the bond market dominates when they are below 0.5. The superscript ^{a} indicates that the GG measure has to be interpreted as 1, because the VECM coefficient λ_1 is not significant. The values of the coefficients λ_i and their standard errors are expressed in units of 10^{-4}. The superscript * indicates that the cointegration test for that country shows no cointegration at the 5% significance level, hence VECM results must be treated with caution.

Panel A: 5-year segment

Sovereign	HAS_1	HAS_2	GG	λ_1	Std.err.	p	λ_2	Std.err.	p
France	0.98	0.98	1.09^a	0.15	0.13	0.19	1.85	0.24	0.00
Germany	1.00	1.00	0.97	0.49	2.95	0.39	-16.25	3.99	0.00
Greece	1.00	1.00	1.00	2.50	6.66	0.37	524.15	34.27	0.00
Ireland*	0.37	0.49	0.50	-15.90	7.02	0.03	16.10	8.34	0.06
Italy	0.70	0.85	0.67	-12.43	8.00	0.12	25.49	7.68	0.00
Portugal	0.60	0.71	0.63	-15.81	6.86	0.03	26.91	8.12	0.00
Spain	0.91	0.99	0.90	-7.27	10.64	0.32	65.33	10.78	0.00

Panel B: 10-year segment

Sovereign	HAS_1	HAS_2	GG	λ_1	Std.err.	p	λ_2	Std.err.	p
France	1.00	1.00	1.02^a	0.14	0.70	0.39	7.20	1.07	0.00
Germany	0.81	0.83	1.57^a	-6.24	3.89	0.11	-17.25	4.97	0.00
Greece	0.99	1.00	1.11^a	10.15	9.51	0.23	99.33	9.99	0.00
Ireland	0.23	0.26	0.25	-27.38	8.73	0.00	9.11	5.20	0.09
Italy	0.69	0.76	0.58	-18.13	7.20	0.02	25.42	5.90	0.00
Portugal	0.43	0.51	0.46	-37.79	10.92	0.00	31.95	9.86	0.00
Spain	0.86	0.91	0.71	-19.63	10.62	0.07	48.43	8.44	0.00

Figure 3: Confidence bands for adjustment speeds in the benchmark case

Confidence bands for λ_1 and λ_2 for the period from October 2008 to end-May 2011. The bootstrap confidence intervals are estimated according to Benkwitz et al. (2001) with 100,000 simulations. The lower bound is the 2.5% percentile. The upper bound is the 97.5% percentile. The 5-year Greek λ_2 is not shown because this would overstretch the y-scale (the 5-year Greek λ_2 is positive and significantly different from zero. The λ_i are expressed in units of 10^{-4}.

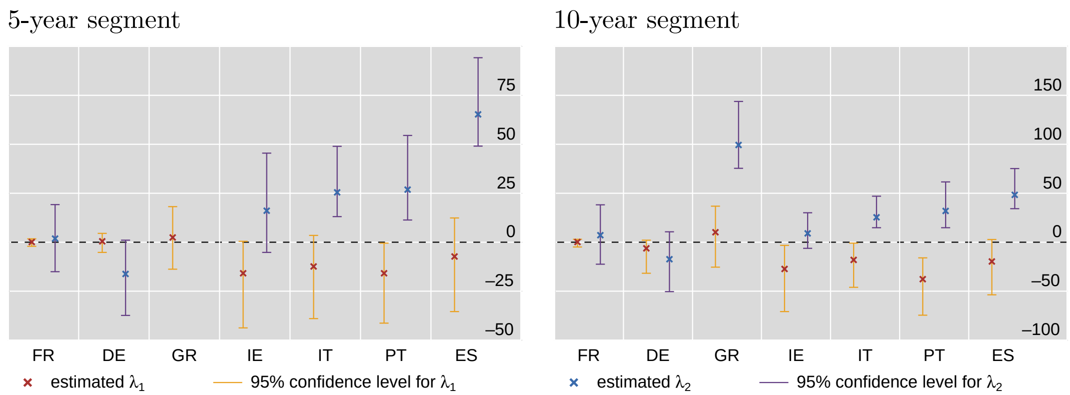
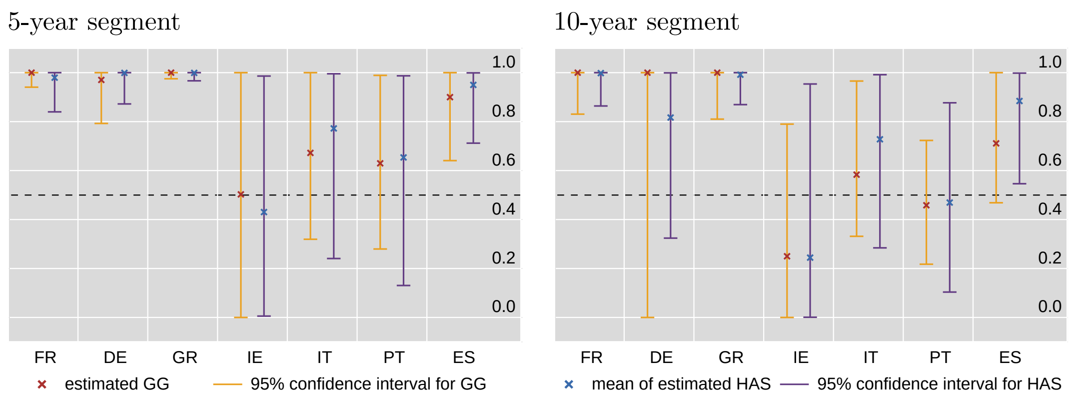


Figure 4: Confidence bands for HAS and GG in the benchmark case

Confidence bands for the HAS and GG measures for the period from October 2008 to end-May 2011. The HAS ratio is the average of HAS_1 and HAS_2. Bootstrap confidence intervals are estimated according to Benkwitz et al. (2001) with 100,000 simulations. The lower bound is the 2.5% percentile. The upper bound is the 97.5% percentile. Appendix J reports the underlying numbers.



5.2 Price discovery and transaction costs

The previous section has demonstrated that CDS and/or bond prices do adjust when discrepancies in the pricing of sovereign credit risk open up between the two market segments. Underlying this adjustment is, of course, the fact that investors take positions in the two markets in order to exploit any pricing differences. This, in turn, suggests that market liquidity conditions are important for investors in these markets, as taking such positions is clearly easier and cheaper when market liquidity is high.

We use this observation to sharpen our analysis by generating transaction cost-adjusted CDS and ASW spreads which we then use to reexamine our price discovery results. This transaction cost adjustment is done by taking into account the relevant bid or ask spreads for setting up a basis trade that could be used to exploit a non-zero CDS-ASW basis. As shown in Figure 1, the basis is almost always positive during our sample period. To bet on a basis decline one shorts credit risk in the bond market and goes long credit risk in the CDS market, i.e. sell the bond *and* sell the CDS.

Since we have access to bid and ask prices (spreads), we can construct the relevant series that investors would care about in this context. For the CDS spread, this means simply using bid rather than mid spreads. For the ASW, we use bid bond prices and recalculate the ASW spreads as discussed in Section 3.4. We refer to the resulting series as the transaction cost adjusted spreads (Appendix H contains figures showing the bid-ask spreads of CDS and ASW spreads). We use these adjusted series to reestimate the VECM model. Again we use the Schwarz information criterion to optimize the lag length of the VECM model. The lag lengths are presented in Table G.1.

The bottom line from this analysis is that the results are consistent with those obtained in the benchmark case, in which only mid-spreads were used. As Table 3 and Figure 5 show, the λ parameters are little changed. One exception is the λ_2 parameter estimate for the German 5-year segment, which switches sign from negative to positive once transaction costs are taken into account. This suggests that the puzzling finding for Germany discussed in relation to the benchmark results may, at least for the 5-year segment, be accounted for by transaction costs.

As for the HAS and GG measures, these are also broadly in line with the benchmark results (Figure 6). There are some signs that the inclusion of transaction costs in the analysis results in somewhat wider confidence bands. This is particularly so for Germany and the Irish 10-year segment.

Table 2: Price discovery for transaction cost adjusted data

This table reports the HAS and GG measures for the period period October 2008 to end-May 2011. The superscript [a] indicates that the GG measure has to be interpreted as 1, because the VECM coefficient λ_1 is not significant. The values of the VECM coefficients λ_i and their standard errors are expressed in units of 10^{-4}. For further details see Table 1.

Panel A: 5-year segment

Sovereign	HAS_1	HAS_2	GG	λ_1	Std.err.	p	λ_2	Std.err.	p
France	0.99	1.00	1.08^a	0.31	0.42	0.31	4.31	0.58	0.00
Germany	0.84	0.86	0.75	-4.94	4.65	0.23	14.56	5.86	0.02
Greece	1.00	1.00	1.01^a	3.48	7.95	0.36	316.72	36.55	0.00
Ireland	0.08	0.14	0.33	-21.35	6.34	0.00	10.29	9.73	0.23
Italy	0.53	0.67	0.59	-19.64	8.38	0.03	28.65	9.66	0.00
Portugal	0.42	0.46	0.65	-18.87	7.78	0.02	35.13	16.50	0.04
Spain	0.80	0.92	0.79	-17.84	10.51	0.09	67.50	12.48	0.00

Panel B: 10-year segment

Sovereign	HAS_1	HAS_2	GG	λ_1	Std.err.	p	λ_2	Std.err.	p
France	0.99	0.99	0.95	-0.35	0.69	0.35	6.56	0.97	0.00
Germany	0.99	1.00	0.94	0.67	2.51	0.39	-10.94	3.05	0.00
Greece	1.00	1.00	1.02^a	1.74	9.52	0.39	80.31	10.56	0.00
Ireland	0.16	0.18	0.23	-40.06	8.21	0.00	11.93	5.52	0.04
Italy	0.54	0.60	0.47	-23.54	7.48	0.00	20.54	5.61	0.00
Portugal	0.42	0.48	0.48	-46.55	11.45	0.00	42.26	11.57	0.00
Spain	0.64	0.69	0.55	-34.83	11.01	0.00	41.95	9.23	0.00

Table 3: Comparison of adjustment speeds

The unadjusted λ estimates are the same as the ones in Table 1. The transaction cost adjusted estimates are obtained by estimating the VECM model using bid CDS and bid ASW spreads. The superscripts *, **, and *** denote statistical significance at the 10, 5, and 1 percent level, respectively. The parameter values are expressed in units of 10^{-4}. For further details see Tables 1 and 2.

Panel A: 5-year segment

Sovereign	Benchmark λ_1	Benchmark λ_2	Cost adjusted λ_1	Cost adjusted λ_2
France	0.15	1.85***	0.31	4.31***
Germany	0.49	-16.25***	-4.94	14.56**
Greece	2.50	524.15***	3.48	316.72***
Ireland	-15.90**	16.10*	-21.35***	10.29
Italy	-12.43	25.49***	-19.64**	28.65***
Portugal	-15.81**	26.91***	-18.87**	35.13**
Spain	-7.27	65.33***	-17.84*	67.50***

Panel B: 10-year segment

Sovereign	Benchmark λ_1	Benchmark λ_2	Cost adjusted λ_1	Cost adjusted λ_2
France	0.14	7.20***	-0.35	6.56***
Germany	-6.24	-17.25***	0.67	-10.94***
Greece	10.15	99.33***	1.74	80.31***
Ireland	-27.38***	9.11*	-40.06***	11.93**
Italy	-18.13**	25.42***	-23.54***	20.54***
Portugal	-37.79***	31.95***	-46.55***	42.26***
Spain	-19.63*	48.43***	-34.83***	41.95***

Figure 5: Confidence bands for adjustment speeds with transaction cost adjusted data

Confidence bands for λ_1 and λ_2 for the period from October 2008 to end-May 2011. The bootstrap confidence intervals are estimated according to Benkwitz et al. (2001) with 100,000 iterations. The lower bound is the 2.5% percentile. The upper bound is the 97.5% percentile. The 5-year Greek λ_2 is not shown because this would overstretch the y-scale (the 5-year Greek λ_2 is positive and significantly different from zero). The λ_i are expressed in units of 10^{-4}.

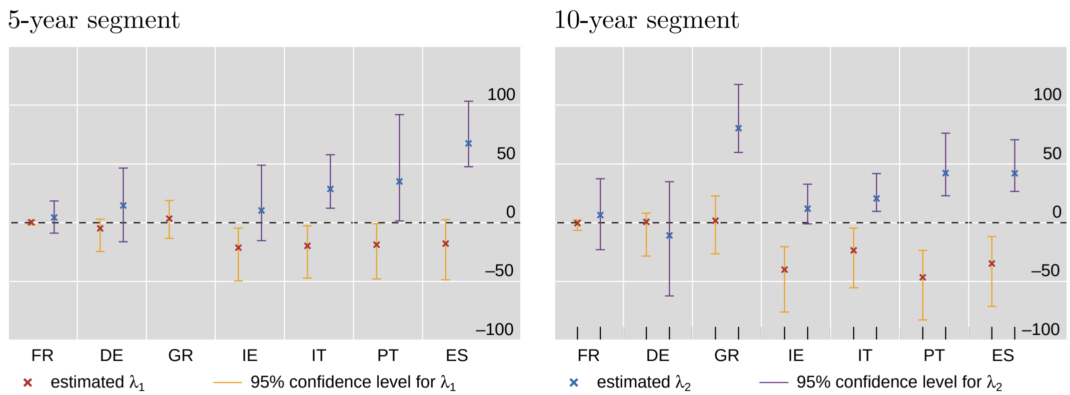
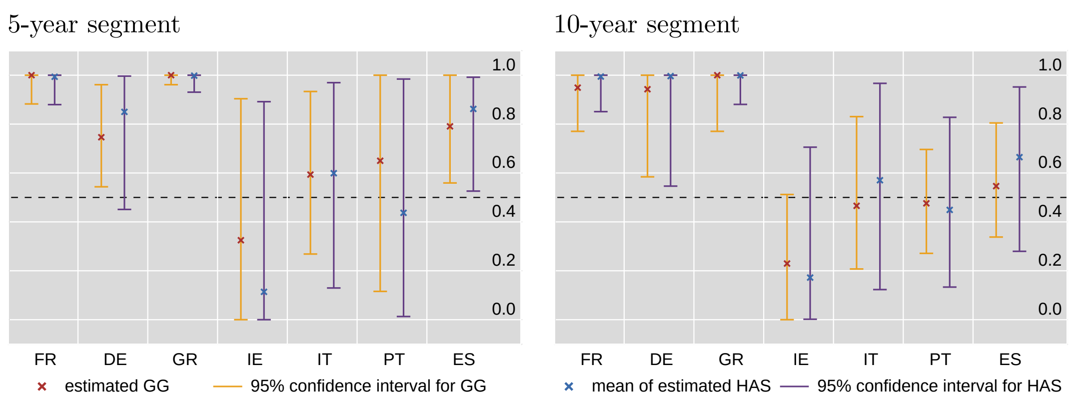


Figure 6: Confidence bands for HAS and GG measures with transaction cost adjusted data

Confidence bands for the HAS and GG measures for the period from October 2008 to end-May 2011. The HAS ratio is calculated as the average of HAS_1 and HAS_2. Bootstrap confidence intervals are estimated according to Benkwitz et al. (2001) with 100,000 iterations. The lower bound is the 2.5% percentile. The upper bound is the 97.5% percentile. Appendix J reports the underlying numbers.



5.3 Daily data

In this section we discuss results obtained using daily data by sampling end-of-day observations of our 30-minute data. Unit root and stationarity test results for the daily data are reported in Appendix E.5 and cointegration tests results are displayed in Appendix F.5. The use of daily data serves as a robustness check and it also allows us to examine whether we obtain results similar to those found by others who have used daily data.

For the 5-year maturity segment the VECM results indicate clear CDS leadership except for Italy, Portugal and Spain (Table 4 and Figure 8). For Italy and Portugal the bond market is clearly leading while in Spain there is mild CDS leadership. In the 10-year case we find CDS leadership in most cases except for Italy. The absolute values of the speed of adjustments (λ_i) are much bigger than in our benchmark case based on 30-minute sampling frequency as we are sampling once per day instead of 18 times per day.

The relative confidence bands of the speed of adjustment parameters are generally wider than in the benchmark case Figure 7. Moreover, The confidence bands of the HAS and GG measures are much wider than for the benchmark case due to the smaller number of observations.

All in all, the use of daily data yields results that are more mixed than in our benchmark case. In addition, the precision of the price discovery measures HAS and GG drops significantly compared to the intraday results, making it more difficult to draw firm conclusions about price discovery. This could be one reason behind the differences in results found elsewhere in studies using daily and weekly data, such as Arce et al. (2012), Palladini and Portes (2011), and Fontana and Scheicher (2010).

Table 4: Price discovery with daily data

This table reports the price discovery analysis for the period from October 2008 to end-May 2011. The superscript ^{a} indicates that the GG measure has to be interpreted as 1, because the VECM coefficient λ_1 is not significant; the superscript ^{b} indicates that GG has to be interpreted as 0, because λ_2 is not significant. The values of the VECM coefficients λ_i and their standard errors are expressed in units of 10^{-4}. The values of the coefficients λ_i and their standard errors are expressed in units of 10^{-4}.

Panel A: 5-year segment

Sovereign	HAS_1	HAS_2	GG	λ_1	Std.err.	p	λ_2	Std.err.	p
France	0.80	0.84	1.64	13.32	5.83	0.03	34.21	7.37	0.00
Germany	0.81	0.92	1.17^a	-51.45	43.06	0.20	-361.84	93.95	0.00
Greece	0.64	0.98	0.87	-73.13	176.35	0.37	502.92	217.26	0.03
Ireland	0.83	0.99	0.94	-68.25	137.21	0.35	1021.54	265.83	0.00
Italy	0.06	0.13	-0.29^b	-419.77	125.67	0.00	-93.68	104.85	0.27
Portugal	0.02	0.19	-0.27^b	-279.41	121.22	0.03	-60.04	171.80	0.38
Spain	0.25	0.89	0.55	-390.53	224.39	0.09	474.70	180.20	0.01

Panel B: 10-year segment

Sovereign	HAS_1	HAS_2	GG	λ_1	Std.err.	p	λ_2	Std.err.	p
France	0.94	0.95	1.25^a	8.19	7.48	21.90	40.66	9.51	0.00
Germany	0.52	0.68	1.61	-96.64	42.33	2.95	-255.39	88.13	0.60
Greece	0.89	1.00	1.95^a	168.74	107.26	11.57	345.85	74.42	0.00
Ireland	0.69	0.93	0.72	-60.97	113.02	34.49	155.14	92.47	9.76
Italy	0.36	0.73	0.47	-225.48	108.89	4.67	198.99	83.83	2.38
Portugal	0.85	1.00	1.01^a	6.52	146.72	39.85	574.14	155.57	0.04
Spain	0.46	0.87	0.56	-236.36	148.07	11.16	298.63	101.27	0.52

Figure 7: Confidence bands for adjustment speeds with daily data

Confidence bands for λ_1 and λ_2 for the period from October 2008 to end-May 2011. The bootstrap confidence intervals are estimated according to Benkwitz et al. (2001) with 100,000 simulations. The lower bound is the 2.5% percentile. The upper bound is the 97.5% percentile. The λ_i are expressed in units of 10^{-4}.

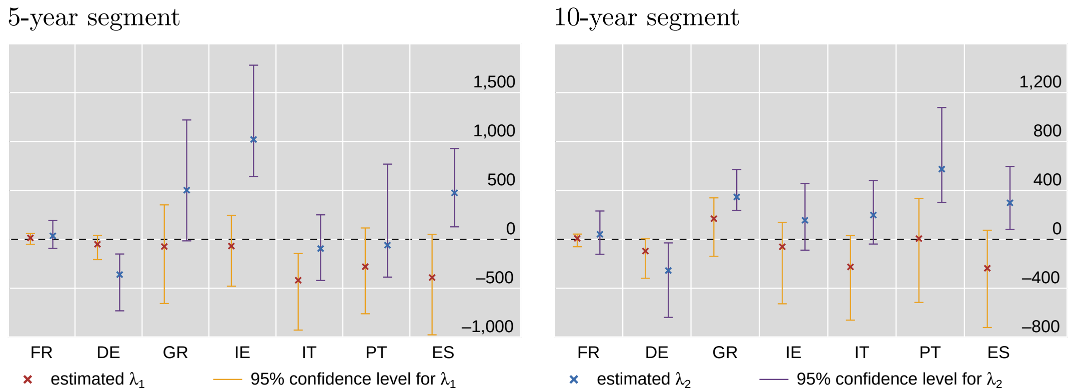
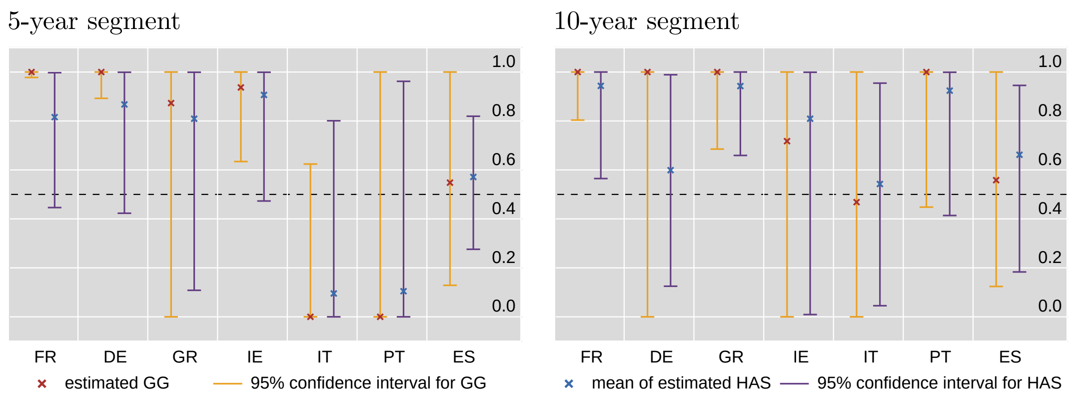


Figure 8: Confidence bands for HAS and GG measures with daily data

Confidence bands for HAS and GG measures for the period from October 2008 to end-May 2011. The HAS ratio is calculated as the average of HAS_1 and HAS_2. Bootstrap confidence intervals are estimated according to Benkwitz et al. (2001) with 100,000 simulations. The lower bound is the 2.5% percentile. The upper bound is the 97.5% percentile. Appendix J reports the underlying numbers.



5.4 Price discovery - a probabilistic approach

An alternative to the bootstrapped confidence bands is to consider the probability that the HAS measure is consistent with CDS price discovery leadership. This can be gauged by considering the share of bootstrapped HAS measures that are above 0.5 as shown in Table 5. Here we see that for intraday data there is a clear tendency to have CDS leadership in the 5-year segment (with the exception of Ireland). In the 10-year segment we find CDS leadership for all countries except Ireland and Portugal.

Table 5: Probability that the Hasbrouck (CDS) measure is above 0.5

This table reports share of bootstrapped *HAS* measures that are above 0.5, i.e. indicating CDS price discovery leadership. The number of simulations is 100,000.

Panel A: 5-year segment

Sovereign	Benchmark	Cost adjusted	daily	1h	2h
France	1.00	1.00	1.00	1.00	1.00
Germany	1.00	0.96	1.00	0.96	0.99
Greece	1.00	1.00	0.98	1.00	0.86
Ireland	0.44	0.16	1.00	0.71	0.75
Italy	0.84	0.65	0.03	0.60	0.97
Portugal	0.70	0.44	0.92	0.69	0.57
Spain	1.00	0.98	0.68	0.99	0.98

Panel B: 10-year segment

Sovereign	Benchmark	Cost adjusted	Daily	1h	2h
France	1.00	1.00	0.99	1.00	1.00
Germany	0.90	0.98	0.65	0.99	1.00
Greece	1.00	1.00	1.00	1.00	0.68
Ireland	0.27	0.10	0.69	0.33	0.14
Italy	0.84	0.61	0.54	0.52	0.65
Portugal	0.46	0.41	0.97	0.24	0.98
Spain	0.99	0.79	0.74	0.46	0.81

Contrary to other recent empirical work we find a clear and significant role of the CDS market in terms of price discovery throughout our sample period. As discussed in Section 1, other studies focusing on euro area sovereign credit markets have found mixed results with respect to price discovery, e.g. Arce et al. (2012), Palladini and Portes (2011), Fontana and Scheicher (2010), and O'Kane (2012). On balance, the findings in these papers point to price discovery taking place to a similar degree in CDS and bond markets.

As pointed out earlier, some of these findings may be due to the fact that all these papers use low-frequency data, i.e. daily or weekly data. Our robustness test using daily data shows that by sampling less frequently, the price discovery results become more mixed and the inference less precise. A further reason for the difference between our results and and those in many of the related studies may be due to the choice of cash spread in the basis construction. As discussed in Section 3.4, we have taken great care in ensuring that we are comparing "apples with apples" in our empirical analysis, by carefully constructing asset swap spreads that allow us to exactly match the maturities and the cash flow structures of the CDS and the cash components. Studies that rely on less precise measures, such as bond yield differences or swap spreads are likely to contaminate their results as they are unable to accurately match the CDS and the cash spreads.

5.5 VECM impulse responses and half-lives

In this subsection we calculate the half-life of sovereign credit risk shocks for the benchmark case, the transaction cost adjusted data and the daily data to illustrate the economic significance of our findings (Table 6). The half-lives for data with 1 and 2 hour sampling can be found in Appendix L.

Overall the half-life of any basis-widening is in most cases below 10 trading days.[12] This suggests that the market forces work reasonably well in the sovereign CDS and bond markets, in the sense that differences in the pricing of sovereign risk in the two segments do not persist for long. Adjusting the spreads for transaction costs does not affect the half-lives by much in most cases, in line with our earlier finding that transaction costs do not seem to play a major role.

Our benchmark estimates imply that Greece exhibits the shortest half-life, with half the shock being reabsorbed in around 5 hours of trading for the 5-year segment and within two and a half trading days for the 10-year segment. Given that Greece has seen the largest swings in credit spreads and in the basis during the sovereign debt crisis, it is not surprising that investors appear particularly quick to exploit sizeable discrepancies in the pricing of sovereign credit risk between CDS and bond markets for Greece. We find the longest half-life of shocks for Ireland, where the benchmark estimates suggest that it takes around 12 days for half of the adjustment to take place in the 5-year and 9 days in the 10-year segment.

With daily data, we find that the half-lives in many cases are significantly higher than those found using intraday data. This suggests that the use of daily data makes it more difficult to accurately measure the speed of adjustment. In other words, information is lost in the aggregation of data from 30-minute intervals to daily frequency.

[12] To illustrate the adjustment process over time we show the VECM impulse responses of ASW and CDS spreads to a unit shock in the cointegration error in Appendix K.

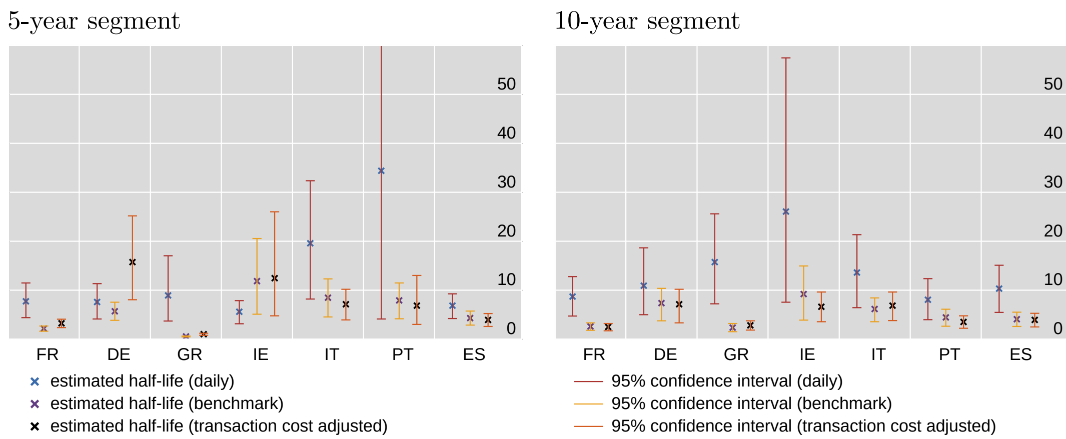
Table 6: Half-life of shocks in days for different sampling frequencies

This table reports the half-life of shocks of 5-year and 10-year CDS and ASW for the period from October 2008 to end-May 2011. The half-lives of shocks are expressed in days, and are calculated using the impulse response function to a one unit shock on the co-integrating error, using Equations 14 and 15.

Sovereign	5-year			10-year		
	Benchmark	Cost adjusted	Daily	Benchmark	Cost adjusted	Daily
France	2.2	3.3	7.7	2.6	2.5	8.7
Germany	5.7	15.8	7.6	7.3	7.1	10.9
Greece	0.6	1.0	9.0	2.4	2.8	15.7
Ireland	11.9	12.5	5.6	9.2	6.6	26.1
Italy	8.5	7.1	19.6	6.1	6.9	13.6
Portugal	7.9	6.9	34.4	4.4	3.5	8.1
Spain	4.3	3.9	6.8	4.1	4.0	10.3

Figure 9: Confidence bands for half-lives

Confidence bands for half-lives for the period from October 2008 to end-May 2011 for daily and 30 min. sampling in days. In the latter case the half-lives for transaction cost adjusted data is also shown. Bootstrap confidence intervals are estimated according to Benkwitz et al. (2001) with 100,000 simulations. The lower and upper bound is the 2.5% and 97.5% percentile, respectively. The crosses correspond to the values in Table 6. The upper bound for the Portuguese 5-year case (not shown) is 204 trading days.



6 Robustness

In this section we perform two robustness checks, one focusing on lower (1- and 2-hour) intraday sampling frequencies and one using alternative intraday money market rates. In both cases we find that for most countries CDS markets lead bond markets, similar to our benchmark finding.

6.1 Alternative intraday data frequencies

So far our analysis focused on data with 30 minutes sampling frequency. We have also analysed daily data, mainly to compare with the existing literature, but also as a robustness check. As an additional robustness check we employ data with 1-hour and 2-hour sampling frequency. We construct the 1-hour data by sampling every other observation from the 30-minute data, and the 2-hour data by sampling every fourth observation.[13]

The unit root and stationarity tests as well as the cointegration tests show a consistent picture across the different sampling frequencies. The detailed results can be found in Appendix E.3, E.4, F.3 and F.4. Similar to the benchmark case the optimal lags are determined using the Schwarz information criterion. These are presented in Table G.1.

The results for the VECM models with alternative intraday data frequencies are presented in Appendix L. They demonstrate that our benchmark findings with respect to the role of CDS markets in price discovery are robust. Both with the 1 and 2-hour sampling frequencies the CDS market in most cases dominates the bond market for both maturities. As before our findings do not provide any conclusive results for the Irish case (Figure J.1). Taking into account the bootstrapped confidence bands (Figure L.3) the half-lives are also robust with both 1 and 2 hour sampling frequencies (Tables L.2 and L.4).[14] This shows that our findings are not due to distortions resulting from microstructure noise that may be more present in the benchmark case (Fulop and Lescourret (2007)). we do note, however, that the estimates become less precise as the sampling frequency is lowered, also in line with the results we obtained using daily data. This confirms that it is preferable to use the highest possible frequency allowed by the quality of the data when performing the empirical analysis.

6.2 Alternative money market rates

As pointed out in Section 3.4, in the construction of our intraday ASW data we make the assumption that intraday moves in the Euribor and the OIS curves mirror those

[13] Alternatively, we could have employed the same approach as for the 30 minutes data, i.e. averaging all observations over one or two hours. However, this would tend to over-smooth the data and reduce its effectiveness as a robustness check.

[14] The only notable exception is the 5-year Irish case with 2-hour sampling frequency.

of the German government curve, since we do not have access to any intraday money market data. We believe this is a reasonable assumption, as high-frequency movements of the money market curve are likely to mainly reflect changing expectations about future overnight rates, and these, in turn, should be well captured by the German yield curve.

Table 7: Price discovery with constant Euribor/OIS

This table reports the price discovery analysis results for the period from October 2008 to end-May 2011 and the assumption of a constant Euribor/OIS rate over the course of the trading day. The superscript [a] indicates that the GG measure has to be interpreted as 1, because the VECM coefficient λ_1 is not significant. The values of the VECM coefficients λ_i and their standard errors are expressed in units of 10^{-4}. For further details see Table 1.

Panel A: 5-year segment

Sovereign	HAS_1	HAS_2	GG	λ_1	Std.err.	p	λ_2	Std.err.	p
France	0.97	0.98	0.92	-0.42	0.21	0.05	4.98	0.46	0.00
Germany	0.90	0.93	0.91	5.54	2.97	0.07	-56.28	10.10	0.00
Greece	1.00	1.00	1.00	1.52	6.05	0.39	654.35	40.88	0.00
Ireland	0.43	0.49	0.69	-20.92	6.96	0.00	46.82	16.86	0.01
Italy	0.12	0.42	0.36	-36.63	9.59	0.00	20.94	11.94	0.09
Portugal	0.70	0.78	0.76	-15.41	7.14	0.04	49.70	12.83	0.00
Spain	0.76	0.86	0.71	-26.62	10.86	0.02	63.83	11.24	0.00

Panel B: 10-year segment

Sovereign	HAS_1	HAS_2	GG	λ_1	Std.err.	p	λ_2	Std.err.	p
France	0.98	0.98	0.92	-1.08	0.99	0.22	12.39	1.81	0.00
Germany	0.98	0.99	1.05[a]	-1.61	2.65	0.33	-33.66	6.00	0.00
Greece	0.99	1.00	1.07[a]	8.29	9.07	0.26	124.81	13.36	0.00
Ireland	0.02	0.03	0.13	-29.10	7.79	0.00	4.44	7.49	0.33
Italy	0.45	0.49	0.48	-24.44	7.18	0.00	22.74	7.10	0.00
Portugal	0.36	0.43	0.45	-37.81	10.38	0.00	31.22	10.83	0.01
Spain	0.72	0.77	0.59	-29.87	10.65	0.01	42.71	8.61	0.00

To gauge the potential impact of this assumption on our empirical results, we reestimate the VECM model using an alternative assumption that the Euribor and OIS curves are fixed throughout the day at their observed end-of-day values. Under this alternative assumption, we obviously fail to capture any movements in money market rates within the day when we price our synthetic asset swaps. This means that such interest rate movements will instead be soaked up by the ASW spread. On the other hand, we will also eliminate any contamination to the ASW spreads that may arise from idiosyncratic fluctuations in the German term structure.

The results from this exercise are displayed in Table 7. The bottom line is that the results reported in Section 5 are very much robust to our assumption about the intraday behaviour of Euribor and OIS rates. Out of the seven countries in our sample, the initial findings about relative price discovery remain unchanged for six of them, as captured by the Hasbrouck and Gonzalo-Granger measures. For the 5-year segment in Italy, we find a change from CDS leadership to weak bond market leadership. Nevertheless, taking into the bootstrapped confidence bands we still have results that are consistent with the benchmark case. For the 10-year segment in Ireland bond leadership remains.

7 Conclusion

In this paper we analyse the intraday dynamics of euro area sovereign credits spreads in CDS and bond markets, focusing in particular on the price discovery process - the efficient and timely incorporation of information implicit in investor trading into market prices. Our main finding is that for most countries the CDS market dominates the bond market in terms of credit risk price discovery. Moreover, our results show that credit spreads in the two markets tend to converge over time as suggested by theory and that deviations do not persist for long, even when taking into account trading costs. Our results are robust to alternative money market rates and the use of both lower intraday and daily sampling frequencies.

A key contribution of this paper is that - via the use of intraday price data from both markets - we are able to estimate the spread dynamics and the price discovery implications substantially more accurately than in existing studies on sovereign credit markets. The use of intraday data allows us to investigate to what extent price discovery takes place intraday, i.e. to what extent credit risk premia are revised during the day in response to new information. First of all we find that the CDS market leads the bond market in terms of credit risk price discovery for all sampling frequencies. With daily data the evidence that the CDS market leads the bond market in terms of credit risk price discovery is however weaker. Our results also show that following a widening of the CDS-bond basis, for all countries it takes less than two weeks for half of this widening to be reabsorbed. For a number of countries it only takes a few days.

Our findings cannot be used directly to address the extent to which higher CDS spreads are likely to result in higher bond market credit spreads and hence lower bond prices than would be warranted by fundamentals. Our findings are however indicative of a situation where the increased perceived credit risk is priced similarly by CDS and bond market participants over time. This follows from the fact that the two credit spreads are cointegrated. The fact that CDS premia are more responsive to new information may reflect that the market participants in these markets on average are more highly leveraged, are more aggressive in taking positions and hence respond more quickly to new information.

In practice, frictions and imperfections such as illiquidity and high trading costs often make trades aimed at arbitraging differences between the two markets difficult and costly to varying degree. In a situation where markets are subject to such frictions, it is possible that the correcting mechanisms may have different regimes with different adjustment speeds. In particular, it is possible that the speed of adjustment towards the long-run equilibrium may be higher once the basis is above a certain threshold than when it is close to zero. This would lead to a nonlinear adjustment process towards the long-run equilibrium. Establishing to what extent this is in fact the case is an interesting avenue for future research.

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A CDS and Bond trade statistics

This section provides descriptive statistics for the bond price data from EuroMTS and CDS data from CMA Datavision.

Figure A.1: CDS data from CMA Datavision

The right-hand scale shows the number (in thousands) of data ticks per year.

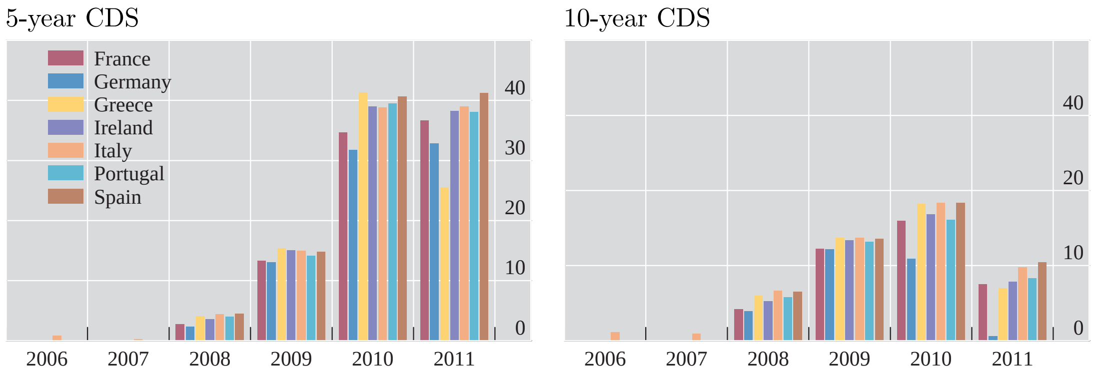


Figure A.2: CDS data from CMA Datavision

The right-hand scale shows the number (in thousands) of non-empty half hour intervals per year. We consider 18 half hour slots per trading day, from 8:30 to 17:30 CET/CEST. The left-hand side scale shows the percentage of 30 min. intervals which contain at least one data tick during the 18 daily half-hour intervals we consider.

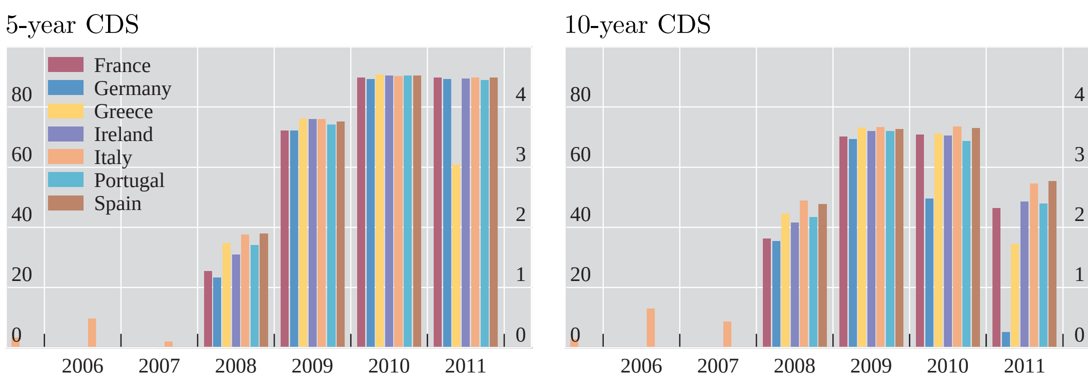


Figure A.3: EuroMTS number of committed trades

The right-hand side scale shows the number (in thousands) of committed trades per year. Italy is shown separately because the number of committed trades are more than an order of magnitude higher than for the other countries.

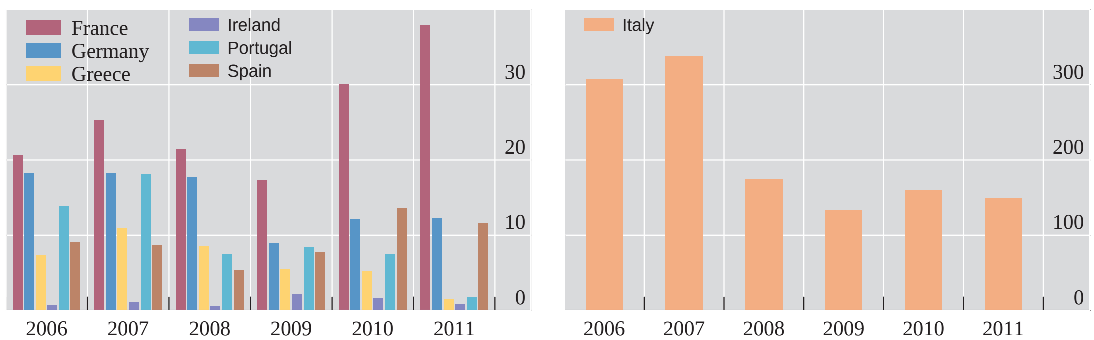


Figure A.4: EuroMTS bond price data from the trading book

The right-hand side scale shows the number (in millions) of data ticks in the trading book. This includes all bonds with a maturity between 4 and 6 years and 9 and 11 years in the 5-year and 10-year segment, respectively.

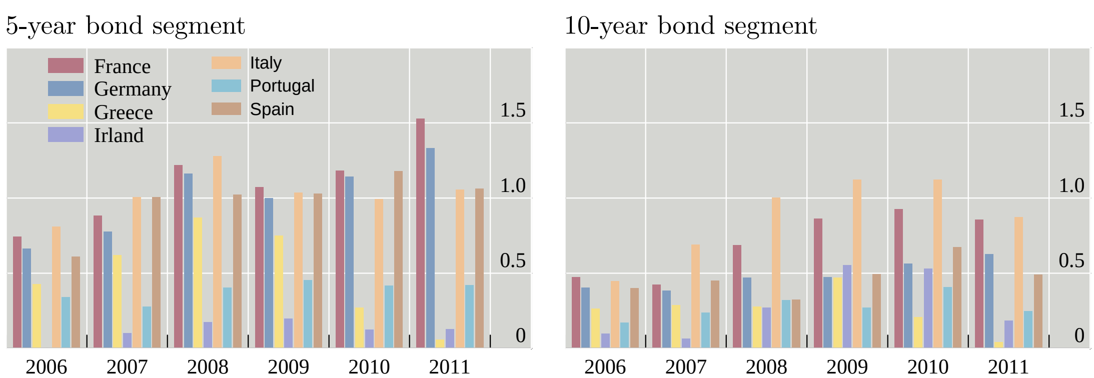
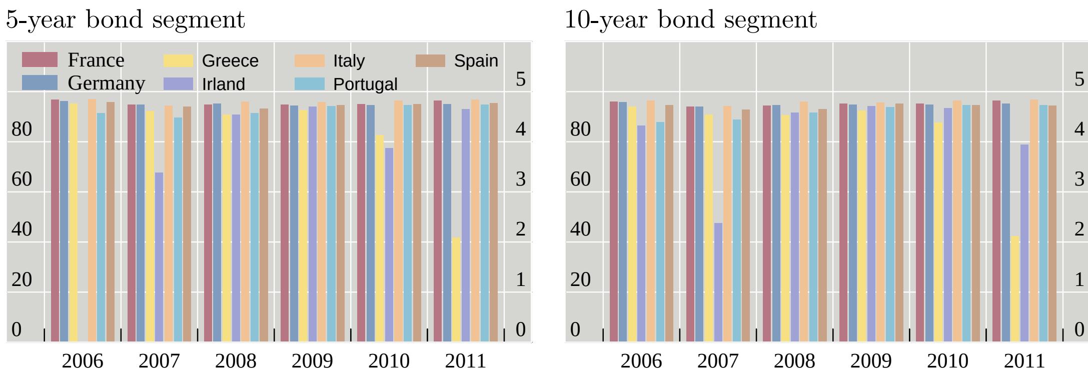


Figure A.5: EuroMTS bond price data from the trading book

The left-hand side scale shows the percentage of 30 min. intervals during the trading period, which contain at least one data tick in the trading book. The right-hand scale shows the number (in thousands) of non-empty half hour intervals per year. We consider 18 half hour slots per trading day, from 8:30 to 17:30 CET/CEST.



B CDS and ASW spreads

Figure B.1: CDS and asset swap spreads in basis points

The figures are based on data with a 30 minute sampling frequency.

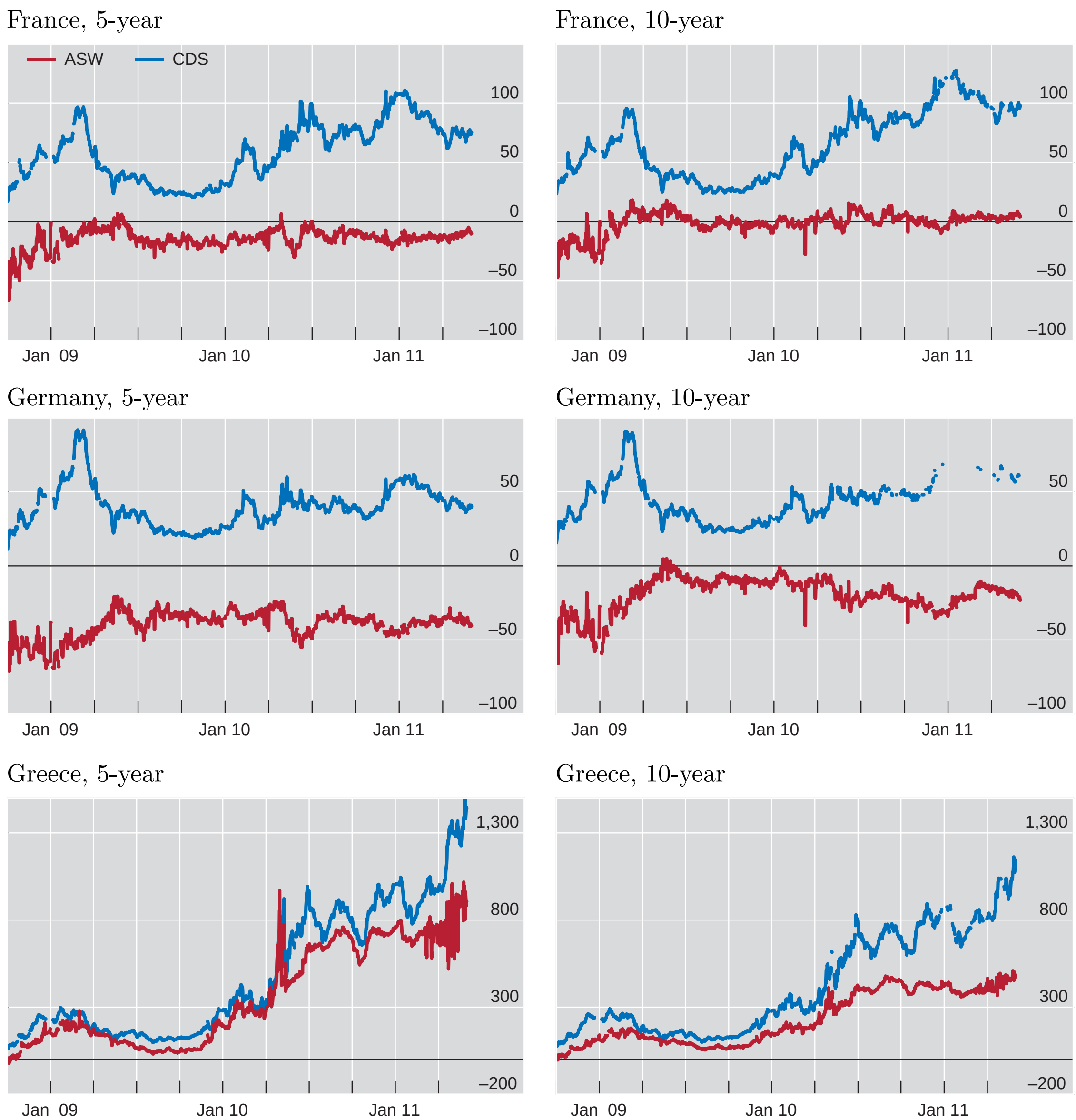
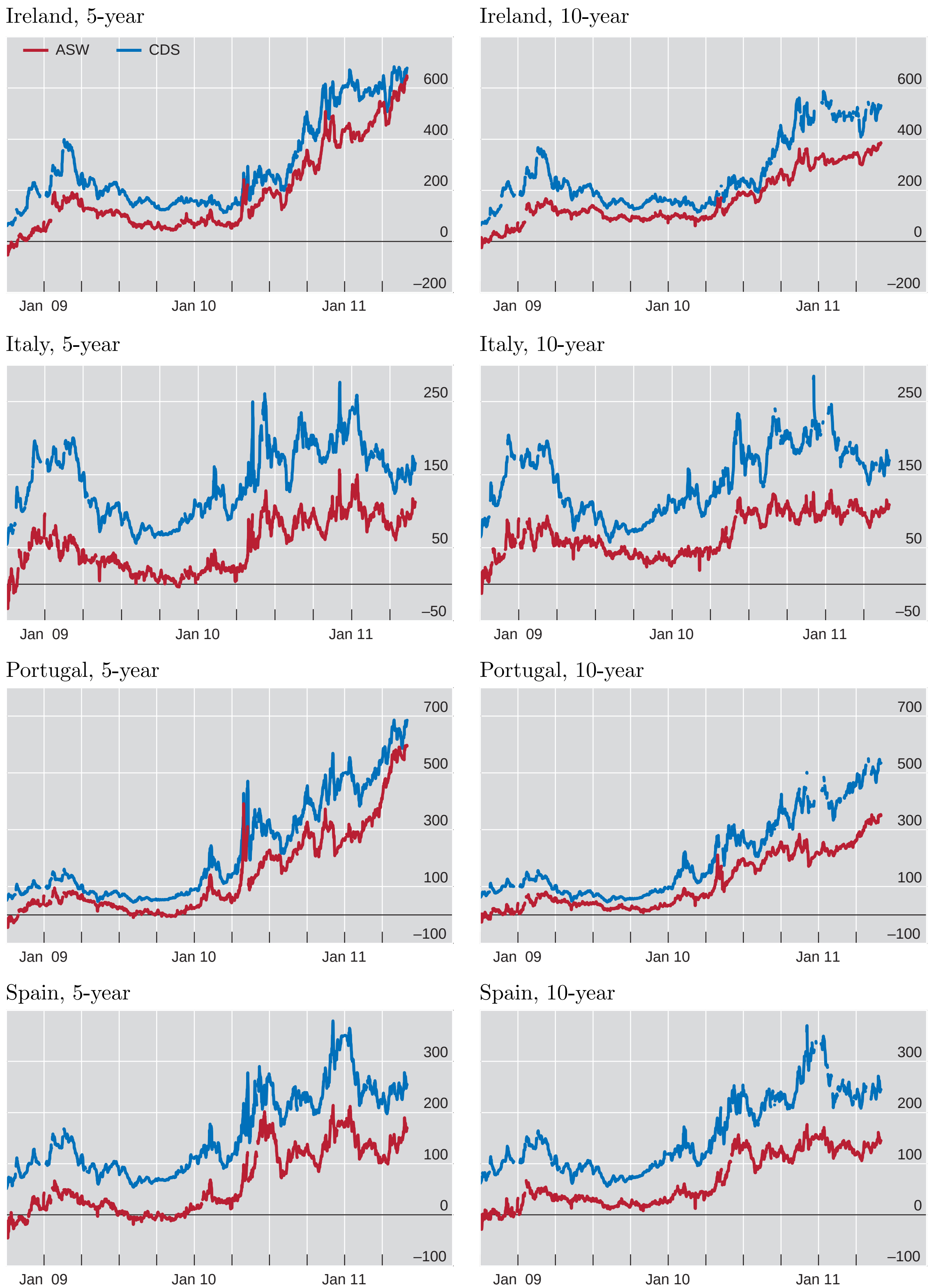


Figure B.1: (Cont.) CDS and asset swap spreads



C Descriptive statistics for Asset Swap Spreads and CDS

Table C.1: Descriptive statistics for ASW in basis points

Descriptive statistics for ASW for the sample period from October 2008 to end-May 2011. Statistics are based on data with 30 minute sampling frequency. The ASW is calculated based on estimated zero-coupon government bond prices using the Nelson-Siegel parametrization.

Panel A: 5-year descriptive statistics

Sovereign	Mean	Median	Maximum	Minimum	Std. Dev.	ACF(1)	Obs.
France	-14.29	-13.79	20.96	-67.21	8.26	0.9832	11743
Germany	-39.30	-37.07	-20.46	-71.28	9.04	0.9943	11759
Greece	355.03	225.71	1215.70	-22.59	286.87	0.9966	11124
Ireland	193.00	126.82	652.03	-53.80	164.41	0.9998	11595
Italy	53.02	50.39	161.55	-33.95	36.00	0.9990	11758
Portugal	141.87	72.00	614.82	-45.83	149.52	0.9997	11692
Spain	63.58	36.91	217.72	-46.09	63.46	0.9995	11731

Panel B: 10-year descriptive statistics

Sovereign	Mean	Median	Maximum	Minimum	Std. Dev.	ACF(1)	Obs.
France	-0.38	1.17	21.21	-47.92	8.83	0.9848	11743
Germany	-18.92	-16.96	4.85	-66.29	11.10	0.9962	11759
Greece	229.31	167.21	529.41	-3.82	150.42	0.9990	11124
Ireland	165.22	122.63	389.23	-25.17	100.99	0.9998	11595
Italy	68.18	61.25	129.71	-13.60	28.17	0.9984	11758
Portugal	114.07	66.80	370.99	-33.07	98.64	0.9996	11692
Spain	67.69	43.90	178.46	-29.78	51.57	0.9994	11731

Table C.2: Descriptive statistics for Credit Default Swaps in basis points

Descriptive statistics for CDS for the sample period from October 2008 to end-May 2011. Statistics based on data with 30 minute sampling frequency. The CDS data is obtained from CMA Datavision.

Panel A: 5-year descriptive statistics

Sovereign	Mean	Median	Maximum	Minimum	Std. Dev.	ACF(1)	Obs.
France	61.36	66.00	111.13	16.25	24.26	0.9996	10195
Germany	40.59	39.38	92.13	11.00	13.68	0.9992	10089
Greece	526.32	374.31	1507.92	62.25	365.43	0.9999	10439
Ireland	307.00	231.70	685.33	60.67	179.46	0.9999	10442
Italy	143.28	146.73	278.67	52.50	48.00	0.9992	10446
Portugal	247.08	173.70	688.50	43.50	181.08	0.9998	10354
Spain	166.11	148.25	384.54	51.33	79.34	0.9996	10434

Panel B: 10-year descriptive statistics

Sovereign	Mean	Median	Maximum	Minimum	Std. Dev.	ACF(1)	Obs.
France	64.25	62.06	128.00	23.00	27.46	0.9996	8568
Germany	41.61	38.55	90.75	14.50	14.64	0.9990	6569
Greece	411.66	284.94	1180.00	74.83	279.98	0.9998	8896
Ireland	257.67	209.17	590.00	63.50	134.17	0.9998	8683
Italy	141.02	139.75	285.00	56.50	45.83	0.9995	9031
Portugal	197.51	135.17	550.00	44.50	141.81	0.9998	8657
Spain	156.23	132.13	370.00	54.50	72.88	0.9997	9069

D Descriptive statistics for the 5- and 10-year basis

Table D.1: Descriptive statistics for the CDS-ASW basis

Descriptive statistics of CDS-ASW basis for the sample period from October 2008 to end-May 2011. Statistics based on data with 30 minute sampling frequency. The basis for each reference entity is defined to be the difference between the CDS spread and the ASW spread and is expressed in basis points.

Panel A: 5-year basis

Sovereign	Mean	Median	Maximum	Minimum	Std. Dev.	ACF(1)	Obs.
France	74.62	79.11	126.69	22.97	23.79	0.9984	10076
Germany	78.84	76.62	146.14	45.21	18.89	0.9989	9993
Greece	121.66	84.05	841.05	-71.96	101.31	0.9683	9738
Ireland	101.21	90.58	251.80	-7.31	42.46	0.9957	10228
Italy	87.65	85.32	157.81	35.64	21.74	0.9957	10333
Portugal	90.52	77.21	288.23	15.16	49.73	0.9963	10180
Spain	96.09	95.66	180.32	40.98	22.69	0.9946	10300

Panel B: 10-year basis

Sovereign	Mean	Median	Maximum	Minimum	Std. Dev.	ACF(1)	Obs.
France	63.74	67.14	128.53	12.27	26.54	0.9988	8496
Germany	57.99	51.51	122.55	20.02	21.58	0.9988	6512
Greece	174.78	117.94	711.78	5.94	138.63	0.9986	8435
Ireland	98.40	76.94	272.73	23.96	53.42	0.9980	8551
Italy	73.60	73.34	165.99	14.90	26.18	0.9975	8958
Portugal	87.95	74.00	272.55	12.64	52.59	0.9978	8562
Spain	88.90	88.65	203.33	32.03	28.61	0.9969	8987

E Unit root and stationarity tests

We test for unit roots and stationarity in the CDS and ASW time-series using the following three methods:

1. the Augmented Dickey-Fuller (ADF) test,
2. the Phillips-Perron (PP) test and
3. the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test.

The null hypothesis of the ADF and PP test states: *the series has a unit root.* The null hypothesis of the KPSS test is: *the series is stationary.* Therefore, if our CDS and ASW data are $I(1)$ time series, we should be unable to reject the null hypothesis in levels for the ADF and PP test and reject H0 under the KPSS test, and vice versa for first differences.

Based on these three different tests we conclude that both the CDS and the bond market asset swap spreads have a unit root for both tenors and all sampling frequencies.

E.1 Unit root and stationarity - benchmark case

Our findings in Table E.1 show that for none of the CDS series we are able to reject the null hypothesis of a unit root using either the ADF or the PP test. For the asset swap spread series the null hypothesis is not rejected, except in the PP test for the French and Greek 5-year segment and the French and German 10-year segment as well as in the ADF test for the French 10-year segment. The KPSS rejects stationarity for all countries and both maturities. The test results for the first differenced spread data is presented in Table E.2. Both the ADF and the PP tests reject the unit root hypothesis across the board, indicating that all series are integrated of order one. We get similar results using the KPSS test. Only in the case of the Irish and Portuguese 10-year CDS is the null hypothesis of stationary rejected for the first-differenced data. Taking all the results from all tests together, we conclude that it is reasonable to view our CDS and ASW data as I(1).

Table E.1: Unit root and stationarity tests for benchmark case in levels

The table reports the statistics of unit root and stationarity tests for the period from October 2008 to end-May 2011. The ADF and PP test for a unit root under the null hypothesis. For the KPSS test, the null hypothesis is stationarity, and the 0.01, 0.05 and 0.10 critical values for the test statistics are 0.739, 0.463 and 0.347, respectively.

Panel A: 5-year spreads

	Credit default swap			Asset Swap		
Sovereign	p_{ADF}	p_{PP}	KPSS stat.	p_{ADF}	p_{PP}	KPSS stat.
France	0.716	0.598	7.805	0.097	0.009	1.590
Germany	0.496	0.486	1.435	0.315	0.095	3.558
Greece	0.978	0.978	13.412	0.195	0.002	13.092
Ireland	0.963	0.909	10.039	0.971	0.946	10.808
Italy	0.159	0.491	6.012	0.332	0.436	8.427
Portugal	0.913	0.889	12.969	0.980	0.963	11.413
Spain	0.550	0.557	11.605	0.320	0.368	11.186

Panel B: 10-year spreads

	Credit default swap			Asset Swap		
Sovereign	p_{ADF}	p_{PP}	KPSS stat.	p_{ADF}	p_{PP}	KPSS stat.
France	0.885	0.932	9.656	0.000	0.000	2.964
Germany	0.808	0.627	1.728	0.126	0.010	2.046
Greece	0.915	0.949	14.154	0.838	0.920	12.712
Ireland	0.997	0.985	9.085	0.939	0.952	11.787
Italy	0.468	0.460	6.821	0.462	0.596	8.555
Portugal	0.995	0.998	13.404	0.762	0.659	12.810
Spain	0.439	0.638	12.699	0.460	0.478	12.486

Table E.2: Unit root and stationarity tests for benchmark case in first differences

The table reports the statistics of unit root and stationarity tests for the period from October 2008 to end-May 2011. The ADF and PP test for a unit root under the null hypothesis. For the KPSS test, the null is stationarity, and the 0.01, 0.05 and 0.10 critical values for the test statistics are 0.739, 0.463 and 0.347, respectively.

Panel A: 5-year spreads

	Credit default swap			Asset Swap		
Sovereign	p_{ADF}	p_{PP}	KPSS stat.	p_{ADF}	p_{PP}	KPSS stat.
France	0.000	0.000	0.074	0.000	0.000	0.033
Germany	0.000	0.000	0.112	0.000	0.000	0.054
Greece	0.000	0.000	0.177	0.000	0.000	0.083
Ireland	0.000	0.000	0.198	0.000	0.000	0.185
Italy	0.000	0.000	0.043	0.000	0.000	0.170
Portugal	0.000	0.000	0.086	0.000	0.000	0.232
Spain	0.000	0.000	0.037	0.000	0.000	0.048

Panel B: 10-year spreads

	Credit default swap			Asset Swap		
Sovereign	p_{ADF}	p_{PP}	KPSS stat.	p_{ADF}	p_{PP}	KPSS stat.
France	0.000	0.000	0.098	0.000	0.000	0.021
Germany	0.000	0.000	0.089	0.000	0.000	0.017
Greece	0.000	0.000	0.135	0.000	0.000	0.378
Ireland	0.000	0.000	0.612	0.000	0.000	0.168
Italy	0.000	0.000	0.123	0.000	0.000	0.059
Portugal	0.000	0.000	0.493	0.000	0.000	0.129
Spain	0.000	0.000	0.079	0.000	0.000	0.040

E.2 Unit root and stationarity - adjustment for transaction costs

The test outcome is similar to the previously described benchmark case, except that we find also a rejection of the existence of a unit root for Italy by the PP test (both tenors) and the ADF test (5-year segment). Taking the results from all tests together, we conclude that it is reasonable to view our CDS and ASW data as I(1).

Table E.3: Unit root and stationarity for transaction cost adjusted data in levels

The table reports the statistics of unit root and stationarity tests for the period from October 2008 to end-May 2011. The ADF and PP test for a unit root under the null hypothesis. For the KPSS test, the null is stationarity, and the 0.01, 0.05 and 0.10 critical values for the test statistics are 0.739, 0.463 and 0.347, respectively.

Panel A: 5-year spreads

	Credit default swap			Asset Swap		
Sovereign	p_{ADF}	p_{PP}	KPSS stat.	p_{ADF}	p_{PP}	KPSS stat.
France	0.751	0.586	8.2009	0.070	0.000	0.673
Germany	0.434	0.466	1.5439	0.150	0.304	3.420
Greece	0.981	0.979	13.486	0.669	0.024	12.941
Ireland	0.966	0.920	10.104	0.997	0.668	10.693
Italy	0.165	0.443	6.2679	0.000	0.000	8.197
Portugal	0.918	0.893	12.995	0.997	0.967	11.385
Spain	0.543	0.554	11.777	0.238	0.000	10.892

Panel B: 10-year spreads

	Credit default swap			Asset Swap		
Sovereign	p_{ADF}	p_{PP}	KPSS stat.	p_{ADF}	p_{PP}	KPSS stat.
France	0.855	0.917	9.910	0.000	0.000	2.4613
Germany	0.788	0.435	1.628	0.492	0.033	2.0132
Greece	0.854	0.911	14.223	0.825	0.965	12.769
Ireland	0.990	0.925	9.160	0.966	0.536	11.860
Italy	0.348	0.350	6.993	0.074	0.018	8.5155
Portugal	0.997	0.999	13.430	0.948	0.305	12.769
Spain	0.629	0.636	12.859	0.614	0.102	12.333

Table E.4: Unit root and stationarity for transaction cost adjusted data in first-differences

The table reports the statistics of unit root and stationarity tests for the period from October 2008 to end-May 2011. The ADF and PP test for a unit root under the null hypothesis. For the KPSS test, the null is stationarity, and the 0.01, 0.05 and 0.10 critical values for the test statistics are 0.739, 0.463 and 0.347, respectively.

Panel A: 5-year spreads

	Credit default swap			Asset Swap		
Sovereign	p_{ADF}	p_{PP}	KPSS stat.	p_{ADF}	p_{PP}	KPSS stat.
France	0.000	0.000	0.100	0.000	0.000	0.050
Germany	0.000	0.000	0.075	0.000	0.000	0.186
Greece	0.000	0.000	0.181	0.000	0.000	0.129
Ireland	0.000	0.000	0.144	0.000	0.000	0.056
Italy	0.000	0.000	0.040	0.000	0.000	0.084
Portugal	0.000	0.000	0.103	0.000	0.000	0.168
Spain	0.000	0.000	0.042	0.000	0.000	0.051

Panel B: 10-year spreads

	Credit default swap			Asset Swap		
Sovereign	p_{ADF}	p_{PP}	KPSS stat.	p_{ADF}	p_{PP}	KPSS stat.
France	0.000	0.000	0.123	0.000	0.000	0.055
Germany	0.000	0.000	0.063	0.000	0.000	0.015
Greece	0.000	0.000	0.186	0.000	0.000	0.376
Ireland	0.000	0.000	0.472	0.010	0.000	0.056
Italy	0.000	0.000	0.147	0.010	0.000	0.053
Portugal	0.000	0.000	0.552	0.000	0.000	0.074
Spain	0.000	0.000	0.088	0.010	0.000	0.092

E.3 Unit root and stationarity - with 1-hour sampling frequency

The test outcome is similar to the previously described benchmark case. Taking the results from all tests together, we conclude that it is reasonable to view our CDS and ASW data as I(1).

Table E.5: Unit root and stationarity for data with 1-hour sampling in levels

The table reports the statistics of unit root and stationarity tests for the period from October 2008 to end-May 2011. The ADF and PP test for a unit root under the null hypothesis. For the KPSS test, the null is stationarity, and the 0.01, 0.05 and 0.10 critical values for the test statistics are 0.739, 0.463 and 0.347, respectively.

Panel A: 5-year spreads

	Credit default swap			Asset Swap		
Sovereign	p_{ADF}	p_{PP}	KPSS test stat.	p_{ADF}	p_{PP}	KPSS test stat.
France	0.690	0.662	5.653	0.104	0.000	1.222
Germany	0.687	0.667	1.036	0.462	0.195	2.665
Greece	0.930	0.977	9.666	0.294	0.000	9.340
Ireland	0.959	0.922	7.223	0.990	0.990	7.826
Italy	0.258	0.373	4.360	0.339	0.347	6.124
Portugal	0.894	0.890	9.360	0.974	0.984	8.262
Spain	0.499	0.527	8.386	0.486	0.552	8.080

Panel B: 10-year spreads

	Credit default swap			Asset Swap		
Sovereign	p_{ADF}	p_{PP}	KPSS test stat.	p_{ADF}	p_{PP}	KPSS test stat.
France	0.986	0.988	6.570	0.000	0.000	2.239
Germany	0.724	0.565	1.282	0.289	0.071	1.503
Greece	0.912	0.921	9.629	0.993	0.549	9.072
Ireland	0.996	0.996	6.210	0.957	0.959	8.522
Italy	0.669	0.623	4.621	0.591	0.595	6.284
Portugal	0.999	0.999	9.181	0.873	0.769	9.258
Spain	0.373	0.369	8.622	0.455	0.576	9.012

Table E.6: Unit root and stationarity for data with 1-hour sampling in first-differences

The table reports the statistics of unit root and stationarity tests for the period from October 2008 to end-May 2011. The ADF and PP test for a unit root under the null hypothesis. For the KPSS test, the null is stationarity, and the 0.01, 0.05 and 0.10 critical values for the test statistics are 0.739, 0.463 and 0.347, respectively.

Panel A: 5-year spreads

	Credit default swap			Asset Swap		
Sovereign	p_{ADF}	p_{PP}	KPSS test stat.	p_{ADF}	p_{PP}	KPSS test stat.
France	0.000	0.000	0.098	0.000	0.000	0.029
Germany	0.000	0.000	0.165	0.000	0.000	0.226
Greece	0.000	0.000	0.161	0.000	0.000	0.103
Ireland	0.000	0.000	0.180	0.000	0.000	0.330
Italy	0.000	0.000	0.036	0.000	0.000	0.095
Portugal	0.000	0.000	0.063	0.000	0.000	0.262
Spain	0.000	0.000	0.032	0.000	0.000	0.098

Panel B: 10-year spreads

	Credit default swap			Asset Swap		
Sovereign	p_{ADF}	p_{PP}	KPSS test stat.	p_{ADF}	p_{PP}	KPSS test stat.
France	0.000	0.000	0.073	0.000	0.000	0.058
Germany	0.000	0.000	0.061	0.000	0.000	0.060
Greece	0.000	0.000	0.058	0.000	0.000	0.033
Ireland	0.000	0.000	0.554	0.000	0.000	0.217
Italy	0.000	0.000	0.078	0.000	0.000	0.047
Portugal	0.000	0.000	0.551	0.000	0.000	0.101
Spain	0.000	0.000	0.191	0.000	0.000	0.085

E.4 Unit root and stationarity - with 2-hour sampling frequency

The outcomes of the tests show similar results as in the benchmark case. Hence, taking the results from all tests together, we can clearly conclude that it is reasonable to view our CDS and ASW data as I(1).

Table E.7: Unit root and stationarity for data with 2-hour sampling in levels

The table reports the statistics of unit root and stationarity tests for the period from October 2008 to end-May 2011. The ADF and PP test for a unit root under the null hypothesis. For the KPSS test, the null is stationarity, and the 0.01, 0.05 and 0.10 critical values for the test statistics are 0.739, 0.463 and 0.347, respectively.

Panel A: 5-year spreads

	Credit default swap			Asset Swap		
Sovereign	p_{ADF}	p_{PP}	KPSS test stat.	p_{ADF}	p_{PP}	KPSS test stat.
France	0.605	0.573	4.219	0.098	0.005	0.929
Germany	0.619	0.587	0.789	0.463	0.194	1.985
Greece	0.971	0.977	7.067	0.784	0.018	6.839
Ireland	0.937	0.917	5.300	0.998	0.996	5.790
Italy	0.183	0.463	3.312	0.347	0.382	4.555
Portugal	0.921	0.880	7.011	0.100	0.994	6.130
Spain	0.565	0.532	6.147	0.590	0.584	5.843

Panel B: 10-year spreads

	Credit default swap			Asset Swap		
Sovereign	p_{ADF}	p_{PP}	KPSS test stat.	p_{ADF}	p_{PP}	KPSS test stat.
France	0.991	0.988	4.907	0.000	0.000	1.675
Germany	0.448	0.448	0.968	0.291	0.070	1.131
Greece	0.987	0.987	7.228	0.854	0.367	6.630
Ireland	0.998	0.997	4.650	0.966	0.978	6.304
Italy	0.563	0.520	3.484	0.524	0.608	4.579
Portugal	0.995	0.996	6.798	0.837	0.725	6.848
Spain	0.189	0.202	6.443	0.521	0.585	6.509

Table E.8: Unit root and stationarity for data with 2-hour sampling in first-differences

The table reports the statistics of unit root and stationarity tests for the period from October 2008 to end-May 2011. The ADF and PP test for a unit root under the null hypothesis. For the KPSS test, the null is stationarity, and the 0.01, 0.05 and 0.10 critical values for the test statistics are 0.739, 0.463 and 0.347, respectively.

Panel A: 5-year spreads

	Credit default swap			Asset Swap		
Sovereign	p_{ADF}	p_{PP}	KPSS test stat.	p_{ADF}	p_{PP}	KPSS test stat.
France	0.000	0.000	0.074	0.000	0.000	0.030
Germany	0.000	0.000	0.134	0.000	0.000	0.227
Greece	0.000	0.000	0.176	0.000	0.000	0.037
Ireland	0.000	0.000	0.222	0.000	0.000	0.420
Italy	0.000	0.000	0.040	0.000	0.000	0.108
Portugal	0.000	0.000	0.078	0.000	0.000	0.309
Spain	0.000	0.000	0.031	0.000	0.000	0.095

Panel B: 10-year spreads

	Credit default swap			Asset Swap		
Sovereign	p_{ADF}	p_{PP}	KPSS test stat.	p_{ADF}	p_{PP}	KPSS test stat.
France	0.000	0.000	0.042	0.000	0.000	0.049
Germany	0.000	0.000	0.054	0.000	0.000	0.059
Greece	0.000	0.000	0.196	0.000	0.000	0.018
Ireland	0.000	0.000	0.703	0.000	0.000	0.131
Italy	0.000	0.000	0.054	0.000	0.000	0.047
Portugal	0.000	0.000	0.375	0.000	0.000	0.059
Spain	0.000	0.000	0.145	0.000	0.000	0.057

E.5 Unit root and stationarity - daily data

The outcomes of the tests show similar results as in the benchmark case. The only critical time series are the French asset swap spreads (both tenors). Nevertheless, taking the results from all tests together, we conclude that it is reasonable to view our CDS and ASW data as I(1).

Table E.9: Unit root and stationarity for daily data in levels

The table reports the statistics of unit root and stationarity tests for the period from October 2008 to end-May 2011. The ADF and PP test for a unit root under the null hypothesis. For the KPSS test, the null is stationarity, and the 0.01, 0.05 and 0.10 critical values for the test statistics are 0.739, 0.463 and 0.347, respectively.

Panel A: 5-year spreads

	Credit default swap			Asset Swap		
Sovereign	p_{ADF}	p_{PP}	KPSS test stat.	p_{ADF}	p_{PP}	KPSS test stat.
France	0.480	0.457	1.573	0.013	0.002	0.488
Germany	0.357	0.332	0.309	0.188	0.039	0.939
Greece	0.982	0.981	2.875	0.928	0.659	2.889
Ireland	0.909	0.874	2.124	0.752	0.963	2.424
Italy	0.255	0.256	1.246	0.250	0.359	1.954
Portugal	0.998	0.975	2.767	0.894	0.977	2.594
Spain	0.481	0.517	2.487	0.313	0.336	2.513

Panel B: 10-year spreads

	Credit default swap			Asset Swap		
Sovereign	p_{ADF}	p_{PP}	KPSS test stat.	p_{ADF}	p_{PP}	KPSS test stat.
France	0.764	0.749	1.973	0.000	0.000	0.810
Germany	0.730	0.681	0.426	0.503	0.177	0.479
Greece	1.000	0.999	2.907	0.954	0.986	2.818
Ireland	0.908	0.874	2.012	0.869	0.881	2.611
Italy	0.187	0.191	1.338	0.447	0.585	2.022
Portugal	0.925	0.902	2.800	0.716	0.946	2.847
Spain	0.671	0.688	2.601	0.480	0.526	2.769

Table E.10: Unit root and stationarity for daily data in first differences

The table reports the statistics of unit root and stationarity tests for the period from October 2008 to end-May 2011. The ADF and PP test for a unit root under the null hypothesis. For the KPSS test, the null is stationarity, and the 0.01, 0.05 and 0.10 critical values for the test statistics are 0.739, 0.463 and 0.347, respectively.

Panel A: 5-year spreads

	Credit default swap			Asset Swap		
Sovereign	p_{ADF}	p_{PP}	KPSS test stat.	p_{ADF}	p_{PP}	KPSS test stat.
France	0.000	0.000	0.083	0.000	0.000	0.064
Germany	0.000	0.000	0.087	0.000	0.000	0.250
Greece	0.000	0.000	0.203	0.000	0.000	0.034
Ireland	0.000	0.000	0.141	0.000	0.000	0.291
Italy	0.000	0.000	0.066	0.000	0.000	0.043
Portugal	0.000	0.000	0.240	0.000	0.000	0.290
Spain	0.000	0.000	0.045	0.000	0.000	0.035

Panel B: 10-year spreads

	Credit default swap			Asset Swap		
Sovereign	p_{ADF}	p_{PP}	KPSS test stat.	p_{ADF}	p_{PP}	KPSS test stat.
France	0.000	0.000	0.079	0.000	0.000	0.066
Germany	0.000	0.000	0.142	0.000	0.000	0.080
Greece	0.000	0.000	0.413	0.000	0.000	0.229
Ireland	0.000	0.000	0.139	0.000	0.000	0.088
Italy	0.000	0.000	0.103	0.000	0.000	0.059
Portugal	0.000	0.000	0.154	0.000	0.000	0.226
Spain	0.000	0.000	0.074	0.000	0.000	0.033

F Cointegration analysis

As discussed earlier, theory suggests that CDS and ASW on the same reference entity and tenor should price credit risk equally. Allowing for real-life frictions that prevent this relationship from always holding, we test for a long-run relationship in the form of cointegration between bond and CDS market credit premia using the tests of Phillips and Ouliaris (1990) and Johansen (1988).

We view two series as cointegrated if either the null hypothesis of no cointegration is rejected using the Johansen or the Phillips-Ouliaris methodology. We use the Johansen test with intercept but no deterministic trend in the co-integrating equation. We use the Schwarz information criterion to estimate the optimal lag length for the Johansen test. The optimal lags are shown in Table G.1 in Appendix G.

F.1 Cointegration analysis for the benchmark case

Except for the 5-year Irish data we find cointegration for the period October 2008 to end of May 2011.

Table F.1: Cointegration tests for benchmark case

This table reports the results obtained from the Johansen and Phillips-Ouliaris cointegration tests, applied to 5-year and 10-year CDS and ASW for the period from October 2008 to end-May 2011. 'not cointegrated' in the table denotes non-rejection of the null hypothesis at the 5 percent significance level for the Johansen (Maximum Eigenvalue and Trace test) and the Phillips-Ouliaris test. We include a constant in the co-integrating equation for the Johansen test and optimize the lag length in the vector autoregression using the Schwarz information criterion. The superscripts ^{a} and ^{b} indicate that the result is dependent on which time series is considered exogenous and that the result of cointegration is based on the trace test, respectively.

	Johansen		Phillips-Ouliaris	
Sovereign	5-year	10-year	5-year	10-year
France	cointegrated	cointegrated	cointegrated	cointegrated^a
Germany	cointegrated	not cointegrated	cointegrated	cointegrated
Greece	cointegrated	cointegrated	cointegrated	cointegrated
Ireland	not cointegrated	not cointegrated	not cointegrated	cointegrated
Italy	cointegrated^b	cointegrated	cointegrated	cointegrated
Portugal	cointegrated	cointegrated	cointegrated	cointegrated
Spain	cointegrated	cointegrated	not cointegrated	cointegrated

Table F.2: Cointegration - p-values for benchmark case

This table reports the probabilities in decimals obtained from the Johansen cointegration and the Phillips-Ouliaris cointegration tests for the period from October 2008 to end-May 2011. For the Johansen test a constant is included in the co-integrating equation and the number of lags in the vector autoregression is optimized using the Schwarz information criterion. The Phillips-Ouliaris tests for no cointegration under the null hypothesis by estimating the long-term equilibrium relationship from a regression of CDS_t on ASW_t or from a regression of ASW_t on CDS_t among the levels of the time series. The column header ASW and CDS indicates which variable is used as dependent variable in the test.

Panel A: Johansen test

	Trace test				Maximum eigenvalue test			
	5-year		10-year		5-year		10-year	
Sovereign	None	at most 1	None	at most 1	None	at most 1	None	at most 1
France	0.000	0.127	0.000	0.183	0.000	0.127	0.000	0.183
Germany	0.048	0.463	0.113	0.647	0.037	0.463	0.071	0.647
Greece	0.000	0.208	0.000	0.422	0.000	0.208	0.000	0.422
Ireland	0.267	0.366	0.024	0.047	0.333	0.366	0.125	0.047
Italy	0.016	0.088	0.001	0.369	0.052	0.088	0.001	0.369
Portugal	0.026	0.431	0.002	0.231	0.020	0.431	0.002	0.231
Spain	0.000	0.308	0.000	0.144	0.000	0.308	0.000	0.144

Panel B: Phillip-Ouliaris test

	τ-statistic				z-statistic			
	5-year		10-year		5-year		10-year	
Sovereign	CDS	ASW	CDS	ASW	CDS	ASW	CDS	ASW
France	0.000	0.000	0.215	0.000	0.000	0.000	0.572	0.000
Germany	0.000	0.000	0.010	0.000	0.000	0.000	0.031	0.003
Greece	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ireland	0.066	0.100	0.003	0.002	0.065	0.081	0.013	0.011
Italy	0.037	0.029	0.000	0.000	0.027	0.019	0.000	0.000
Portugal	0.010	0.012	0.001	0.001	0.010	0.011	0.002	0.002
Spain	0.135	0.075	0.003	0.001	0.109	0.071	0.010	0.006

F.2 Cointegration analysis for the benchmark case with cost adjustment

We find cointegration for all countries and all tenors at 0.95 significance level.

Table F.3: Cointegration tests with transaction cost adjustment

This table reports the results obtained from the Johansen and Phillips-Ouliaris cointegration tests, applied to 5-year and 10-year CDS and ASW for the period from October 2008 to end-May 2011. 'not cointegrated' in the table denotes non-rejection of the null hypothesis at the 5 percent significance level for the Johansen (Maximum Eigenvalue and Trace test) and the Phillips-Ouliaris test. We include a constant in the co-integrating equation for the Johansen test and optimize the lag length in the vector autoregression using the Schwarz information criterion. The superscripts ^{a}, ^{b} and ^{c} indicate that the result of cointegration is based on the τ statistic, that the result of cointegration is based on the z-statistic and that the result is dependent on which time series is considered exogenous, respectively.

	Johansen		Phillips-Ouliaris	
Sovereign	5-year	10-year	5-year	10-year
France	cointegrated	cointegrated	cointegrated	cointegrated^a
Germany	not cointegrated	not cointegrated	cointegrated	cointegrated
Greece	cointegrated	cointegrated	cointegrated	cointegrated
Ireland	not cointegrated	cointegrated	cointegrated^b	cointegrated
Italy	not cointegrated	cointegrated	cointegrated	cointegrated
Portugal	not cointegrated	cointegrated	cointegrated^b	cointegrated
Spain	cointegrated	cointegrated	cointegrated^c	cointegrated

Table F.4: Cointegration - p-values with transaction cost adjustment

This table reports the probabilities in decimals obtained from the Johansen cointegration and the Phillips-Ouliaris cointegration tests for the period from October 2008 to end-May 2011. For the Johansen test a constant is included in the co-integrating equation and the number of lags in the vector autoregression is optimized using the Schwarz information criterion. The Phillips-Ouliaris tests for no cointegration under the null hypothesis by estimating the long-term equilibrium relationship from a regression of CDS_t on ASW_t or from a regression of ASW_t on CDS_t among the levels of the time series. The column header ASW and CDS indicates which variable is used as dependent variable in the test.

Panel A: Johansen test

	Trace test				Maximum eigenvalue test			
	5-year		10-year		5-year		10-year	
Sovereign	None	at most 1	None	at most 1	None	at most 1	None	at most 1
France	0.000	0.234	0.000	0.184	0.000	0.234	0.000	0.184
Germany	0.609	0.575	0.145	0.442	0.635	0.575	0.141	0.442
Greece	0.000	0.161	0.000	0.297	0.000	0.161	0.000	0.297
Ireland	0.085	0.250	0.000	0.122	0.126	0.250	0.000	0.122
Italy	0.005	0.030	0.003	0.415	0.039	0.030	0.002	0.415
Portugal	0.041	0.034	0.000	0.252	0.265	0.034	0.000	0.252
Spain	0.000	0.146	0.000	0.269	0.000	0.146	0.000	0.269

Panel B: Phillip-Ouliaris test

	τ-statistic				z-statistic			
	5-year		10-year		5-year		10-year	
Sovereign	CDS	ASW	CDS	ASW	CDS	ASW	CDS	ASW
France	0.000	0.000	0.024	0.000	0.000	0.000	0.163	0.000
Germany	0.000	0.000	0.018	0.001	0.001	0.001	0.040	0.006
Greece	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ireland	0.052	0.037	0.000	0.000	0.038	0.031	0.001	0.001
Italy	0.012	0.000	0.002	0.001	0.008	0.001	0.002	0.001
Portugal	0.098	0.056	0.003	0.000	0.011	0.006	0.001	0.000
Spain	0.111	0.015	0.009	0.001	0.074	0.023	0.012	0.004

F.3 Cointegration analysis with 1-hour sampling frequency

Similar to the benchmark case, we find cointegration for the period October 2008 to end of May 2011 except for the 5-year Irish data.

Table F.5: Cointegration tests with 1-hour sampling

This table reports the results obtained from the Johansen and Phillips-Ouliaris cointegration tests, applied to 5-year and 10-year CDS and ASW for the period from October 2008 to end-May 2011. 'not cointegrated' in the table denotes non-rejection of the null hypothesis at the 5 percent significance level for the Johansen (Maximum Eigenvalue and Trace test) and the Phillips-Ouliaris test. We include a constant in the co-integrating equation for the Johansen test and optimize the lag length in the vector autoregression using the Schwarz information criterion. The superscripts ^{a}, ^{b} and ^{c} indicate that the result is dependent on which time series is considered exogenous, that the result is based on the τ statistics and that the results is based on the z-statistic, respectively.

	Johansen		Phillips-Ouliaris	
Sovereign	5-year	10-year	5-year	10-year
France	cointegrated	cointegrated	cointegrated	cointegrated[a]
Germany	not cointegrated	not cointegrated	cointegrated	cointegrated[b]
Greece	cointegrated	cointegrated	cointegrated	cointegrated
Ireland	not cointegrated	cointegrated	not cointegrated	cointegrated
Italy	cointegrated	cointegrated	cointegrated	cointegrated
Portugal	cointegrated	not cointegrated	cointegrated[c]	cointegrated[c]
Spain	cointegrated	cointegrated	cointegrated[b]	not cointegrated

Table F.6: Cointegration - p-values with 1-hour sampling

This table reports the probabilities in decimals obtained from the Johansen cointegration and the Phillips-Ouliaris cointegration tests for the period from October 2008 to end-May 2011. For the Johansen test a constant is included in the co-integrating equation and the number of lags in the vector autoregression is optimized using the Schwarz information criterion. The Phillips-Ouliaris tests for no cointegration under the null hypothesis by estimating the long-term equilibrium relationship from a regression of CDS_t on ASW_t or from a regression of ASW_t on CDS_t among the levels of the time series. The column header ASW and CDS indicates which variable is used as dependent variable in the test.

Panel A: Johansen test

	Trace test				Maximum eigenvalue test			
	5-year		10-year		5-year		10-year	
Sovereign	None	at most 1	None	at most 1	None	at most 1	None	at most 1
France	0.000	0.175	0.000	0.183	0.000	0.175	0.000	0.183
Germany	0.152	0.393	0.054	0.332	0.165	0.393	0.059	0.332
Greece	0.000	0.054	0.000	0.051	0.000	0.054	0.000	0.051
Ireland	0.142	0.196	0.007	0.112	0.266	0.196	0.017	0.112
Italy	0.015	0.119	0.006	0.210	0.037	0.119	0.008	0.210
Portugal	0.019	0.296	0.077	0.138	0.020	0.296	0.182	0.138
Spain	0.000	0.277	0.000	0.064	0.000	0.277	0.000	0.064

Panel B: Phillip-Ouliaris test

	τ-statistic				z-statistic			
	5-year		10-year		5-year		10-year	
Sovereign	CDS	ASW	CDS	ASW	CDS	ASW	CDS	ASW
France	0.000	0.000	0.471	0.000	0.001	0.000	0.699	0.000
Germany	0.000	0.000	0.032	0.002	0.000	0.000	0.050	0.006
Greece	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ireland	0.189	0.295	0.022	0.010	0.148	0.198	0.038	0.027
Italy	0.006	0.006	0.000	0.000	0.013	0.010	0.001	0.001
Portugal	0.038	0.076	0.100	0.116	0.032	0.046	0.039	0.043
Spain	0.040	0.042	0.079	0.085	0.076	0.070	0.072	0.071

F.4 Cointegration analysis with 2-hour sampling frequency

Similar to the benchmark case, we find cointegration for the period October 2008 to end of May 2011 except for the 5-year Irish data.

Table F.7: Cointegration tests with 2-hour sampling

This table reports the results obtained from the Johansen and Phillips-Ouliaris cointegration tests, applied to 5-year and 10-year CDS and ASW for the period from October 2008 to end-May 2011. 'not cointegrated' in the table denotes non-rejection of the null hypothesis at the 5 percent significance level for the Johansen (Maximum Eigenvalue and Trace test) and the Phillips-Ouliaris test. We include a constant in the co-integrating equation for the Johansen test and optimize the lag length in the vector autoregression using the Schwarz information criterion. The superscripts ^{a} and ^{b} indicate that the result is dependent on which time series is considered exogenous and that the result of cointegration is based on the trace statistic, respectively.

	Johansen		Phillips-Ouliaris	
Sovereign	5-year	10-year	5-year	10-year
France	cointegrated	cointegrated	cointegrated	cointegrated^a
Germany	cointegrated^b	cointegrated	cointegrated	cointegrated^a
Greece	cointegrated	not cointegrated	cointegrated	cointegrated
Ireland	not cointegrated	not cointegrated	not cointegrated	cointegrated
Italy	not cointegrated	cointegrated	cointegrated	cointegrated
Portugal	cointegrated	cointegrated	cointegrated	cointegrated
Spain	cointegrated	cointegrated	not cointegrated	not cointegrated

Table F.8: Cointegration - p-values with 2-hour sampling

This table reports the probabilities in decimals obtained from the Johansen cointegration and the Phillips-Ouliaris cointegration tests for the period from October 2008 to end-May 2011. For the Johansen test a constant is included in the co-integrating equation and the number of lags in the vector autoregression is optimized using the Schwarz information criterion. The Phillips-Ouliaris tests for no cointegration under the null hypothesis by estimating the long-term equilibrium relationship from a regression of CDS_t on ASW_t or from a regression of ASW_t on CDS_t among the levels of the time series. The column header ASW and CDS indicates which variable is used as dependent variable in the test.

Panel A: Johansen test

	Trace test				Maximum eigenvalue test			
	5-year		10-year		5-year		10-year	
Sovereign	None	at most 1	None	at most 1	None	at most 1	None	at most 1
France	0.000	0.396	0.000	0.304	0.000	0.396	0.000	0.304
Germany	0.040	0.190	0.030	0.589	0.070	0.190	0.017	0.589
Greece	0.003	0.220	0.601	0.845	0.004	0.220	0.462	0.845
Ireland	0.086	0.124	0.062	0.078	0.221	0.124	0.222	0.078
Italy	0.008	0.043	0.000	0.126	0.048	0.043	0.000	0.126
Portugal	0.017	0.212	0.003	0.112	0.025	0.212	0.006	0.112
Spain	0.000	0.095	0.000	0.058	0.000	0.095	0.000	0.058

Panel B: Phillip-Ouliaris test

	τ-statistic				z-statistic			
	5-year		10-year		5-year		10-year	
Sovereign	CDS	ASW	CDS	ASW	CDS	ASW	CDS	ASW
France	0.000	0.000	0.484	0.000	0.000	0.000	0.724	0.000
Germany	0.000	0.000	0.056	0.004	0.000	0.000	0.088	0.013
Greece	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ireland	0.208	0.355	0.002	0.001	0.176	0.249	0.019	0.015
Italy	0.039	0.030	0.000	0.000	0.039	0.028	0.001	0.001
Portugal	0.017	0.044	0.021	0.031	0.023	0.036	0.016	0.020
Spain	0.100	0.103	0.068	0.102	0.121	0.110	0.085	0.100

F.5 Cointegration analysis with daily data

Table F.9: Cointegration tests with daily data

This table reports the results obtained from the Johansen and Phillips-Ouliaris cointegration tests, applied to 5-year and 10-year CDS and ASW for the period from October 2008 to end-May 2011. 'not cointegrated' in the table denotes non-rejection of the null hypothesis at the 5 percent significance level for the Johansen (Maximum Eigenvalue and Trace test) and the Phillips-Ouliaris test. We include a constant in the co-integrating equation for the Johansen test and use the Schwarz information criteria for the lag length in the vector autoregression. The superscripts ^{a}, ^{b} and ^{c} indicate that the result is dependent on which time series is considered exogenous, that the result is based on maximum eigenvalue test and that the results is based on the trace test, respectively.

	Johansen		Phillips-Ouliaris	
Sovereign	5-year	10-year	5-year	10-year
France	cointegrated	cointegrated	cointegrated	cointegrated^a
Germany	not cointegrated	cointegrated	cointegrated	cointegrated
Greece	not cointegrated	cointegrated	cointegrated	cointegrated
Ireland	cointegrated^b	not cointegrated	cointegrated	cointegrated^a
Italy	cointegrated^c	cointegrated^c	not cointegrated	cointegrated
Portugal	not cointegrated	cointegrated^b	cointegrated	cointegrated
Spain	cointegrated	cointegrated	not cointegrated	not cointegrated

Table F.10: Cointegration - p-values with daily data

This table reports the probabilities in decimals obtained from the Johansen cointegration and the Phillips-Ouliaris cointegration tests for the period from October 2008 to end-May 2011. For the Johansen test a constant is included in the co-integrating equation and the number of lags in the vector autoregression is optimized using the Schwarz information criterion. The Phillips-Ouliaris tests for no cointegration under the null hypothesis by estimating the long-term equilibrium relationship from a regression of CDS_t on ASW_t or from a regression of ASW_t on CDS_t among the levels of the time series. The column header ASW and CDS indicates which variable is used as dependent variable in the test.

Panel A: Johansen test

	Trace test				Maximum eigenvalue test			
	5-year		10-year		5-year		10-year	
Sovereign	None	at most 1	None	at most 1	None	at most 1	None	at most 1
France	0.001	0.162	0.039	0.775	0.001	0.162	0.016	0.775
Germany	0.002	0.013	0.016	0.092	0.022	0.013	0.050	0.092
Greece	0.211	0.143	0.003	0.133	0.480	0.143	0.006	0.133
Ireland	0.059	0.780	0.889	0.578	0.026	0.780	0.952	0.578
Italy	0.039	0.073	0.036	0.213	0.146	0.073	0.056	0.213
Portugal	0.514	0.327	0.071	0.552	0.710	0.327	0.049	0.552
Spain	0.001	0.425	0.046	0.819	0.001	0.425	0.018	0.819

Panel B: Phillip-Ouliaris test

	τ-statistic				z-statistic			
	5-year		10-year		5-year		10-year	
Sovereign	CDS	ASW	CDS	ASW	CDS	ASW	CDS	ASW
France	0.001	0.000	0.947	0.000	0.013	0.001	0.942	0.000
Germany	0.000	0.000	0.005	0.000	0.000	0.000	0.015	0.002
Greece	0.000	0.000	0.013	0.011	0.000	0.000	0.009	0.008
Ireland	0.000	0.000	0.058	0.066	0.000	0.000	0.048	0.052
Italy	0.121	0.096	0.003	0.004	0.115	0.082	0.006	0.008
Portugal	0.006	0.007	0.000	0.000	0.005	0.005	0.000	0.000
Spain	0.216	0.164	0.059	0.062	0.253	0.192	0.124	0.118

G Optimal lags for cointegration tests

We use the Schwarz information criterion to estimate the optimal lag length for the Johansen test. We use these findings also to determine the lag length in the VAR part of the VECM.

Table G.1: Optimal lag length - Schwarz criterion

This table reports the number of lags for 5-year and 10-year CDS and ASW which we have used in our VECM analysis for the period from October 2008 to end-May 2011 and 30 min, 1 hour, 2 hours and daily sampling frequency. We optimize the number of lags in the vector autoregression using the Schwarz information criteria in order to reduce the autoregressive process to white noise.

Sovereign	30 min		30 min cost adj.		1 hour		2 hours		Daily	
	5-year	10-year	5-year	10-year	5-year	10-year	5-year	10-year	5-year	10-year
France	3	2	1	2	3	1	2	1	2	1
Germany	19	1	19	2	10	1	6	1	2	1
Greece	2	2	3	1	2	1	3	3	6	1
Ireland	4	2	3	1	2	1	2	1	2	2
Italy	3	1	3	1	2	1	2	1	2	1
Portugal	3	1	6	1	2	1	2	1	5	2
Spain	3	1	3	1	2	2	2	1	1	1

H Bid-ask spreads of CDS and ASW spreads

Figure H.1: Bid-Ask spreads for CDS and ASW in basis points

The figures are based on data with 30 minute sampling frequency.

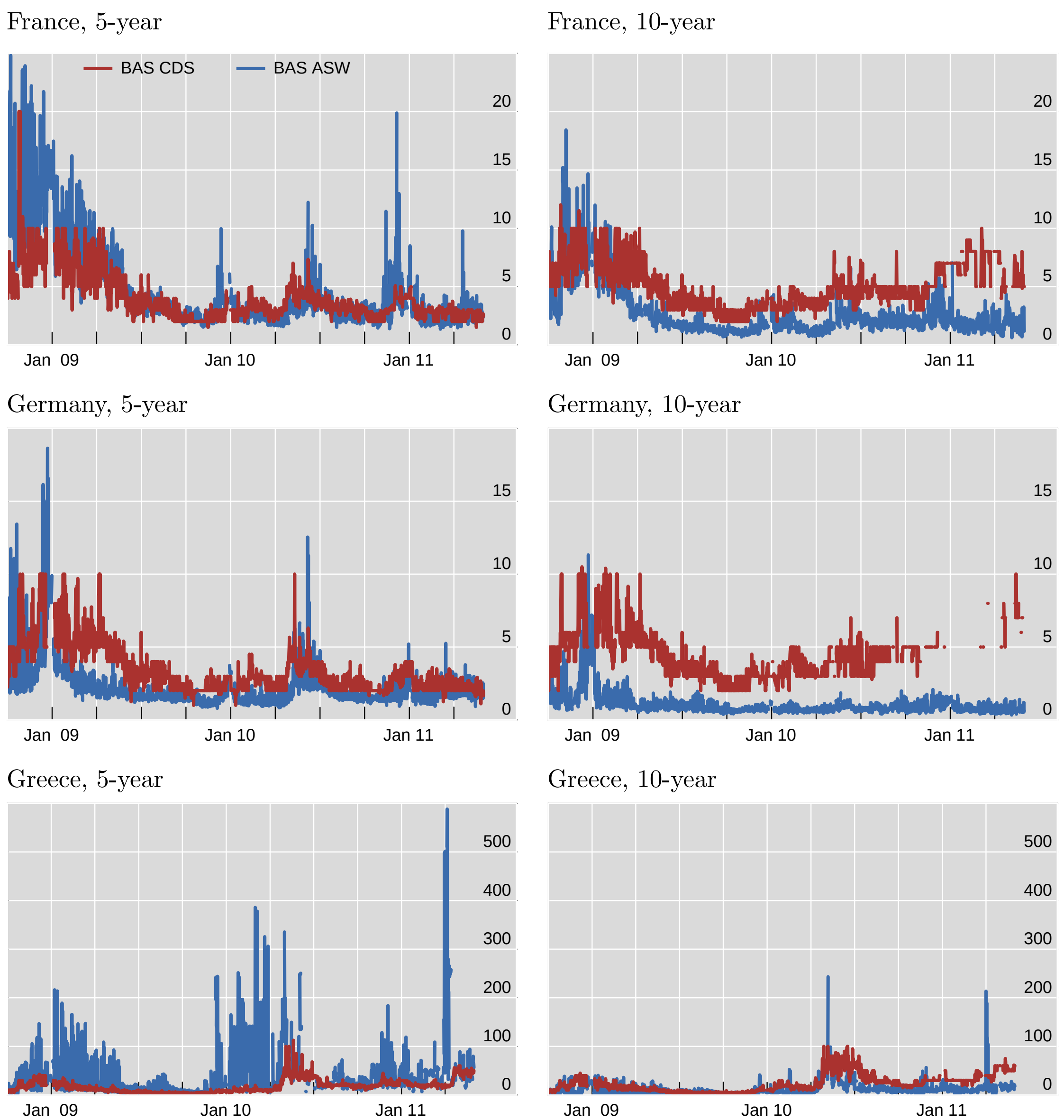
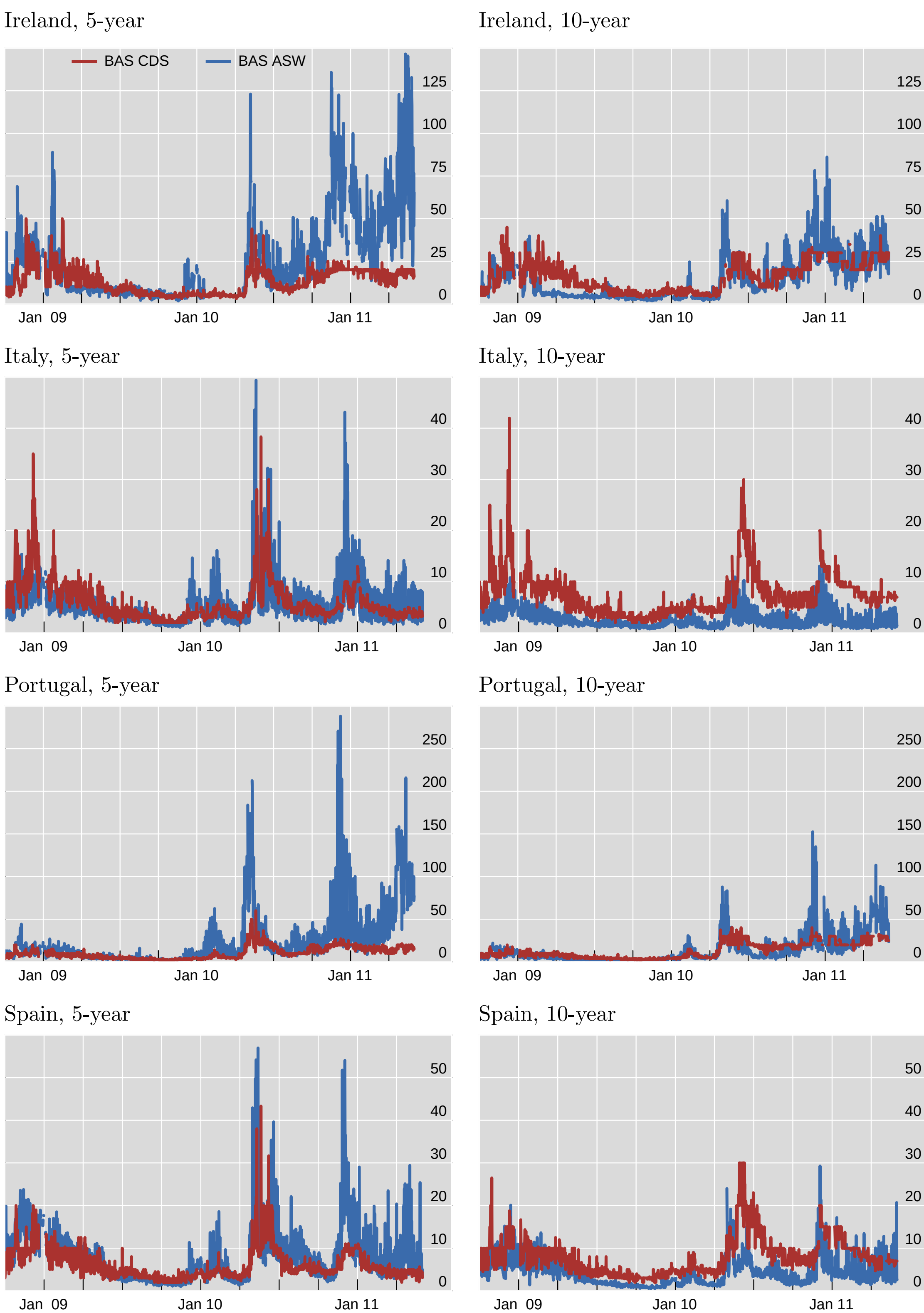


Figure H.1: (Cont.) Bid-Ask spreads for CDS and ASW in basis points



I VECM coefficients

Table I.1: Confidence bands for price discovery measures

This table reports the VECM parameters α_0 and α_1.

Panel A: 5-year segment

	α_0					α_1				
Sovereign	Bench-mark	Cost adj.	1 hour	2 hour	daily	Bench-mark	Cost adj.	1-hour	2-hour	daily
France	-1249.24	-385.84	10250.73	-6338.39	-436.31	94.86	27.29	-822.41	504.28	25.44
Germany	116.06	-96.56	393.57	147.42	49.95	-4.18	1.34	-11.69	-5.09	-2.27
Greece	-10.85	13.10	-5.35	-11.92	-7.42	1.27	1.20	1.28	1.27	1.34
Ireland	-104.91	-138.86	-96.25	51.43	-83.40	1.02	0.92	0.99	0.68	1.08
Italy	-70.39	-74.49	-69.30	-53.07	-98.00	1.29	1.19	1.27	1.47	0.77
Portugal	-52.30	-77.49	-62.31	-66.54	-75.96	1.22	1.05	1.13	1.09	1.33
Spain	-77.93	-78.79	-78.97	-78.90	-82.52	1.25	1.17	1.24	1.23	1.21

Panel B: 10-year segment

	α_0					α_1				
Sovereign	Bench-mark	Cost adj.	1 hour	2 hour	daily	Bench-mark	Cost adj.	1 hour	2 hour	daily
France	-6.76	15.74	-7.62	-27.29	-77.80	20.36	23.16	15.57	12.67	19.01
Germany	-3.57	31.52	47.42	65.09	-6.17	-2.67	-4.98	-6.22	-7.71	-2.03
Greece	19.03	36.12	21.06	86.15	19.75	1.73	1.71	1.76	1.58	1.73
Ireland	-16.15	-14.34	-9.81	-5.62	-36.82	1.57	1.50	1.64	1.78	1.30
Italy	-24.20	-37.67	-35.52	-24.00	-46.85	1.75	1.58	1.60	1.66	1.36
Portugal	-32.72	-32.48	-39.21	-29.37	-33.30	1.53	1.46	1.51	1.39	1.45
Spain	-53.72	-54.85	-59.36	-52.89	-63.64	1.53	1.48	1.41	1.46	1.38

J Hasbrouck and Gonzalo-Granger confidence bands

J.1 Results for benchmark case

Table J.1: Confidence bands for price discovery measures

This table reports confidence bands for Hasbrouck and Gonzalo-Granger ratios for the period from October 2008 to end-May 2011. The HAS ratio is calculated as 50% HAS_1 and 50% HAS_2. Bootstrap confidence intervals are estimated according to Benkwitz et al. (2001) with 100.000 iterations. The lower bound is the 2.5% percentile. The upper bound is the 97.5% percentile.

Panel A: 5-year segment

	HAS bounds			GG bounds		
Sovereign	lower	point estimate	upper	lower	point estimate	upper
France	0.84	0.98	1.00	0.94	1.00	1.00
Germany	0.87	1.00	1.00	0.79	0.97	1.00
Greece	0.97	1.00	1.00	0.97	1.00	1.00
Ireland	0.01	0.43	0.99	0.00	0.50	1.00
Italy	0.24	0.77	1.00	0.32	0.67	1.00
Portugal	0.13	0.65	0.99	0.28	0.63	0.99
Spain	0.71	0.95	1.00	0.64	0.90	1.00

Panel B: 10-year segment

	HAS bounds			GG bounds		
Sovereign	lower	point estimate	upper	lower	point estimate	upper
France	0.86	1.00	1.00	0.83	1.00	1.00
Germany	0.33	0.82	1.00	0.00	1.00	1.00
Greece	0.87	0.99	1.00	0.81	1.00	1.00
Ireland	0.00	0.24	0.96	0.00	0.25	0.79
Italy	0.28	0.73	0.99	0.33	0.58	0.97
Portugal	0.10	0.47	0.88	0.21	0.46	0.73
Spain	0.55	0.88	1.00	0.47	0.71	1.00

J.2 Results for data adjusted for transaction costs

Table J.2: Confidence bands for price discovery measures

This table reports confidence bands for Hasbrouck and Gonzalo-Granger ratios for the period from October 2008 to end-May 2011. The HAS ratio is calculated as 50% HAS_1 and 50% HAS_2. Bootstrap confidence intervals are estimated according to Benkwitz et al. (2001) with 100.000 iterations. The lower bound is the 2.5% percentile. The upper bound is the 97.5% percentile.

Panel A: 5-year segment

	HAS bounds			GG bounds		
Sovereign	lower	point estimate	upper	lower	point estimate	upper
France	0.88	0.99	1.00	0.88	1.00	1.00
Germany	0.45	0.85	1.00	0.54	0.75	0.96
Greece	0.93	1.00	1.00	0.96	1.00	1.00
Ireland	0.00	0.11	0.89	0.00	0.33	0.92
Italy	0.13	0.60	0.97	0.27	0.59	0.94
Portugal	0.01	0.44	0.98	0.11	0.65	1.00
Spain	0.53	0.86	0.99	0.56	0.79	1.00

Panel B: 10-year segment

	HAS bounds			GG bounds		
Sovereign	lower	point estimate	upper	lower	point estimate	upper
France	0.85	0.99	1.00	0.77	0.95	1.00
Germany	0.55	1.00	1.00	0.58	0.94	1.00
Greece	0.88	1.00	1.00	0.77	1.00	1.00
Ireland	0.00	0.17	0.70	0.00	0.23	0.51
Italy	0.13	0.57	0.97	0.21	0.47	0.83
Portugal	0.13	0.45	0.82	0.27	0.48	0.69
Spain	0.28	0.67	0.95	0.34	0.55	0.80

J.3 Results for daily data

Table J.3: Confidence bands for price discovery measures

This table reports confidence bands for Hasbrouck Gonzalo-Granger ratios for the period from October 2008 to end-May 2011. The HAS ratio is calculated as 50% HAS_1 and 50% HAS_2. Bootstrap confidence intervals are estimated according to Benkwitz et al. (2001) with 100.000 iterations. The lower bound is the 2.5% percentile. The upper bound is the 97.5% percentile.

Panel A: 5-year segment

	HAS bounds			GG bounds		
Sovereign	lower	point estimate	upper	lower	point estimate	upper
France	0.45	0.82	1.00	0.98	1.00	1.00
Germany	0.42	0.87	1.00	0.89	1.00	1.00
Greece	0.11	0.81	1.00	0.00	0.87	1.00
Ireland	0.47	0.91	1.00	0.63	0.94	1.00
Italy	0.00	0.10	0.80	0.00	0.00	0.62
Portugal	0.00	0.11	0.96	0.00	0.00	1.00
Spain	0.28	0.57	0.82	0.13	0.55	1.00

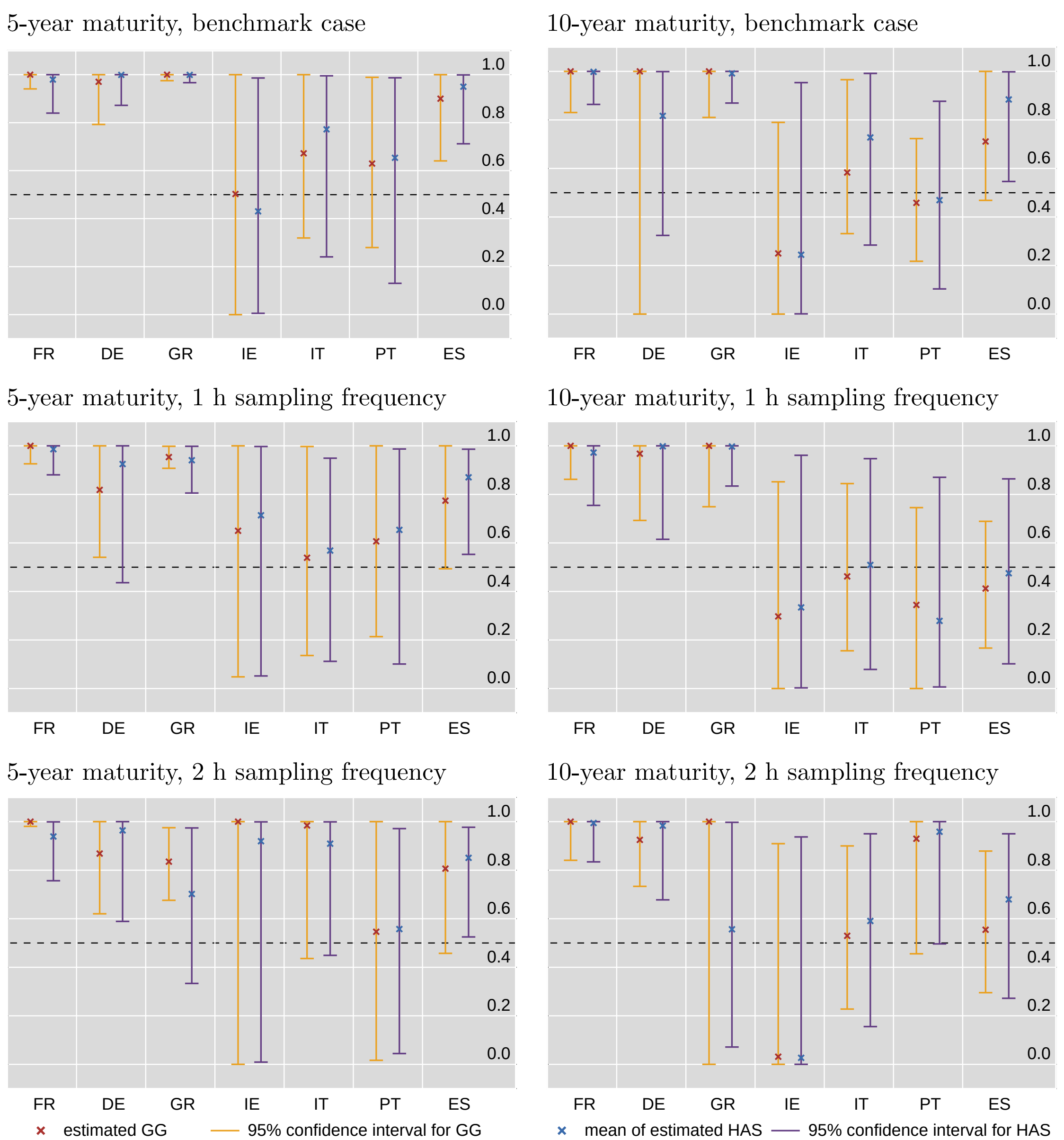
Panel B: 10-year segment

	HAS bounds			GG bounds		
Sovereign	lower	point estimate	upper	lower	point estimate	upper
France	0.56	0.94	1.00	0.80	1.00	1.00
Germany	0.12	0.60	0.99	0.00	1.00	1.00
Greece	0.66	0.94	1.00	0.68	1.00	1.00
Ireland	0.01	0.81	1.00	0.00	0.72	1.00
Italy	0.05	0.54	0.95	0.00	0.47	1.00
Portugal	0.41	0.92	1.00	0.45	1.00	1.00
Spain	0.18	0.66	0.95	0.12	0.56	1.00

J.4 Summary Figures

Figure J.1: Confidence bands for Hasbrouck and Gonzalo-Granger measures

Confidence bands for Hasbrouck Gonzalo-Granger ratios for the period from October 2008 to end-May 2011. The HAS ratio is calculated as 50% HAS_1 and 50% HAS_2. Bootstrap confidence intervals are estimated according to Benkwitz et al. (2001) with 100.000 iterations. The lower bound is the 2.5% percentile. The upper bound is the 97.5% percentile.



K VECM impulse response figures

Figure K.1: Impulse response functions for benchmark case

This figure illustrates the impulse response for CDS and ASW to a one unit shock on the co-integrating error for the period from October 2008 to end-May 2011. The vertical line represents the half-life of shocks while the number of 30 min. time intervals are described by the x-axis. The blue and yellow lines are the speed of adjustment for the ASW and CDS. When only one of the error correction coefficients is significant, the corresponding non-significant variable will adjust instantaneously to its long-run equilibrium level. This is represented by a horizontal line after the instantaneous adjustment. The dashed line (red) plots the response of the system towards its long-run equilibrium.

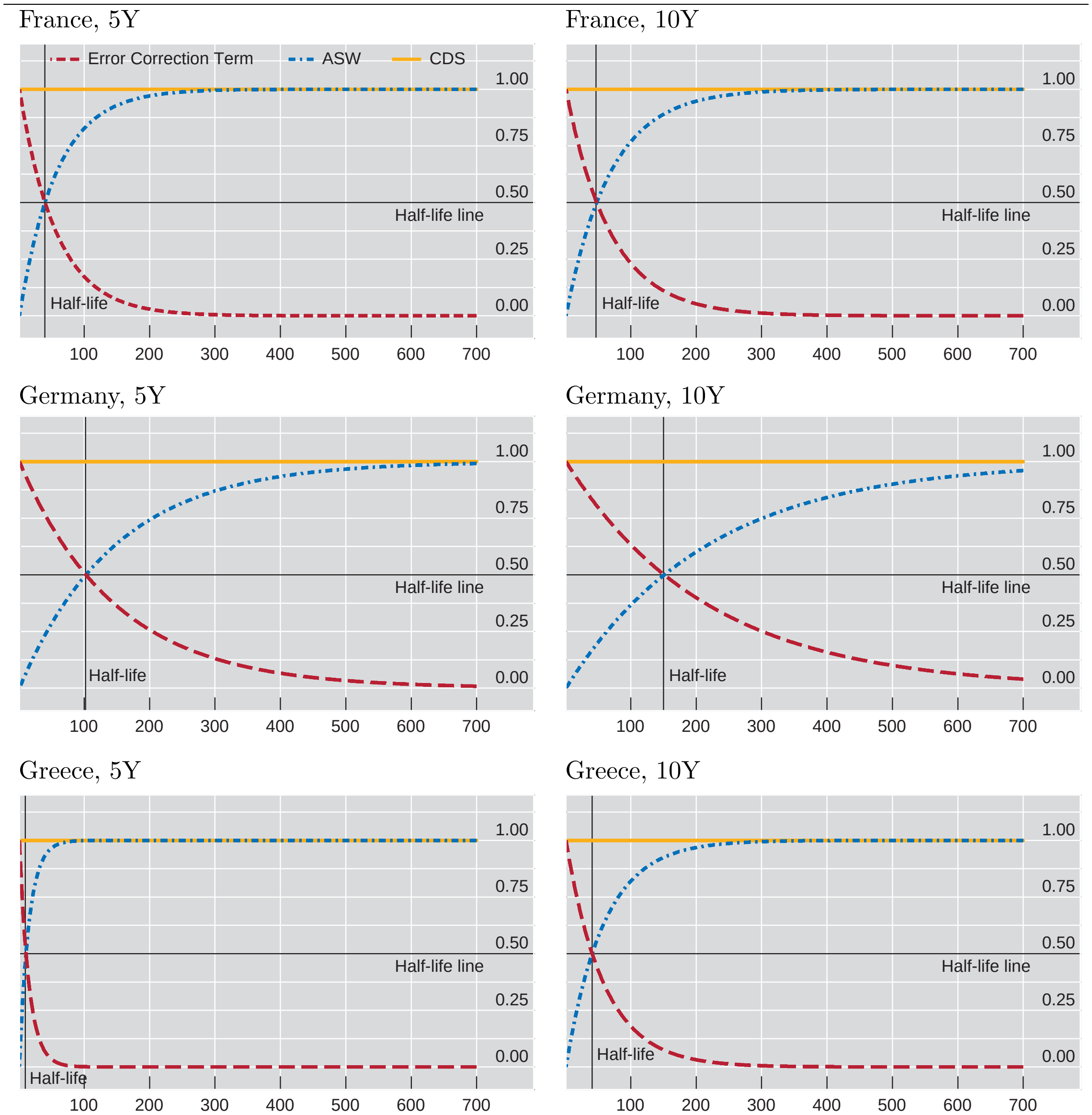
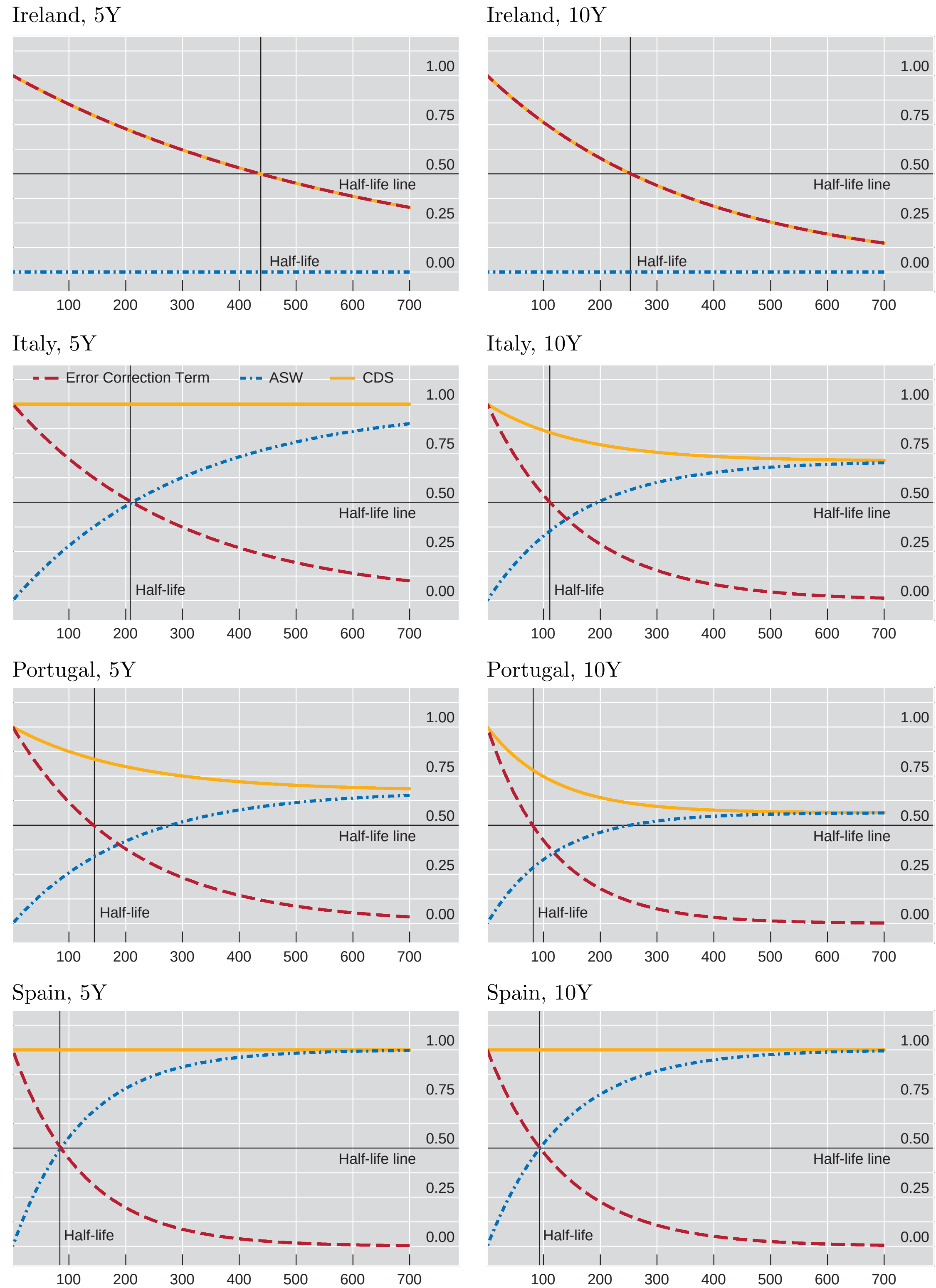


Figure K.1: (Cont.) Impulse response functions for benchmark case



L VECM results with 1-hour and 2-hour intervals

L.1 Results for data with 1-hour sampling frequency

Table L.1: VECM parameters and measures of price discovery

This table reports the price discovery analysis results for the period from October 2008 to end-May 2011. The two measures of price discovery, (i) the information share or Hasbrouck measure (HAS) and ii) the common factor component weight or Gonzalo-Granger measure (GG), are based on a vector error correction model. The HAS measure (8) to (11) provides upper and lower bounds to the price discovery contribution made in the CDS market. The CDS market leads in terms of credit risk price discovery whenever the GG and HAS measures are above 0.5, and the bond market leads when they are below 0.5. The superscript ^{a} indicates that the GG measure has to be interpreted as 1, because the VECM coefficient λ_1 is not significant. The values of the VECM coefficients λ_i and their standard errors are expressed in units of 10^{-4}. The cointegration test for country names marked with a * reject cointegration at 0.95 significance level, hence VECM results must be treated with caution.

Panel A: 5-year segment

Sovereign	HAS_1	HAS_2	GG	λ_1	Std.err.	p	λ_2	Std.err.	p
France	0.98	0.99	1.06^a	-0.03	0.03	0.26	-0.51	0.06	0.00
Germany	0.92	0.93	0.82	1.83	1.85	0.24	-8.30	2.45	0.00
Greece	0.93	0.95	0.95	-29.23	13.82	0.04	603.01	63.53	0.00
Ireland*	0.62	0.81	0.65	-21.75	15.13	0.14	40.35	15.60	0.01
Italy	0.42	0.72	0.54	-37.31	17.27	0.04	43.63	16.53	0.01
Portugal	0.59	0.72	0.61	-35.03	15.51	0.03	54.02	16.47	0.00
Spain	0.79	0.95	0.77	-33.54	25.11	0.16	115.02	21.04	0.00

Panel B: 10-year segment

Sovereign	HAS_1	HAS_2	GG	λ_1	Std.err.	p	λ_2	Std.err.	p
France	0.97	0.98	1.12^a	1.41	1.52	0.26	13.55	2.28	0.00
Germany	1.00	1.00	0.97	0.63	2.91	0.39	-18.68	4.75	0.00
Greece	1.00	1.00	1.04^a	5.54	16.56	0.38	151.42	18.10	0.00
Ireland	0.29	0.38	0.30	-47.41	13.89	0.00	20.09	8.62	0.03
Italy	0.44	0.58	0.46	-45.18	15.18	0.00	38.85	12.79	0.00
Portugal	0.21	0.34	0.34	-61.06	21.70	0.01	32.05	19.94	0.11
Spain	0.41	0.54	0.41	-101.45	24.67	0.00	71.16	18.36	0.00

Figure L.1: Confidence bands for the speeds of adjustment

The graphs show confidence bands for λ_1 and λ_2 for the period from October 2008 to end-May 2011. The bootstrapped confidence intervals are estimated as suggested by Benkwitz et al. (2001) with 100.000 iterations. The lower bound is the 2.5% percentile. The upper bound is the 97.5% percentile. The 5-year Greek λ_2 is not shown because this would overstretch the y-scale. It is important however to note that the 5-year Greek λ_2 has a positive sign and is significantly different from zero, as one would expect and as it is already indicated in Table L.1. The λ_i is expressed in units of 10^{-4}.

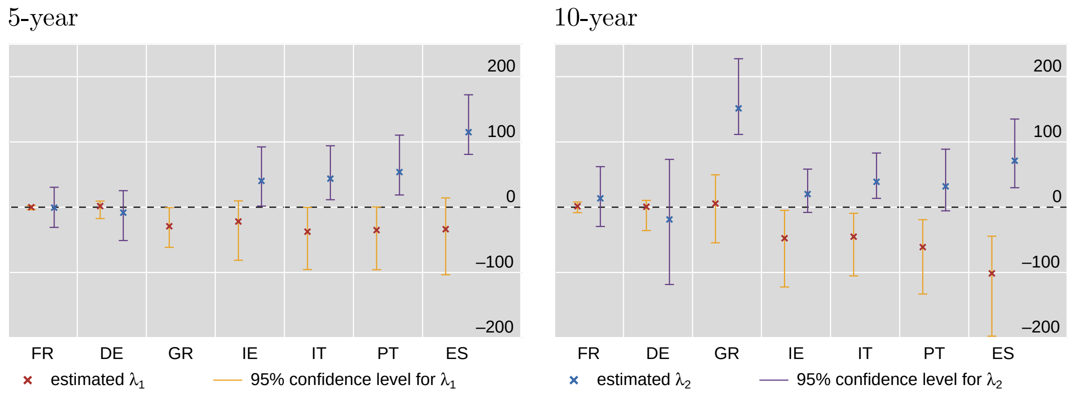


Table L.2: Half-lives of shocks

This table reports the half-lives of shocks for the period from October 2008 to end-May 2011. The half-lives of shocks calculated using the impulse response function to a one unit shock on the co-integrating error. The VECM mechanism directly links the speed of adjustment of CDS and ASW to the cointegration residual u_t which follows an implied AR(1) process: $u_t = (1 + \lambda_1 - \alpha_1\lambda_2)u_{t-1} + \varepsilon_t^{CDS} - \alpha_1\varepsilon_t^{ASW} \equiv \phi u_{t-1} + \varepsilon_t^{CDS} - \alpha_1\varepsilon_t^{ASW}$ from which the half life of shock n is calculated as follows: $n = ln(0.5)/ln(\phi)$.

Sovereign	5-year		10-year	
	In periods	In days	In periods	In days
France	16.1	1.8	32.7	3.6
Germany	72.4	8.0	59.6	6.6
Greece	8.3	0.9	26.3	2.9
Ireland	112.1	12.5	85.9	9.5
Italy	74.5	8.3	64.1	7.1
Portugal	71.7	8.0	63.1	7.0
Spain	39.1	4.3	34.0	3.8

L.2 Results for data with 2-hour sampling frequency

Table L.3: VECM parameters and measures of price discovery

This table reports the price discovery analysis results for the period from October 2008 to end-May 2011. The two measures of price discovery, (i) the information share or Hasbrouck measure (HAS) and (ii) the common factor component weight or Gonzalo-Granger measure (GG), are based on a vector error correction model. Results for Ireland are not shown as cointegration was rejected by both the Johansen and Phillips-Ouliaris test. The superscript ^{a} indicates that the GG measure has to be interpreted as 1, because the VECM coefficient λ_1 is not significant. The values of the VECM coefficients λ_i and their standard errors are expressed in units of 10^{-4}. The cointegration test for country names marked with a * reject cointegration at 0.95 significance level, hence VECM results must be treated with caution.

Panel A: 5-year segment

Sovereign	HAS_1	HAS_2	GG	λ_1	Std.err	p	λ_2	Std.err	p
France	0.94	0.94	1.25^a	0.19	0.10	0.07	0.95	0.13	0.00
Germany	0.96	0.97	0.87	6.14	7.95	0.30	-40.55	10.67	0.00
Greece	0.64	0.76	0.84	-75.06	32.07	0.03	380.90	99.24	0.00
Ireland*	0.85	0.99	1.69^a	6.96	5.32	0.17	17.05	5.07	0.00
Italy	0.82	1.00	0.98	-1.50	29.34	0.40	93.98	25.92	0.00
Portugal	0.43	0.69	0.55	-70.50	29.76	0.02	84.97	30.70	0.01
Spain	0.73	0.98	0.81	-46.28	49.91	0.26	193.12	38.30	0.00

Panel B: 10-year segment

Sovereign	HAS_1	HAS_2	GG	λ_1	Std.err	p	λ_2	Std.err	p
France	0.99	1.00	1.05^a	1.56	3.63	0.36	32.50	5.65	0.00
Germany	0.98	0.99	0.93	2.87	4.28	0.32	-35.48	8.19	0.00
Greece	0.49	0.62	16.95	33.43	15.91	0.04	35.53	15.28	0.03
Ireland	0.00	0.05	0.03	-66.73	20.25	0.00	2.18	12.19	0.39
Italy	0.49	0.69	0.53	-83.36	27.51	0.00	93.88	24.54	0.00
Portugal	0.92	1.00	0.93	-10.97	38.95	0.38	145.66	32.55	0.00
Spain	0.59	0.77	0.56	-118.44	41.64	0.01	147.83	32.28	0.00

Figure L.2: Confidence bands for the speeds of adjustment

The graphs show confidence bands for λ_1 and λ_2 for the period from October 2008 to end-May 2011. The bootstrap confidence intervals are estimated according to Benkwitz et al. (2001) with 100.000 iterations. The lower bound is the 2.5% percentile. The upper bound is the 97.5% percentile. The 5-year Greek λ_2 is not shown because this would overstretch the y-scale. It is important however to note that the 5-year Greek λ_2 has a positive sign and is significantly different from zero, as one would expect and as it is already indicated in Table L.3. The λ_i is expressed in units of 10^{-4}.

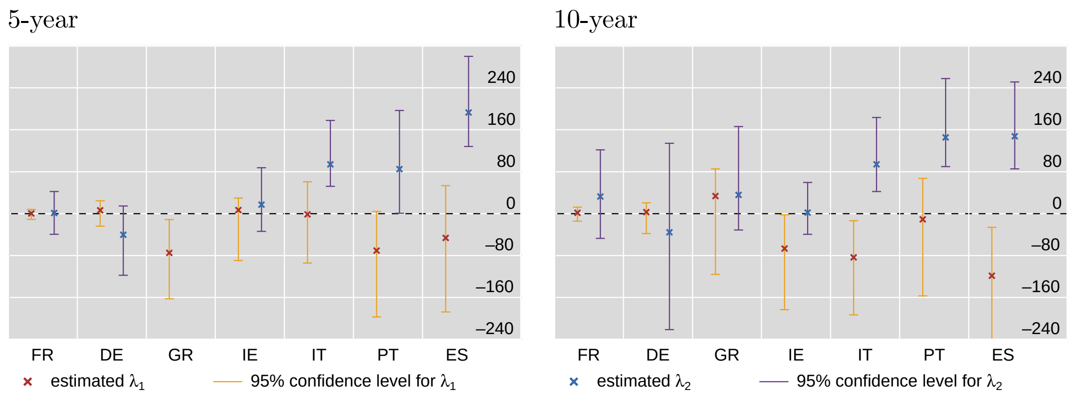


Table L.4: Half-lives of shocks

This table reports the half-lives of shocks for the period from October 2008 to end-May 2011. The half-lives of shocks calculated using the impulse response function to a one unit shock on the co-integrating error. The VECM mechanism directly links the speed of adjustment of CDS and ASW to the cointegration residual u_t which follows an implied AR(1) process: $u_t = (1 + \lambda_1 - \alpha_1\lambda_2)u_{t-1} + \varepsilon_t^{CDS} - \alpha_1\varepsilon_t^{ASW} \equiv \phi u_{t-1} + \varepsilon_t^{CDS} - \alpha_1\varepsilon_t^{ASW}$ from which the half life of shock n is calculated as follows: $n = ln(0.5)/ln(\phi)$.

Sovereign	5-year		10-year	
	In periods	In days	In periods	In days
France	14.2	2.8	16.5	3.3
Germany	34.2	6.8	25.3	5.1
Greece	12.0	2.4	304.3	60.9
Ireland	1511.7	302.3	97.8	19.6
Italy	49.2	9.8	28.7	5.7
Portugal	42.1	8.4	32.0	6.4
Spain	24.1	4.8	20.3	4.1

The 5-year Irish CDS and ASW are critical regarding cointegration (Table F.7). Hence, the VECM results need to be treated with caution. This may explain the unreasonable value of 302.3 days for the Irish half-life. The 10-year Greek half-life is also very high, especially if it is compared to results at other sampling frequencies (Figure L.3).

L.3 Confidence bands for half-lives

Here we compare the results of half-lives of our robustness checks.

Figure L.3: Confidence bands for half-lives

The graphs show confidence bands for the half-lives at 30 min, 1-hour, 2-hour and daily sampling frequencies for the period from October 2008 to end-May 2011. The bootstrap confidence intervals are estimated according to Benkwitz et al. (2001) with 100.000 iterations. The lower bound is the 2.5% percentile. The upper bound is the 97.5% percentile. The 5-year Irish half-life (Table L.4) and its confidence interval is not shown as it is obviously a statistical instability, The upper bound of the 10-year Greek half-life is also not shown, because it would overstretch the scale and is obviously also a statistical artefact. The cointegration test of the Irish 2-hour data shows no-cointegration. Therefore, the VECM results need to be treated with caution anyway.