Liquidity Interactions in Credit Markets: An Analysis of The Eurozone Sovereign Debt Crisis

Giovanni Calice, Jing Chen, Julian Williams[1,]

Abstract

At the end of 2009, countries in the Eurozone began to experience a sudden divergence of bond yields as sovereign default risk increased. This paper examines the potential spillovers between the liquidity of the sovereign credit default swap (CDS) market and the liquidity of the sovereign bond market for a group of Eurozone countries. Empirically, we consider the differential spread on various Eurozone members sovereign bonds over the equivalent German benchmark. Using a unique dataset, constructed from the tick by tick transaction history from the 5-10 year maturity of the sovereign bond and CDS markets, we find that for countries such as Portugal, Spain and Ireland, the CDS market reveals a growing influence on bond yields post 2009. We provide substantial evidence that Greek sovereign CDS spreads and debt spreads do not exhibit the same time varying correlative patterns. Furthermore, we suggest that CDS spreads and bond credit spreads for Greek debt have correctly priced the default risk and that the trend patterns observed have not been substantially affected by changes in the liquidity profiles of either market. On a general note, we show that the bond yield liquidity spreads have increased substantially over the 2007-2010 period whilst CDS liquidity spreads have fallen dramatically. For some countries, such as Portugal, liquidity risk plays an important role in the sovereign bond market.

Keywords: Credit Derivatives, Liquidity, Sovereign Bonds, Credit Spreads
JEL Classification: G11, G12, G14

1. Introduction

In early 2010, fears of a sovereign debt crisis, the 2010 euro crisis (also known as the Aegean Contagion) developed concerning some European nations, including European Union (EU) members Greece, Spain, and Portugal. This led to a crisis of confidence as well as the widening of bond yield spreads and risk insurance on CDS between these countries and other EU members, most importantly Germany.

Concern about rising government deficits and debt levels across the globe together with a wave of downgrading of European government debt has created alarm in financial markets. The euro crisis has been mostly centred on recent events in Greece, where there is concern about the rising cost of financing government debt. On May 2, 2010, the Eurozone countries and the International Monetary Fund (IMF) agreed to a 110 billion euro loan for Greece, conditional on the implementation of a package of severe austerity measures. On 9 May 2010, Europe's Finance Ministers approved the creation of the European Financial Stability Facility (EFSF) aimed at preserving financial stability in Europe by providing financial

Email addresses: g.calice@soton.ac.uk (Giovanni Calice), j.chen@swan.ac.uk (Jing Chen), julian.williams@abdn.ac.uk (Julian Williams)

assistance to eurozone states in economic difficulty. The objective of the EFSF is to collect funds and provide loans in conjunction with the IMF to cover the financing needs of euro area Member States in difficulty, subject to strict policy conditionality. Euro area Member States will provide guarantees for EFSF issuance up to a total of 440 billion euro on a pro rata basis.

During the crisis, several commentators expressed concern that the manipulation of the CDS market by speculative investors was playing a significant role in exacerbating the liquidity dry up in the market for Greek, Irish, Portuguese and Spanish sovereign debt. In particular,'naked' CDS positions were blamed for driving bond yields on Greek, Irish, Spanish and Portuguese debt higher during the first half of 2010. In this context, Greece was adjudged to be a victim of short-term speculative short selling practices on its sovereign debt and naked shorting in the CDS market.

In this paper, we investigate the potential spillover effects between the liquidity in the sovereign bond market (hereinafter, referred to as the bond market) and the sovereign credit default swap (CDS) market during the 2010 European sovereign debt crisis. We focus primarily on the time varying relationship between the concurrent daily liquidity of the bond and CDS market and the resultant observed bond yields and CDS premia for a selected group of Eurozone countries relative to German bonds and sovereign CDS, which we use as a benchmark. We estimate a time varying vector autoregression (VAR) model to observe the change in the dynamics of the 'price' discovery mechanism over the period January 1, 2007 to August 12, 2010. Overall, we document that, during the pre-crisis period, the spreads on bond yields over the benchmark determined CDS spreads.

In Table **??**, we present some of the background statistics that underlie the sovereign debt crisis. In columns two to seven we outline six country's macroeconomic measures: GDP growth, unemployment, consumer price inflation, house price inflation, current account and trade balance. The columns are further divided to report average figures over the five years from 2002 to the end of 2006 and the averages for the calendar years 2007, 2008 and 2009. In columns seven to thirteen we compute these as a simple percentage difference from the equivalent German data. The important information here is the decoupling of various parts of the Eurozone area in economic terms during the crisis. For our analysis, we concentrate on mid-maturing sovereign bonds and corresponding CDS with maturities of between five and ten years. These are considered in fact to be benchmark bonds with generally the highest levels of liquidity.

Our analysis is primarily a bivariate time series investigation of the price formation mechanism driving bond yields and CDS spreads. For this purpose, we propose and implement a Time Varying Vector Autoregression (TV-VAR) for the evolution of the risk premia information prescribed by the bond and CDS markets. We also use the liquidity spreads (the log bid-ask ratio of the bid and ask yields and spreads) of the aforementioned markets as contemporaneous exogenous variables in the regression.

The data is collected from tick data of quotes and transactions from the sovereign debt market and a combination of tick and closing day data for the CDS markets to compute average daily logarithmic bid-ask spreads and use these as proxies for liquidity[1].

For each day, we also compute the log ratio of their CDS spreads over the German CDS spreads. Therefore, our analysis attempts to capture the liquidity and risk premia of the bond market and the liquidity and spreads in the CDS market. We then estimate a time varying coefficients vector error correction model with exogenous drivers (TV-VARX) to analyse the changing transmission structure between the sovereign bond and the sovereign CDS market.

Our main empirical findings are as follows. First, we find that whilst the liquidity of the sovereign debt market dries up over the crisis period, the liquidity of the CDS market increases dramatically with spread bids and spreads asked (offered) approaching a one to one ratio. Second, the time varying betas and robust estimation suggest that for Ireland and the 'club med' countries, such as Spain, Greece and Portugal, the transmission effect from the CDS market to the bond spreads is large and significant. Interestingly, the drop in the spread bid to spread asked (offered) ratio for the CDS market suggests that this is attributable to a change in the yield discovery mechanism during the crisis rather than a liquidity dry up in the CDS market. Third, recursive lagged analysis suggests that prior to the crisis the spread of the bond yields over the benchmark determined the CDS spreads. However, we show that during the crisis this causality mechanism reversed with the CDS spread leading the bond yields.

The liquidity of the bond market is proxied by the yield bid to yield asked (offered) ratio, which we define as the bond liquidity spread. The liquidity of the CDS market is proxied by the spread bid to spread offered ratio and we define this as the CDS liquidity spread. The risk premia in a given bond market is calculated as the log ratio of the transacted yield on 5 to 10 year debt versus the yield on the equivalent German sovereign debt. We designate this as the bond premia spread. Similarly, for the CDS market we compute the CDS premia spread as the log ratio of the transacted CDS spread on a given Eurozone sovereign debt versus the equivalent CDS spread on German sovereign debt.

We believe that our results are of interest to academics and practitioners and of relevance to policymakers in understanding better the information transmission channels between sovereign CDS and sovereign debt markets. The remainder of the paper is organised as follows. §(2) reviews the literature on bond and CDS market pricing and liquidity. §(3) outlines a model of defaultable bonds and credit derivatives (CDs) in a complete market. §(4) describes our empirical methodology and the data processing used in the study. §(5) contains our analysis of the results and §(6) offers concluding remarks.

2. Related Literature

Early studies about liquidity effects have been focused on traditional securities, such as stocks and bonds, for which adequate data is available to proxy or estimate liquidity effects. As a result, the focus of

[1] In the literature the general term is bid/ask spread. For bonds the terminology generally states yield bid to yield asked or offered. For CDSs, the general term is spread bid to spread offered and sometimes spread asked.

Table 1: This table reports eight sets of fundamental statistics of the ten typical Eurozone countries and the entire Eurozone. The statistics reported include the real GDP growth, government debt, the government revenue, employment rate, government expenditure, government fixed investment, government deficit and inflation. The average of each of the statistical variable are taken for each sample country and the Eurozone during the 1999-2006 period, by contrast, the annual statistics of these variables are collected and outlined since 2007 to 2010.

	GDPGrowth					GovDebt					Revenue				
Country	1999-2006	2007	2008	2009	2010	1999-2006	2007	2008	2009	2010	1999-2006	2007	2008	2009	2010
Austria	2.31	3.70	2.20	-3.90	2.00	65.45	59.30	62.50	67.50	-	49.84	47.90	48.20	48.80	-
Belgium	2.23	2.90	1.00	-2.80	2.00	100.58	84.20	89.60	96.20	-	49.49	48.10	48.80	48.10	-
France	2.23	2.40	0.20	-2.60	1.60	61.23	63.80	67.50	78.10	-	50.01	49.60	49.50	48.40	-
Greece	4.08	4.30	1.30	-2.30	-4.20	100.61	105.00	110.30	126.80	-	40.04	39.80	39.70	37.80	-
Germany	1.45	2.70	1.00	-4.70	3.70	63.14	64.90	66.30	73.40	-	44.64	43.80	43.90	44.50	-
Ireland	6.64	5.60	-3.50	-7.60	-0.20	33.38	25.00	44.30	65.50	-	35.19	36.80	35.40	34.50	-
Italy	1.46	1.50	-1.30	-5.00	1.10	107.25	103.60	106.30	116.00	-	44.90	46.40	46.20	46.60	-
Netherlands	2.31	3.90	1.90	-3.90	1.70	52.46	45.30	58.20	60.80	-	45.06	45.40	46.60	46.00	-
Portugal	1.70	2.40	0.00	-2.50	1.30	56.64	62.70	65.30	76.10	-	39.56	40.90	40.60	38.80	-
Spain	3.75	3.60	0.90	-3.70	-0.20	50.89	36.10	39.80	53.20	-	38.68	41.10	37.10	34.70	-
Eurozone	2.16	2.80	0.40	-4.10	1.70	69.29	66.20	69.80	79.20	-	45.34	45.30	44.90	44.50	-

	Employment					Expenditure					GovInvestment				
Country	1999-2006	2007	2008	2009	2010	1999-2006	2007	2008	2009	2010	1999-2006	2007	2008	2009	2010
Austria	68.73	71.40	72.10	71.60	-	51.69	48.50	48.80	52.30	-	2822.31	2778.60	3032.00	3088.40	-
Belgium	60.20	62.00	62.40	61.60	-	49.96	48.40	50.20	54.20	-	4775.61	5446.00	5902.00	6346.00	-
France	63.00	64.30	64.90	64.20	-	52.63	52.30	52.80	56.00	-	48789.88	62223.00	63412.00	63873.00	-
Greece	58.18	61.40	61.90	61.20	-	45.11	46.50	49.20	53.20	-	5878.39	7731.00	7710.00	7938.00	-
Germany	65.69	69.40	70.70	70.90	-	47.08	43.60	43.80	47.50	-	34400.00	34310.00	36740.00	39300.00	-
Ireland	65.99	69.20	67.60	61.80	-	33.39	36.80	42.70	48.90	-	4999.49	8869.80	9306.80	7545.90	-
Italy	55.80	58.70	58.70	57.50	-	47.84	47.90	48.80	51.90	-	30173.25	35796.00	34602.00	37040.00	-
Netherlands	73.41	76.00	77.20	77.00	-	45.66	45.30	46.00	51.40	-	15402.50	18986.00	20775.00	22092.00	-
Portugal	68.11	67.80	68.20	66.30	-	43.21	43.80	43.60	48.20	-	4513.88	4103.40	3965.50	4048.50	-
Spain	59.43	65.60	64.30	59.80	-	38.83	39.20	41.30	45.80	-	26631.00	42587.00	42724.00	46068.00	-
Eurozone	62.53	65.60	66.00	64.70	-	47.31	46.00	46.90	50.80	-	185156.08	231602.70	237609.90	247397.10	-

	Deficit					Inflation				
Country	1999-2006	2007	2008	2009	2010	1999-2006	2007	2008	2009	2010
Austria	-3845.58	-1159.90	-1328.20	-9607.50	-	1.70	2.20	3.20	0.40	-
Belgium	-1199.73	-1105.00	-4622.30	-20351.40	-	2.00	1.80	4.50	0.00	-
France	-41679.25	-51433.00	-64677.00	-143834.00	-	1.80	1.60	3.20	0.10	-
Greece	-9279.23	-14465.00	-22363.00	-36150.00	-	3.23	3.00	4.20	1.30	-
Germany	-52707.50	6550.00	2820.00	-72910.00	-	1.48	2.30	2.80	0.20	-
Ireland	2313.63	46.50	-13148.80	-22957.90	-	3.46	2.90	3.10	-1.70	-
Italy	-38954.63	-23517.00	-42694.00	-80863.00	-	2.34	2.00	3.50	0.80	-
Netherlands	-2857.88	1048.00	3389.00	-30915.00	-	2.51	1.60	2.20	1.00	-
Portugal	-5061.71	-4671.20	-5037.70	-15700.90	-	3.00	2.40	2.70	-0.90	-
Spain	254.25	20066.00	-45189.00	-117306.00	-	3.16	2.80	4.10	-0.20	-
Eurozone	-149421.94	-58518.60	-186009.50	-563418.90	-	2.10	2.10	3.30	0.30	-

the mainstream literature on liquidity is on these markets, rather than emerging securities such as CDSs. An eminently sensible standpoint to take is that CDSs are simply a short position in a defaultable bond. This is an entirely consistent argument in that once protection equivalent to the par value of the underlying bond has been purchased, then the portfolio of underlying and derivative should replicate the risk free rate, as it is a synthetic risk free rate. Following from this argument, the spread on the yield of the defaultable bond over the risk free rate should in effect be replicated by the cost of holding the protectio (i.e. there is a risk premia in holding bonds and under arbitrage free pricing the cost of protection should fully offset this premia). However, recent studies (see, for instance, Calice, Chen and Williams (2010)) suggest that trading strategies in corporate CDS generate far higher returns than the equivalent cost of the premia.

The ability to construct replicating positions by combinations of short and long positions in the defaultable bond, risk free rate and CDS markets is complicated by variations in the underlying liquidity of each market and the non-aligned incentives created by holding one of the three instruments exclusively, e.g. a short naked CDS position. The incentive structure is easy to understand, if an investor is able to create a highly leveraged speculative bet on default (by use of a naked CDS position for instance, which often requires no initial margin). In this situation, it would then be highly desirable to alter the liquidity of the alternatives markets to suit an investor's purposes, (e.g. by withdrawing liquidity from the defaultable bond market and driving up required yields and complicating restructuring of distressed debt).

Manipulation of market liquidity is often the primary mechanism through which speculative attacks are channelled and in this case the object of interest is the bilateral liquidity structure of the sovereign debt market and the sovereign CDS market. A comprehensive survey of this literature is beyond the scope of this study. Thus, we touch upon a few contributions that underpin the prevailing academic perspective on the effects of liquidity, asset prices and credit instruments.

Chen, Lesmond, and Wei (2004) illustrate the relationship between corporate bond liquidity and yield spreads. They use three models of the bid-ask spread, the proportion of zero returns and the LOT model to measure over 4,000 corporate bonds spanning both investment grade and speculative issuers. Their results suggest that illiquidity bonds leads higher yield spreads and an increase in liquidity results in a decrease in yield spreads. Additionally, they point out that the level of yield spreads cannot be fully explained by default risk per se.

A similar study by Ericsson and Renault (2002) also reveals the association of corporate bond liquidity and yield spreads. They entertain a structural bond valuation model to illustrate the influence of liquidity risk on the yield spreads of the bond. The major findings are that liquidity spreads are positively related to the default components of yield spreads and liquidity spreads decrease with the time to maturity.

Liquidity has been reported as an important factor influencing prices in the Treasury bond market. Amihud and Mendelson (1991) attempt to examine the relationship between asset liquidity, yield spreads and maturities by using securities data from U.S. Treasury notes and bills and provide a strong evidence of liquidity effects on asset prices. Their results show that there is a significant and negative association between yield to maturity and liquidity of notes. Additionally, yield spreads decrease with time to maturity.

There are a few studies that use CDS spreads as a benchmark to control for credit risk in order to study liquidity effects in bond markets. Longstaff, Mithal, and Neis (2005) use the credit default swap spreads as information to measure the default and non-default risk components in corporate spreads and find that default risk is the main determinant of bond spreads. With respect to the non-default component, they find that this component is time varying and there is a strong relationship between the non-default component and the evaluation of bond-specific illiquidity. Moreover, changes in the non-default component are related to measures of Treasury yield spreads as well as to measures of the overall liquidity of fixed income markets.

Similarly, Han and Zhou (2007) examine the size of non-default components in corporate bond yield spreads and find a relationship with bond liquidity. They use intraday transactions data and the term structure of CDS to measure bond liquidity and default components, respectively. Their results show that the non-default components positively and significantly relate with bond illiquidity for investment-grade bonds but not for the speculative-grade segment of the market. This result is analogous to Longstaff, Mithal, and Neis (2005). In addition, Han and Zhou (2007) suggest that the non-default component of bond spreads fluctuate with macroeconomic and financial variables such as the Treasury term structure and stock market implied volatility.

A study by Mahanti, Nashikkar, Subrahmanyam (2007) also relates CDS spreads to bond yield spreads. The authors develop a new method, termed "latent liquidity", to investigate whether expected liquidity is priced in the corporate bond market. They first study the difference between CDS premium and corporate bond yield, the CDS-bond basis, which is used to measure the non-default component in the corporate bond yield. They primarily focus on the liquidity impact on corporate bond prices and show that liquidity plays a critical role in the CDS-bond basis and bond yield. Their results also lend support to the hypothesis that higher liquidity levels are generally associated with a lower value in the non-default component of corporate bond yield spreads and higher bond prices.

In contrast, De Jong and Driessen (2005) introduce Treasury bond liquidity and equity market liquidity as significant factors influencing corporate bond spreads to discuss the liquidity impact on the pricing of corporate bonds. They provide evidence of a positive relationship between corporate bond returns and the fluctuations in the equity and bond market liquidity measures though time-series regressions. In terms of cross-sectional regression, their results suggests that the liquidity risk premium is a factor that does have an impact on the level of corporate bond yields, the latter of a similar size to that of the market risk premium.

A recent contribution about the liquidity effect on corporate bond is due to Wang (2009). The author develops a new approach which eliminates the credit risk component, the fixed effect as well as the time effect in corporate bond returns and only consider the liquidity component in the corporate bond. As a result, the bond yield difference should be due only to the liquidity component. Regression results have confirmed this assumption. However, most of the liquidity proxies have high marginal effects on the liquidity component for both investment- and speculative-grade bonds regardless they can only explain a fractional part of the difference in the liquidity components.

A set of possible proxies of corporate bond liquidity is provided by Houweling, Mentink, and Vorst (2005). They use the Brennan and Subrahmanyam (1996) methodology and consider eight measures to quantify corporate bond market liquidity. These are issued amount, coupon, listed, age, missing prices, price volatility, as well as a number of contributors and yield dispersion. They adopt two regression models and the results illustrate that 7 out of 8 liquidity measures turn out to reject the null hypothesis that a liquidity premium is not priced in corporate bonds. The liquidity premium ranges between 9bp and 24bp. Moreover, age and yield dispersion present the more elevated values.

Downing, Underwood, and Xing (2005) also explore the role of liquidity risk in corporate bond pricing. They employ the TRACE corporate bond dataset and develop a linear APT-style factor model to perform the test. Their main results suggest that liquidity can exactly hold for some fractions as the determination of corporate bond prices. Illiquidity is an importance factor that should not to be ignored in bond yields. Moreover, the results also show a significant relationship between liquidity and the time to maturity as well as credit risk.

A significant body of the literature has developed that explores the pricing of liquidity on derivative assets and its relationship with bond and equity markets.

Bongaerts, Jong and Driessen (2009) in their study examine the role of liquidity in CDS pricing. They develop an asset-pricing model LCAPM based on the Acharya and Pedersen (2005) model to test for CDS contracts expected liquidity and liquidity exposure. They use 300.000 CDS bid and ask quotes and a sample period spanning from 2000 to 2006. The repeated sales methodology is adopted to explore a CDS portfolio level and the bid-ask spreads are used to measure liquidity. Their main results throughout two-step regression suggest that first, credit risk and liquidity are significant determinants in CDS contracts pricing and the liquidity premium can be ascribed to the protection seller. Second, there is an association between expected excess CDS returns and expected loss of CDS portfolio. Third, the expected liquidity effect exceeds the liquidity risk effect.

Tang and Yan (2006) analyse liquidity spillovers from corporate bonds, stocks and option markets on CDS spreads. They adopt a large set of proxies including the total number of quotes and trades, order imbalance, and bid-ask spread to measure market liquidity. They report that the role of the liquidity factor in the CDS markets is surprisingly important than generally assumed. The illiquidity in CDS markets spillover from bond, stock and option markets and lead to an increase in CDS spreads. Moreover, notably the impact of liquidity and liquidity spillover effects increasingly weaken with the improvement of CDS market liquidity.

Acharya and Engle (2009) perform an empirical study on trading and liquidity in the credit default swaps market. The objectives of their research are examining the extent and the nature of trading in CDS market, measuring CDS liquidity and investigating the trading and liquidity of the CDS market in the stressed event during the 2007-2008 credit crisis. They use a set of trade-level data of North American single-name CDS provided by DTCC and Markit. They adopt the Amihud (2002) approach, namely the ratio of price fluctuation over a period divided by the turnover. They test the time-series variation in CDS market liquidity and then the impact of market liquidity during the crisis.

Jacoby, Jiang and Theocharides (2009) examine the market liquidity effects and the liquidity spillover across the CDS market, the corporate bond market and the equity market. They use multiple measures to evaluate the liquidity in these markets. Their vector auto-regression results illustrate the presence of a common component between the stock market and both the CDS and the corporate bond market whilst no common component is found between the CDS and the bond market. Moreover, they find evidence of a liquidity spillover only from the equity market to the CDS market. Finally, the study documents a time lag in liquidity shocks from the CDS to both corporate bond markets and stock markets.

A number of recent studies have addressed the comovement of CDS markets, bond markets and equity markets. Bystrom (2005), for instance, finds a linkage between stock indices return volatilities and CDS spreads for a set of sub-indices of the European iTraxx index. The empirical results show that CDS spreads have a negative relation with stock prices whereas they are positively related to stock price volatility. The European CDS market and its relationship with the stock market has been investigated by Norden and Weber (2004), who find that the CDS market is sensitive to equity market movements. Furthermore, CDS spreads are negatively related to stock returns. They also point out that the CDS market has a leading role in price discovery. Buhler and Trapp (2008) examine credit risk and liquidity premium in bond and CDS markets. They show that liquidity in CDS markets exhibits a less explicit behavior and the average liquidity in the sub-investment grade CDS market is higher than the corresponding premium in the investment-grade segment of the CDS market. Zhu (2006) provides a direct confirmation of the relationship between bond spreads and CDS spreads and find that both of spreads change in the same direction in the long-term while in the short-term this correlation is found not identical.

3. Motivation

In a CDS transaction the buyer makes periodic payments to the seller and in return receives a payoff if the underlying instrument defaults. Another way of viewing this transaction is that the buyer is acquiring the right to protect the notional value of the underlying asset at a particular payment rate (quoted in basis points per fixed amount of the underlying notional).

Credit Default Swaps and Defaultable Bonds in a Complete Market

To build a portfolio of CDS positions, we need to specify the relationship between the quoted spread and the value of the position as a tradeable asset. Moreover, we need to understand how a CDS fits into a complete market of alternative assets. To justify the construction of our nominal returns on a naked CDS contract, we follow an adaptation of the model of Bielecki and Rutkowski (2002) and Bielecki Jenablanc and Rutkowski (2005). Taking our notation scheme from Musiela and Rutkowski (2005), we define a random default time τ on a filtered probability space $(\Omega, \mathcal{G}, \mathbb{Q})$ with jump process $H_t = \mathbf{1}_{\tau \leq t}$. The associated jump filtration $\mathbb{H}$ is generated by this default time process. Furthermore, we define an auxiliary stochastic process with filtration $\mathbb{F}$ such that $\mathcal{G}_t = \sigma\left(\mathcal{H}_t, \mathcal{F}_t\right)$ for every $t \in \mathbb{R}_+$. For a defaultable claim with promised payoffs X, promised dividends A and recovery process Z, designated (X, A, Z, τ) maturing at time T, X is an $\mathcal{F}_T$ measurable random variable, A is an adapted process with finite variation and filtration in $\mathbb{F}$ and Z is an $\mathbb{F}$-predictable process. The cash flows of a dividend process D maturing at time T is

$$D_t = X\mathbf{1}_{\tau > T}\mathbf{1}_{\tau > \infty}(t) + \int_0^t (1 - H_u)\, dA_u + \int_0^t Z_u dH_u \tag{1}$$

where $\mathbf{1}$ is the indicator function and the premium at $t = 0$ is considered, by convention, to be equal to zero. If $A_t = -\kappa t$, for some constant $\kappa > 0$, then the price of the CDS is the continuously paid credit default spread or premium. Typically, in a CDS contract the promised payoff, X, is zero and Z is determined in reference to a specific recovery rate, for example 25%. This is represented by

$$\int_0^t (1 - H_u)\, dA_u = \int_0^t \mathbf{1}_{\tau > u} dA_u = A_{\tau-}\mathbf{1}_{(\tau \leq t)} + A_\tau \mathbf{1}_{(\tau > t)}. \tag{2}$$

In the event of a default, the remaining promised dividend $A_t - A_{t-}$ can be disregarded. Therefore

$$\int_0^t Z_u dH_u = Z_{\min(\tau,t)}\mathbf{1}_{(\tau \leq t)} = Z_\tau \mathbf{1}_{(\tau \leq t)}. \tag{3}$$

For an investor purchasing a defaultable claim at t, $D_u - D_t$, $u \in [t, T]$ denotes all cash flows received from the defaultable claim over the time frame u. For a risk neutral probability measure $\mathbb{Q}^*$, such that $\mathbb{Q}$ is on $(\Omega, \mathcal{G}_t)$, the value of a unit of account $B = S^k$ is $B_t = \exp \int_0^t r_u du$ for a continuous interest rate r_t. The discounted price of an asset S^{i*} is $S_t^{i*} = S_t^i B_t^{-1}$, for $i \in 1, \ldots, k-1$ assets with nominal price S^i on a filtered probability space $(\Omega, \mathbb{G}, \mathbb{Q})$, where $\mathbb{Q}$ is the observed measure. Note that this is the complete market with arbitrage free pricing described in Karatzas (1996, 2006). To this setup we add the traded security of a defaultable claim, with price S, by convention considered to be asset zero. We now introduce a process $x \in \mathbb{R}^{k+1}$ measured on $\mathbb{G}$ representing a trading strategy where x_t^j is the investment weighting of a $j \in 0, \ldots, k$ indexed asset held at time t.

Trading Protection in a Complete Market

At time $t = 0$, one unit of S is purchased at an initial price S_0 and it is held until expiration T. Following Bielecki, Jeanblanc and Rutkowski (2005), if all proceeds from the savings account are reinvested in B, i.e. $x = \{x_0 = 1, x_{k+1} = x^k\}$, the wealth process $U(x)$ is $U_t(x) = S_t + x_t^k B_t$, $\forall t \in [0, T]$. As with a conventional derivative, the self financing value of the portfolio is driven by a differential equation, $dU_t(x) = dS_t + dD_t + x_t^k dB_t$. Therefore, for every $t \in [0, T]$, the nominal wealth is

$$U_t(x) - U_0(x) = S_t - S_0 + D_t + \int_0^t x_u^k dB_u \tag{4}$$

and the relative wealth is

$$U_t^*(x) = U_t^*(x) + S_t^* - S_t^* + \int_0^t S_u (S^*)^{-1} dD_u \tag{5}$$

Bielecki, Jeanblanc and Rutkowski (2005) derive the ex-dividend continuous price process at $t \in [0, T]$ of the defaultable claim as

$$S_t = B_t \mathbb{E}_{Q^*}\left(\int_t^T B_u^{-1} dD_u \,|\mathcal{G}_t \right). \tag{6}$$

If we now consider a CDS, with spread κ, this is a defaultable claim $(0, A, Z, \tau)$ where $Z_t = \delta(t)$, $A = -\kappa t$ for every $t \in [0, T]$, $\delta : [0, T] \to \mathbb{R}$ is a càdlàg function that represents the protection payment and κ is the CDS spread or premium. Bielecki and Rutkowski (2002) provides a simple model of default where the filtration $\mathbb{G} = \mathbb{H}$ is generated by a counting process $H_t = \mathbf{1}_{\{\tau \leq t\}}$. For a survival probability function $G = 1 - F$, where F is a cumulative distribution of the default time τ under $\mathbb{Q}^*$, such that $G(t) > 0$, $\forall t \in [0, T]$. For our purposes, we will think of a CDS position being rolled over every day. Therefore, we assume that the interest $r \to 0$. From this setup, the ex-dividend price of the CDS is

$$S_t(\kappa) = \mathbb{E}_{\mathbb{Q}^*}\left(\delta(\tau) \mathbf{1}_{\{t < \tau \leq T\}} - \mathbf{1}_{\{t < \tau\}} \kappa \left(\min(\tau, T) - t \right) |\mathcal{H}_t \right) \tag{7}$$

Hence, the ex dividend price at time $t \in [s, T]$, for a CDS instigated at some time s before t, is

$$S_t(\kappa) = \mathbf{1}_{\{t < \tau\}} \frac{1}{G(t)} \left(-\int_t^T \delta(u) \, dG(u) - \kappa \int_t^T G(u) \, du \right) \tag{8}$$

We now present an important definition for the nominal return calculation on a CDS contract with changing spread. The spread $\kappa(s, T)$ of a market CDS at the inception of the contract is determined by $S_s(\kappa(s, T)) =$

0. For the T maturity market spread the value of the contract is the solution to

$$\int_s^T \delta(u)\, dG(u) + \kappa(s,T) \int_s^T G(u)\, du = 0 \tag{9}$$

and therefore for a traded CDS for $s \in [0,T]$, the spread is

$$\kappa(s,T) = \int_s^T \delta(u)\, dG(u) \left(\int_s^T G(u)\, du \right)^{-1}. \tag{10}$$

The difference $v(t,s) = \kappa(t) - \kappa(s)$ represents the calendar spread between s and t and for a rolled over position such that $t - s$ is a short time period where $v(t,s)$ represents the nominal return on the naked only position.

Introducing Liquidity Shocks

In a recent seminal contribution to the literature, Çetin, Jarrow and Protter (2004) and Jarrow and Protter (2005) outline a continuous time model with liquidity risk. Following Jarrow and Protter (2005), we postulate a stochastic supply curve for both the defaultable claim $S(\cdot)$ and the traded spread $\kappa(\cdot)$. Let $S(t,x,\omega)$ represent the price of the claim for a given order size $x \in \mathbb{R}$, for a state contingent outcome as set out previously and summarised as $\omega \in \Omega$. A positive order, $x > 0$, is a buy whilst a negative or zero order, $x \leq 0$, is a sell or marginal trade. We can appeal to classical microstructure theory such as the multivariate rational expectations model of Admati (1984) and the Bayesian approach of Kyle (1985) to motivate this assumption. In these cases well informed and liquid market makers occupy the market and the recursive outcome of their trading interactions result in supply side dynamics. In effect, the volume traded by strategic traders can only be absorbed by price takers to a certain degree. During crisis periods, the structure of the demand curve steepens (in classical models of continuous time markets the supply curve is assumed to be horizontal).

The assumed properties of the Jarrow and Protter (2005) [pp: 5-6] curve are as follows

1. $S(t,x,\cdot)$ is an $\mathcal{F}_t$ measurable and non negative.
2. $x \mapsto S(t,x,\omega)$ is a.e. t non-decreasing in x.
3. S is C^2 in its second argument, $\frac{\partial S(t,x)}{\partial x}$ is continuous in t, and similarly $\frac{\partial^2 S(t,x)}{\partial x^2}$ is continuous in t.
4. $S(\cdot,0)$ is a semi-martingale.
5. $S(\cdot,x)$ has continuous sample paths (including time 0) for all x.

We can apply the same supply and demand criterion for $\kappa(t,\tilde{x},\omega)$ where $\tilde{x}$ is the quantity demanded for the CDS. The self-financing strategy is a triplet $(\{X_t, Y_t : t \in [0,T]\}), \tau$, where X_t is the defaultable bond account size at time t and Y_t is the holding in the non-defaultable reference bond. Similar to the complete market definition of the CDS, τ represents the proposed liquidation time of the whole portfolio. As stated above, we set $X_{0-} \equiv Y_{0-} \equiv 0$ and $X_T = 0$. Setting up a self-financing strategy that generates no cash flows in $[0, T)$, implies that the investment in the money market account Y_t is determined entirely by X_t, τ. This is an important property in the case of CDS contracts, because under the frictionless condition, a completely protected portfolio should perfectly replicate the risk-free rate. Therefore, in the presence of liquidity risk the only variation between the perfectly protected portfolio and the risk free rate is the price of liquidity of the defaultable bond. This should be cancelled out in any protection direction by the value of the liquidity of protection. Following Jarrow and Protter (2005), the self financing position of the trading strategy is

$$Y_t = Y_0 + X_0 S(0, X_0) + \int_0^t X_{u-} dS(u, 0) - X_t S(t, 0) - \tag{11}$$

$$\sum_{0 \leqslant u \leqslant t} \Delta X_u \left[S(u, \Delta X_u) - S(u, 0) \right] - \int_0^t \frac{\partial S}{\partial x}(u, 0)\, d[X, X]_u^c \tag{12}$$

where $(\{X_t, Y_t : t \in [0, T]\}), \tau$, and X_t is right continuous and left limited (càdlàg) with finite quadratic variation, such that $([X, X]_T < \infty)$. Therefore, as discussed previously, we allow continuous combinations of the complete market. Under the assumption of a perfectly elastic supply curve, the mark to market value of the portfolio of the strategy (X, Y, τ) is $Y_t + X_t S(t, 0)$. From this setting, the liquidity cost is derived by Jarrow and Protter (2005) as

$$L_t = \sum_{0 \leqslant u \leqslant t} \Delta X_u \left[S(u, \Delta X_u) - S(u, 0) \right] + \int_0^t \frac{\partial S}{\partial x}(u, 0)\, d[X, X]_u^c \geqslant 0 \tag{13}$$

$$\equiv \int_0^t X_u dS(u, 0) - \left[Y_t + X_t S(t, 0) \right] \tag{14}$$

We now formulate two assumptions. First, the market for the benchmark non-defaultable instrument has a perfectly elastic supply curve. Second, the market for protection, traded by quoting $\kappa(t)$, has a C^2 stochastic supply curve (i.e. a cost in trade size, but not for the transaction).

Speculating on Liquidity Risk

In this section we consider the implications of this market structure. Let us consider a portfolio $\Pi(t) = S(t) + \beta(t)\Lambda(\kappa(t))$, that is held per X_t of $S(0, X_0)$. Suppose $\beta(t)$ to be the hedge ratio in CDS that exactly offsets all default risk in $S(t, 0)$. Under the complete market theorems stated earlier, the value of the portfolio is

$$\Pi_t = \exp \int_0^t r_u du \tag{15}$$

However, liquidation risk implies that the value of $\Pi(t)$ be supplemented by a liquidity premium

$$\begin{aligned} \Pi(t) &= S(t) + \delta\Lambda(\kappa(t)) && (16) \\ \Pi_t &= \exp \int_0^t r_u du + L_t^S + L_t^\kappa && (17) \end{aligned}$$

In this simplified setting it easy to see that the value of $S(t, \cdot)$ and $\kappa(t)$ are related by equation 10. This implies that the liquidity cost of being short in the CDS market should exactly replicate the cost of $-X_t$ lots of being long in the defaultable bond market. Jarrow (2006) suggests the multi-asset portfolio does not have a trivial and computational adjustment.

Implications

1. In a complete market, the liquidity spread on CDSs should be correlated to approaching unity.
2. If the supply and demand curve schedules are unknown, the relationship between the joint liquidity on both the bond and CDS market is uncertain (can be positive or negative correcting for the relative supply and demand slopes in each market).
3. Assuming the supply curve is stochastic and similarly time varying in expectations relative to $\mathcal{F}_\sqcup$, then the correlations between the liquidity profile and the spreads and the subsequent premia dynamics will be affected in different ways at different times dependent on an unknown and stochastic supply curve.

This has a direct implication for the empirical modelling of the discovery dynamics. Consider an empirical price discovery model

$$\left(r_{t+\Delta t}^*, \kappa_{t+\Delta t}^s\right) = f\left(r_t^*, \kappa_t^s \,|\omega\right) + g\left(\lambda_t^s, \lambda_t^\kappa \,|\omega\right) + \int_t^{t+\Delta t} \sigma(u) W(du) \tag{18}$$

where $r_t^* = r_t^s - r_f$ is the traded yield on $S(t)$, κ_t^s is the quoted spread on CDS protection on the bond and $\sigma(\cdot)$ is a multivariate stochastic volatility function. For two liquidity measures λ_t^s and λ_t^κ proportional to the slope of the supply curve at $S(t, 0)$ and $\kappa(t, 0)$, the functions f, g will be determined by the supply and demand profiles and as such a random process in ω.

4. Methodology and Data

Using a simple model of bond and CDS dynamics we have demonstrated that a) liquidity premia are stochastic and dependent on the unobserved supply and demand schedules of the relative markets; b) the covariant relationship between spreads is most likely to be driven by differential supply and demand profiles in each market. To investigate the relative dynamics we employ a vector autoregression with contemporaneous liquidity and time varying coefficients estimated by recursive re-weighted and iterated least squares procedure.

4.1. Data

Data is sourced from Thomson-Reuters Tick History. Sovereign bond data is collected using the 'Super RICs' or Reuters Information Codes described in Table 2. The super RICs collect all trades on instruments in the tag range set by the code. We collect all traded sovereign bonds with a maturity of between 5 and 10 years for the countries selected in the sample. Originally all Eurozone countries were included in the sample. However, to obtain a sample with a reasonable long history for the CDS market and truncation of the sample at January 1, 2007 requires us to exclude some of the smaller countries from the sample.

Bond Data

We collect the tick by tick quotes and trades on sovereign bonds from January 1, 2007 to August 12, 2010, resulting in a full sample consisting of 943 trading days. For the quotes and trades we compute the bid yield, the ask yield and the transacted yield. The frequency of the time series analysis is driven by the tick updates from the CDS market, which is often very sparse at points during the day. We therefore aggregate the intraday ticks to a daily frequency. We stratify them by bond maturity (i.e. closest to 5 years and closest to 10 years) and compute the logarithmic average spread of the transacted bond yields for each country over the equivalent German bond. Next, we aggregate the yield bid and ask to compute the average logarithmic daily liquidity spread for the 5 to 10 year sovereign bonds, again equally weighted over maturities.

CDS Data

The CDS data is pre-aggregated on a daily basis by Thomson-Reuters and CMA. Some of the transaction data is available, although this is a small fraction of the total daily OTC trades. To obtain a complete overview of the 'true' liquidity of the market, CDS data needs to be extracted from various over the counter (OTC) sources. Thomson Reuters provides access to these data through the Tick History system and DataStream at the daily frequency, using the super RIC codes, outlined in Table 2. Table 3 presents the complete list of OTC sources used to compile these daily statistics. The CDS data is divided into three parts: the spread offered (asked), spread bid and spread transacted. To proxy for CDS market liquidity, we compute the logarithmic ratio of the daily average spread bid to the spread offered. To compute the risk premium then we compute the log ratio of the daily average transacted spread for each sovereign CDS relative to the transacted CDS spread using German bonds as a benchmark. For the bond data we are able

Table 2: Reuters Information Codes. The 'Super' Reuters Information Codes are parent codes for a type of instrument. Each is set out with equals '=' sign at the end. For the CDS data, this corresponds to the source, e.g. MD denotes Markit. A blank provides the data from all available sources. In addition, CMA DataStream provides end of day aggregates spreads for CDSs on sovereign debt. Our 'macro' measure of the liquidity of the CDS market is an average of these sources.

Name	BOND RICs		CDS RICs and DataStream/CMA Codes			
AUSTRIA	AT5YT=	AT10YT=	ATGV5YUSAC=	ATGV10YUSAC=	OEGVTS5	OEGVTSX
BELGIUM	BE5YT=	BE10YT=	BEGV5YUSAC=	BEGV10YUSAC=	BGGVTS5	BGGVTSX
FRANCE	FR5YT=	FR10YT=	FRGV5YUSAC=	FRGV10YUSAC=	FRGVTS5	FRGVTSX
GERMANY	DE5YT=	DE10YT=	DEGV5YUSAC=	DEGV10YUSAC=	BDGVTS5	BDGVTSX
GREECE	GR5YT=	GR10YT=	GRGV5YUSAC=	GRGV10YUSAC=	GRGVTS5	GRGVTSX
IRELAND	IE5YT=	IE10YT=	IEGV5YUSAC=	IEGV10YUSAC=	IRGVTS5	IRGVTSX
ITALY	IT5YT=	IT10YT=	ITGV5YUSAC=	ITGV10YUSAC=	ITGVTS5	ITGVTSX
NETHERLANDS	NL5YT=	NL10YT=	NLGV5YUSAC=	NLGV10YUSAC=	NLGVTS5	NLGVTSX
PORTUGAL	PT5YT=	PT10YT=	PTGV5YUSAC=	PTGV10YUSAC=	PTGVTS5	PTGVTSX
SPAIN	ES5YT=	ES10YT=	ESGV5YUSAC=	ESGV10YUSAC=	ESGVTS5	ESGVTSX

Table 3: Tick History CDS, OTC Source: Thomson-Reuters Tick History Data Service. As a decentralised and global market, the CDS spread bid, spread asked (offered) and spread transacted data are aggregated daily from OTC transactions and recorded by the following sources. At present we do not have access to the entire transaction history for the CDS market. As a result, we do not know the total daily numbers of informative ticks for the CDS sources.

ABN AMRO	ANZ Investment Bank (Asia)
Barclays CDS NYC	Barclays Tokyo
BNP Paribas	Citigroup Global Mkts
Deutsche Bank NY	Deutsche Bank Singapore
DZ Bank, Frankfurt	GFI Market Recap
Handelsbanken	Hypovereinsbank
ICAP	ING Manila
J.P.Morgan	Mizuho Securities
Natexis	Nord LB, Hannover
RBS Japan	SEB
Standard Chartered Singapore	TIFFE
Tullett Prebon	UBS Japan
UBS Singapore	CMA
Markit	

to supply the full descriptive outline for the cleaning procedures. Note that unfortunately we are unable to supply this information for the CDS market due to data vendor restrictions.

4.2. Econometric Specification

A serious issue that arises when dealing with interest rates related data is that is commonly found to be near integrated. However, there is a substantial empirical evidence to suggest that structural breaks play a role in the excessive failure to reject the null of a unit root. The nature of potential structural breaks in bond yields data is unclear. For instance, crash breaks as proposed in Perron (1989) are typically changes in intercept. Yet, a fundamental change in the liquidity dynamics of a country's bond markets (particularly, during a financial crisis) may reveal itself in a very different manner. To capture this potentially time varying effect, we propose and implement a recursive and iterated coefficients model. The obvious alternative to this least squares approach would be the adoption of a state space model to generate a fully random stochastic vector that describes the evolution of the coefficients. Experimentation with such models has yielded mixed results. First, we have found in preliminary data analysis that operating at the daily frequency reduces our sample and results in critical issues such as computing correct standard errors and general over fitting.

Table 4: Bond Data Information

The bond data is sourced from Thomson-Reuters. Ticks are the number of quotes and transactions (they are collected as a 3-tuple bid yield, ask yield and a corresponding nearest time after transaction yield) included in the dataset for each country. Zero yields reports the number of ticks which have been removed because one of the three data items is reported as a zero (in this case exactly equal to zero to 5 decimals, as during 2008 the yield on certain bonds declined towards zero). Corrupted ticks are the number of ticks removed because either the yield is not a number or the time stamp is incongruous with the surrounding time stamp or a negative bid ask spread. Rogue ticks are those quotes removed because they are 800% greater or smaller than the daily median quote using a logarithmic proportion. It is interesting to note the lack of informative ticks for Belgium and France. We are assured by the data vendor that all informative ticks have been utilised and comparison with a short Bloomberg sample of yield data does suggest that Belgium and France have indeed less informative updated ticks for the 2009-10 period. We ascribe this to the relatively benign state of the French and Belgium sovereign debt markets as the overall value of bonds transacted is, GDP adjusted, very similar (source Markit). Greece by contrast has a relatively low tick update frequency prior to 2009, but this significantly increases during the crisis period. Despite the low number of ticks for France and Belgium, this still averages nearly 1,000 updated ticks per day with matched bid, ask and transacted yields.

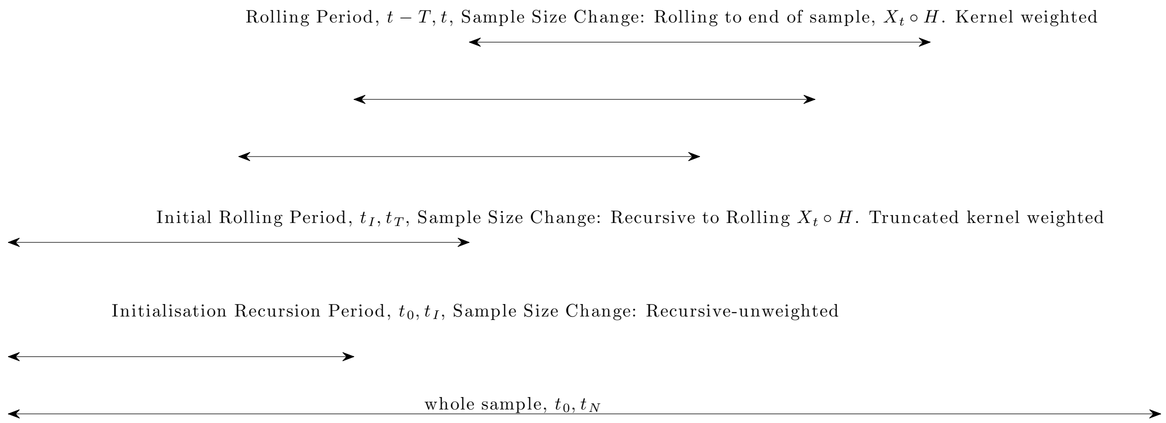
Country	Ticks	Zero Yields	Corrupted Ticks	Rogue Ticks
Spain	4,010,003	606	0	24
Austria	5,609,129	348	0	12
Belgium	978,395	55,981	0	0
France	708,122	31,168	0	2
Germany	2,141,828	61	0	2
Greece	2,800,111	18,574	0	4
Ireland	3,151,086	4,982	0	6
Italy	3,800,255	299,131	0	3
Netherlands	4,866,969	593	0	4
Portugal	4,616,628	10,253	0	3

Use of a higher frequency data set is difficult as the CDS market is plagued, in its early phases, by intraday stale prices and very high levels of microstructure contaminants and broken transaction information (missing volumes and bid-offer information). Consequently, we propose an augmented multivariate least squares regression estimator that explicitly accounts for heteroskedasticity and autocorrelation and has a single simple bandwidth parameter that dictates the memory of the model and is easily optimised using maximum likelihood or some other penalty function approach (for example, the Diebold and Mariano (1996) approach or the recursive Giacomini and Rossi (2010) forecast breakdown).

Figure 1 illustrates the estimation procedure of the model over the sample period. For a sample of size N, an initialisation period t_0, t_I is selected. Over this period, we use an approach in which we estimate a standard recursive coefficients model with increasing sample size. Once the recursion has moved beyond t_I, the model data is weighted using a kernel function $k(\cdot)$. For most kernels this weighting results in a natural truncation at lag length T. For instance, using an exponentially weighted moving average, the lag length for 99% of the sample weight is $T = \frac{\log 0.01}{\log 1-\alpha}$. Alternatively the weighting could be chosen equal over an arbitrary rolling window T. This is subject to the discretion of the econometrician. From time t_T onwards, the model is estimated over a rolling sample window equal to $t - T, t$.

To capture the time varying spillover effect between the bond and the CDS market, for each country we

Figure 1: Time windows used to compute the recursive and rolling coefficients.



compute the following variables

$$XBDY_t = \text{Daily Average}\{\log BDY_t - \log BMBDY_t\} \tag{19}$$

$$XCDS_t = \text{Daily Average}\{\log CDS_t - \log BMCDS_t\} \tag{20}$$

$$BDYBA_t = \text{Daily Average}\{\log BDY_t^{ask} - \log BDY_t^{bid}\} \tag{21}$$

$$CDSBA_t = \text{Daily Average}\{\log CDS_t^{ask} - \log CDS_t^{bid}\} \tag{22}$$

where BDY_t is the transacted tick yield on the benchmark government bond with 5-10 year maturity for each country; $BMBDY_t$ is the tick yield on the closest time and maturity matched German government bond; CDS_t is the transacted spread on CDSs on sovereign debt and $BMCDS_t$ is the transacted spread on the closest time and maturity matured German sovereign CDS; BDY_t^{bid} is the tick yield bid on sovereign debt and BDY_t^{ask} is the tick ask yield on sovereign debt of equivalent maturity to BDY_t; similarly CDS_t^{ask} is the tick spread ask and CDS_t^{bid} is the tick spread bid on CDS on equivalent sovereign bonds to BDY_t. Setting

$$\xi_t = [XBDY_t, XCDS_t]' \tag{23}$$

$$\nu_t = [BDYBA_t, CDSBA_t]' \tag{24}$$

We postulate the following TV-VARX model

$$\xi_t = Z_{0,t}\xi_{t-1} + Z_{1,t}\nu_t + u_t \tag{25}$$

We estimate the model by using recursive and iterative least squares as follows. First, we rewrite 25 as a system of time varying equations

$$y_{1,t} = \beta_{1,0,t} + \beta_{1,1,t}y_{1,t-1} + \beta_{1,2,t}y_{2,t-1} + \beta_{1,3,t}x_{1,t} + \beta_{1,4,t}x_{1,t} + u_{1,t} \tag{26}$$

$$y_{2,t} = \beta_{2,0,t} + \beta_{2,1,t}y_{1,t-1} + \beta_{2,2,t}y_{2,t-1} + \beta_{2,3,t}x_{1,t} + \beta_{2,4,t}x_{1,t} + u_{2,t} \tag{27}$$

Collecting the coefficients into a time varying parameter matrix $B_t = [b'_{1,t}, b'_{2,t}]$ where

$$b_{1,t} = [\beta_{1,0,t}, \beta_{1,1,t}, \beta_{1,2,t}, \beta_{1,3,t}, \beta_{1,4,t}] \tag{28}$$

$$b_{2,t} = [\beta_{2,0,t}, \beta_{2,1,t}, \beta_{2,2,t}, \beta_{2,3,t}, \beta_{2,4,t}] \tag{29}$$

as illustrated previously the model runs recursively for an initialisation period and is then estimated over a rolling sample of size T. The data is gathered into rolling matrices X_t and Y_t, with rows

$$y_t = [y_{1,t}, y_{2,t}], \quad x_t = [1, y_{1,t-1}, y_{2,t-1}, x_{1,t}, x_{2,t}] \tag{30}$$

Therefore

$$Y_t = \left[y'_{t-T}, \ldots, y'_t\right]', \quad X_t = [x'_{t-T}, \ldots, x'_t]' \tag{31}$$

For each time step, the estimated time varying coefficient matrix $\hat{B}_t$ is computed using an iteratively re-weighted least squares approach. First, the data matrices X_t and Y_t are element by element weighted using kernel weights H^x and H^y. In the simplest case, these are equivalent sized matrices of one. Alternatively, the matrices can be weighted using a linear decay or exponentially weighted decay. The first iteration of $\hat{B}_{i,t}$ is computed by ordinary least squares

$$\hat{B}_{i=1,t} = \left((X_t \circ H^x)' (X_t \circ H^x)\right)^{-1} (X_t \circ H^x)(Y_t \circ H^y) \tag{32}$$

where $\circ$ is the Hadamard product and the kernel weighted residuals $\hat{E}_{i=1,t} = Y_t \circ H^y - (X_t \circ H^x)\hat{B}_{i=1,t}$ and the diagonal elements of the outer product are collected. The iterative weighting, W_i, is computed in the standard manner $W_i = diag\left(\left|diag\left(\hat{E}_{i,t}\hat{E}'_{i,t}\right)\right|^{p-2}\right)$. The updated WLS is now

$$\hat{B}_{i,t} = \left((X_t \circ H^x)' W_{i,t} (X_t \circ H^x)\right)^{-1} (X_t \circ H^x)' W_{i,t} (Y_t \circ H^y) \tag{33}$$

Once again, $\hat{E}_{i,t} = Y_t \circ H^y - (X_t \circ H^x)\hat{B}_{i,t}$ and the next iteration of W_i is computed. At each iteration $\lambda_i = \left\|\hat{B}_{i=n,t} - \hat{B}_{i=n-1,t}\right\|_F$ is computed. $|\cdot|_F$ indicates the Frobenius norm, when $\lambda_i < c$ the algorithm terminates and the iterated value of $\hat{B}_t$ is recorded. The array of coefficients $\mathcal{B} = [B_t]$ is called the transmission function.

The final set of model residuals for the model are collected $y_t = \hat{B}_{i,t}x_t + \hat{u}_t$. A standard matrix equality test can be used to extend the Andrews-Quandt test for structural breaks. Setting $\hat{\Sigma}_t = T^{-1}\hat{E}'_{i,t}\hat{E}_{i,t}$ to be the conditional covariance matrix and $\hat{\Sigma} = m^{-1}\sum_{t=1}^{m}\hat{u}_t\hat{u}_t$. For a candidate break point t' the equality test is of the form

$$\hat{\Sigma}_{t'+1} = \hat{\Sigma}_{t'+2} = \ldots = \hat{\Sigma}_{t'=m} = \hat{\Sigma} \tag{34}$$

versus

$$\hat{\Sigma}_{t''+1} = \hat{\Sigma}_{t''+2} = \ldots = \hat{\Sigma}_{t'=m} = \hat{\Sigma} \tag{35}$$

for some prior sample point $t'' < t'$ (see Muirhead (1981) or Ledoit and Wolf (2003) for more details). Inference is constructed using a Chow style adjustment for the estimated parameters. The discretion of the econometrician is in choosing the minimum size of the proportion of the sample between t''', t' and m. In our case, we select a value of 10%. We sample all daily candidate break points from the first 10% to the last 10% of the sample. Table 6 presents the date of the last break point and the parameters of the static VARX model estimated over the sample period.

5. Analysis

The following results correspond to the coefficient plots presented in Figures B.14 to Figure A.10. The plots are presented in eight quadrants. For space reasons, we do not plot the constants. These are available on request, along with the evolution of the conditional covariance matrix from the TV-VAR models. The plots are arranged such that they report the evolution of $\beta_{1,1,t}$ (top left) to $\beta_{2,4,t}$ (bottom right). Each plot presents the coefficient and the 2 standard error bounds. The plots are organised as follows:

- First Equation:
  - The plot labelled $\beta_{1,1}$ is the coefficient that transmits information from the lag of the bond spread ($XBDY_{t-1}$) over its benchmark to the current bond spread over benchmark ($XBDY_t$).
  - The plot labelled $\beta_{1,2}$ is the coefficient that transmits information from the lag of the CDS spread ($XCDS_{t-1}$) over its benchmark to the current bond spread over benchmark ($XBDY_t$).
  - The plot labelled $\beta_{1,3}$ is the coefficient that transmits information from the current liquidity of the bond market, measured by yield bid to yield offered ($BDYBA_{t-1}$), to the current bond spread over benchmark ($XBDY_t$).
  - The plot labelled $\beta_{1,4}$ is the coefficient that transmits information from the current liquidity of the CDS market, measured by spread bid to spread offered ($CDSBA_{t-1}$), to the current bond spread over benchmark ($XBDY_t$).
- Second Equation:
  - The plot labelled $\beta_{2,1}$ is the coefficient that transmits information from the lag of the bond spread ($XBDY_{t-1}$) over its benchmark to the current CDS over benchmark ($XCDS_t$).
  - The plot labelled $\beta_{2,2}$ is the coefficient that transmits information from the lag of the CDS spread ($XCDS_{t-1}$) over its benchmark to the current CDS over benchmark ($XCDS_t$).

– The plot labelled $\beta_{2,3}$ is the coefficient that transmits information from the current liquidity of the bond market, measured by yield bid to yield offered ($BDYBA_{t-1}$), to the CDS spread over benchmark ($XCDS_t$).
– The plot labelled $\beta_{2,4}$ is the coefficient that transmits information from the current liquidity of the CDS market, measured by spread bid to spread offered ($CDSBA_{t-1}$), to the CDS spread over benchmark ($XCDS_t$).

We interpret the magnitude of the coefficients as being the level of information conveyed between the variables in the model. The system contains lagged and contemporary regressors and is therefore a VARX model. We have also computed the eigenvalues of the time varying matrix

$$\begin{bmatrix} \beta_{1,1} & \beta_{1,2} \\ \beta_{2,1} & \beta_{2,2} \end{bmatrix}_t \tag{36}$$

The results for all countries suggest that the conditional models exhibit some non-stationary properties over the sample period.

Results by Country

We first summarise our results by country and then draw some more overarching conclusions about the structure of the information transmission mechanism.

Austria

The first equation shows that the lagged transmission coefficient tends to unity for the majority of the sample. However, the lagged coefficient decreases marginally (but significantly) below unity for parts of the latter period of the sample. The transmission from $XCDS_{t-1}$ to $XBDY_t$ is zero until 2008 and then begins to rise steadily until the beginning of 2010, reflecting the increased information transmission from the CDS market to the bond market. Interestingly and strikingly the coefficient reverses from being positive to negative changing from a spike of +0.07 at the end of 2009 to -0.02 to -0.04 as 2010 progresses. This reflects the changes in the Eurozone policy that occurred in early 2010 as the Greek debt crisis intensified. The evolution of the liquidity coefficients also tell us an interesting story. The evolution of $\beta_{1,3}$ shows that the second most important coefficient (in terms of magnitude) for the early part of the pre crisis sample is the liquidity of the bond market. However, after 2009, the liquidity of the CDS market becomes far more important in transmitting information to $XBDY_t$. This is a significant result as it shows that the contemporary liquidity of the sovereign CDS market has a substantial impact on the sovereign debt spread over the benchmark, even for a relatively healthy country (see Table **??**) such as Austria.

The second equation explains the risk premia of the CDS for Austria over the German benchmark. The coefficients in the model transmitting information from $XBDY_{t-1}$ and $XCDS_{t-1}$ to $XCDS_t$ reflect the change in the information structure of the CDS market over the 2007-2010 sample period. During the initial phase, the primary information content in the CDS market is from the bond spread. However, this coefficient fluctuates sharply just before 2008 and then collapses to zero. From 2008 onwards the coefficient on $XCDS_{t-1}$, which had varied substantially in the preceding period, increases towards unity. The liquidity transmission mechanism exhibits substantial variation over the sample period. The liquidity of the bond market appears to have a substantial impact in the early period, although this reflects the highly variable nature of the CDS spreads in the early part of the sample (see Figure B.12). During 2008, this influences collapses to zero. Moreover, we can see that the liquidity of the CDS market commands some influence which is even more persistent of the liquidity of the bond market in the early period of the sample.

Generally the Austria results suggest that the influence of the CDS market (both in the risk premia and the liquidity structure) has increased over the bond market over the sample period. Note that the most interesting aspect is the change in the influence of the liquidity of the CDS market. Yet, the converse is not really observed. In fact, whilst the key driver of the CDS spread used is the bond spread, this then declines and the CDS process appears to tend toward an independent unit root process.

Belgium

The pattern of the information structure for the sovereign bond and CDS spreads of Belgium is very similar to the Austrian sovereign bond and CDS spreads. However, we are able to identify notable characteristics. The information structure, captured by the first equation, indicates that the Belgian bond spreads ($XBDY_t$) are highly integrated, with a first order autoregression with high persistence $\beta_{1,1} \to 1$. However, we observe a sharp drop in mid 2007 that appears to be explained by the contemporaneous liquidity ($BDYBS_t$) of the bond market, whose coefficient ($\beta_{1,3}$) spikes during that period. The influence of the Belgian sovereign CDS market on the bond spread grows over time. However, this influence does not remain consistent over time. For instance, the coefficient on $XCDS_t$ ($\beta_{1,2}$) jumps to 0.08 during 2009, then falls to -0.04 before rising again to around 0.08. Meanwhile, the coefficient on $CDSBA_t$ ($\beta_{1,4}$) decreases substantially to -0.3 as the influence of the $XCDS_t$ drops. This finding is important since it suggests that during 2009 the liquidity of the CDS market was *more* important that the actual spread of the CDS market over the benchmark.

The second equation, which explains the information transmission mechanism for Belgian sovereign CDS spreads over the equivalent German sovereign CDS spreads, reveals that $XBDY_t$ has little impact on the CDS spread after 2008, i.e. the bond market does not lead the CDS market. Interestingly the autoregressive coefficient on the Belgian sovereign CDS ($\beta_{2,2}$) is significantly less than one for most of the sample. We can also see that the coefficient on $CDSBA_t$, ($\beta_{2,4}$) is negative for most of the sample, i.e. as illiquidity increases, so does the spread over the German benchmark. Towards the end of 2010, this effect seems to dissipate. However, the history of the coefficient indicates that a fluctuation back to this negative position is entirely possible.

The evolution of the Belgian coefficients suggest that the liquidity of the Belgian CDS market does play an important role in the price formation mechanism for the CDS spreads and, in turn, the CDS spread has a prominent influence in the price discovery mechanism of the sovereign bond yield spread over the German benchmark.

France

Several striking features emerge immediatiately when analysing the evolution of the coefficients for the model estimated on the French data. First, that $XCDS_t$ for France is primarily driven by a unit root in itself, i.e. $\beta_{1,1} \to 1$ for almost the entire sample. $\beta_{1,2}$ does become significantly different from zero during 2009, with its highest value being 0.06 at the end of the sample (suggesting a positive transmission from $XCDS_{t-1}$ to $XBDY_t$).

The dynamics of the first equation are less interesting than the second equation. The information transmission mechanism to $XCDS_t$ is dominated by $XBDY_{t-1}$ during 2007 and, for short periods in 2007 and 2008, by $BDYBA_t$. However, $XCDS_{t-1}$ and $CDSBA_t$ appear to oscillate in tandem with each other. There are long periods where the dominant driver in the CDS price discovery mechanism is the liquidity component of the CDS market. For other periods, however, the coefficient on the lag of the returns is generally less than one, suggesting that shocks to $XCDS_t$ are not as persistent as shocks to $XBDY_t$. The liquidity effect is of remarkable magnitude, as it appears that the liquidity of the CDS market plays an important role in determining the price of the CDS spread and in turn this affects, albeit to a lesser degree than in other markets, the spread on French sovereign debt over the German benchmark.

Greece

The evolution of the Greek coefficients is indicative of the narrative that has been presented on the Greek sovereign debt crisis (see **??**). The first interesting observation is that for the first equation the coefficient on $XBDY_{t-1}$ remains near unity for virtually the whole of the sample period suggesting that the primary driving process of the bond spread is a unit root in itself. We can also see that $\beta_{1,2}$ increases substantially after 2009, to roughly 0.10, with the two standard error upper bound at nearly 0.15. Moreover, we see the liquidity of the bond market being significant for only short periods during the sample, specifically for a short time in 2008. The most dramatic interaction is the change in the coefficient relating the $CDSBA_t$ to $XBDY_t$. The coefficient is zero, or indistinguishable from zero during the early part of the sample (from 2007 to mid-2008). The coefficient drops below zero in early 2009 (approximately -0.5) and then rises sharply to 1.5 at the start of 2010. What is interesting is that it drops sharply in the second half of 2010 to a much lower and stable level. On May 9, 2010 the EU established the European Financial Stability Facility, to provide members of the Eurozone a substantial lending facility in the event that a euro area member state is unable to borrow on markets at acceptable rates. Greece began to make use of this facility in May 2010 in addition to a suite of lending and refinancing facilities implemented by the European Central Bank and the IMF. We see this effect in the evolution of the coefficient transmitting information from the liquidity of the CDS market to the sovereign debt market and *not* in the autoregressive coefficient. It is obvious that the information structure of the sovereign debt market has changed substantially over the 2007-2010 period. It is additionally evident that whilst the CDS default spreads and liquidity spreads have influenced the evolution of the sovereign debt spreads, the core driver is a unit root process in $XBDY_t$ itself. This clearly indicates that a considerable part of information is in the form of accumulated shocks and that moves in the spread are not attributable to changes in the liquidity of the CDS market.

The second equation in the TV-VARX model suggests that like many other Eurozone countries the CDS spread was initially driven by the sovereign debt spread and the liquidity of the sovereign debt market, i.e. $\beta_{2,1}$ and $\beta_{2,3}$ are statistically significantly different from zero for some sub-periods of 2007 and 2008. However, the primary driver of the evolution of $XCDS_t$ is the autoregressive coefficient on $XCDS_{t-1}$, with substantial input from $CDSBA_t$, as the coefficient is almost always less than -1 and statistically distinguishable from zero for the majority of the sample. It appears that the influence of the liquidity of the CDS market does begin to vanish in the latter part of 2010.

It is evident that there is some permeation from the CDS market into the Greek sovereign debt spread over the German benchmark, but the primary stochastic trend is driven by the sovereign debt market itself and not directly from the CDS market.

Ireland

In the case of Ireland, the first equation explaining the information structure of $XBDY_t$ suggests that the autoregressive coefficient on $XBDY_{t-1}$ has exploded to around 1.2 after 2010, suggesting that the discount rate on Irish sovereign debt has reached a critical level in late 2010, with a coefficient greater than unity. Interestingly, the CDS market appears to be acting as a break on the sovereign debt market as the coefficient dives to -0.2 as 2010 draws to a close. Importantly, this finding appears to be at odds with a growing body of anecdotal evidence which suggest that speculation in the CDS market has accelerated the increase in the yield spread over the benchmark. The information structure in the model suggests that this is not the case.

The second equation for Irish CDS spreads over benchmark indicates that the information structure of the CDS market is primarily driven by a mixture of the lagged spread and the liquidity of the market. Here, $\beta_{2,4}$ is significantly different from zero and is relatively stable at between -0.5 and -1 for most of the sample from 2007 to mid 2010. This suggests that substantial decreases in liquidity actually *reduces* the default spread. However, during 2010 this trend reverses and increased liquidity in the CDS market now positively and significantly impact the default spread over the benchmark.

Overall, for Ireland, there is no indication that the CDS market is leading the sovereign debt market during the crisis. In addition, we find very little evidence that the liquidity of the CDS market has any statistically significant impact (other than slightly reducing the spread during part of 2009-2010) on $XBDY_t$.

In view of this evidence, we conclude that the primary driver of $XBDY_t$ is the information content of the debt market itself.

Overall Results

Our results above suggest that those members of the Eurozone most affected by the sovereign debt crisis, i.e. Greece, Ireland, Portugal and to some extent Spain, have a very different information transmission structure from the remaining Eurozone countries in our sample. First, it appears that for Greece, Ireland and Portugal the primary information driver in the sovereign debt spreads is the sovereign debt market itself and not the CDS market. This is a striking result, as it counters outspoken criticism of the CDS market by politicians in Greece, Ireland and Portugal that manipulation of the CDS market (see §(**??**)) has eroded confidence in the sovereign debt market. However, for countries such as Netherlands, France and Italy, the CDS market does play a substantial role in the price formation mechanism for sovereign debt. Our estimations show that price discovery in this market is primarily driven by the liquidity of the CDS market. Therefore rises in yields on this debt could be the direct result of manipulation of the liquidity structure of the CDS market and are not driven solely by the sovereign debt market. Additionally, it should be noted that we observe some substantial fluctuations in the model coefficients in both the sovereign debt and sovereign CDS equations. The issue that arises for Eurozone members not in substantial difficulty in terms of their public finances is that the CDS market does appear to be a channel that can drain liquidity from both the CDS and debt markets and lead yields spreads to important deviations from equilibrium. These deviations could then lead to runaway yield increases, as we see in the case of Ireland where the autoregressive coefficient exceeds unity, suggesting an explosive process has taken hold within the sovereign market.

6. Conclusions

We have outlined a theoretical model of cross liquidity in parallel markets and estimated a time varying vector autoregression to elucidate the impact of this cross liquidity effect on the Eurozone sovereign debt and CDS spreads during the recent crisis. We find little evidence to suggest that there was any causation in the explosive bond spreads between the CDS and the sovereign debt market for the most seriously affected countries (Greece, Portugal and Ireland). However, for countries such as France, The Netherlands, Austria and Belgium we do see significant transmission of information between the lagged coefficients on the CDS market and the contemporaneous bond and CDS liquidity spreads. This indicates that the CDS market did play a role in determining the yield spreads in the sovereign debt market as the crisis continued into 2010. This does indicate that policy makers should be aware of the impact o the CDS market on the sovereign debt market. However, any outright regulatory intervention should be weighed against the positive role that the CDS market played in reducing the Irish sovereign spreads in the latter part of 2010.

Table 5: Whole Sample Daily Descriptive Statistics. XBDY is the average transacted logarithmic bond yield ratio for a given day for a 5-10 year sovereign bond over equivalent maturity matched German sovereign bond. XCDS is the average transacted logarithmic CDS spread ratio for a given day for 5-10 year sovereign CDS spread over equivalent maturity matched German sovereign CDS. BDYBA is the average of the daily tick yield bid to yield ask logarithmic ratio for 5-10 sovereign bonds. CDSBA is the average of the daily tick yield bid to yield ask logarithmic ratio for 5-10 sovereign CDS. Note that zero (0) without decimal places indicates that spread bid to spread ask were recorded as being identical. All negative bid ask spreads are excluded as corrupted observations.

	Variable	Austria	Belgium	France	Greece	Ireland	Italy	Neth.	Portugal	Spain
Mean	XBDY	0.10497	0.11235	0.05584	0.44844	0.31000	0.18545	0.06468	0.22164	0.16418
	XCDS	0.31983	0.38397	0.01658	1.58093	1.10342	1.17681	-0.01151	1.00952	0.96143
	BDYBA	0.01129	0.00742	0.00724	0.01041	0.01835	0.00706	0.00638	0.01419	0.00855
	CDSBA	0.20563	0.21014	0.23841	0.08057	0.14857	0.08142	0.29507	0.10838	0.07736
Median	XBDY	0.06433	0.06345	0.03916	0.23796	0.27419	0.13895	0.03021	0.12799	0.10475
	XCDS	0.39051	0.45372	0.05762	1.55814	1.22188	1.14772	0.08004	0.98229	0.96336
	BDYBA	0.00597	0.00459	0.00709	0.00288	0.00711	0.00533	0.00572	0.00542	0.00472
	CDSBA	0.11247	0.09785	0.12516	0.05815	0.07645	0.05672	0.13626	0.07176	0.06108
Std. Dev.	XBDY	0.10063	0.11895	0.05518	0.51383	0.25310	0.16426	0.07543	0.25217	0.20058
	XCDS	0.60626	0.45454	0.35677	0.44429	0.58903	0.24342	0.68326	0.38006	0.35115
	BDYBA	0.01217	0.00737	0.00580	0.01781	0.02796	0.00581	0.00410	0.02609	0.01003
	CDSBA	0.28497	0.26262	0.31978	0.05510	0.21600	0.06369	0.41170	0.09732	0.06560
Min	XBDY	-0.05445	-0.05525	-0.17325	-0.03673	0.01664	-0.03775	-0.06063	-0.05025	-0.05145
	XCDS	-2.14006	-1.59826	-1.79175	0.50890	-1.64561	0.44320	-2.43611	-0.43078	-0.60841
	BDYBA	0.00143	0.00138	0.00126	0	0.00162	0	0.00154	0.00134	0.00109
	CDSBA	0.03077	0.03489	0.03222	0.01864	0.01370	0.01636	0	0.02014	0.01672
Max	XBDY	0.45632	0.58529	0.29134	2.12995	1.01982	0.83340	0.32812	1.20873	0.97711
	XCDS	1.12247	1.36276	0.67655	3.01671	2.45100	2.65257	3.51110	1.87575	1.82301
	BDYBA	0.07737	0.04009	0.02383	0.15865	0.22475	0.05429	0.02170	0.30161	0.09450
	CDSBA	2.14006	1.24703	2.77258	0.29205	1.61990	0.27675	1.87180	0.46368	0.57013
Obs	XBDY	943	943	943	943	729	943	943	943	943
	XCDS	943	943	943	943	943	943	943	943	943
	BDYBA	943	943	943	943	729	943	943	943	943
	CDSBA	943	943	943	943	943	943	943	943	943
Exc.	XBDY	0	0	0	0	214	0	0	0	0
	XCDS	0	0	0	0	0	0	0	0	0
	BDYBA	0	0	0	0	214	0	0	0	0
	CDSBA	0	0	0	0	0	0	0	0	0

Table 6: VAR model parameters evaluated at the last structural break (August 12, 2010). Andrews-Quandt method include 10% or 94 days in the sample (73 in the case of Ireland).

	Austria		Belgium		France		Greece	
BP	January 9, 2010		December 8, 2009		February 3, 2010		March 1, 2010	
$i =$	1	2	1	2	1	2	1	2
$\beta_{i,0}$	0.01490	0.02375	0.01686	0.03846	0.00137	0.06009	-0.02939	0.14476
	(2.35592)	(1.33818)	(2.13004)	(2.35701)	(0.23866)	(2.94313)	(-0.72774)	(3.14807)
$\beta_{i,1}$	(0.97392	-0.02096	0.97093	0.06126	0.95149	0.06243	0.98368	0.02962
	(74.28461)	(-0.56972)	(61.21898)	(1.87396)	(49.32725)	(0.91102)	(58.18772)	(1.53922)
$\beta_{i,2}$	-0.00510	0.98405	0.01143	0.94612	0.00930	0.90525	0.02201	0.92279
	(-1.21592)	(83.52367)	(1.28248)	(51.47549)	(1.21442)	(33.24671)	(0.89540)	(32.96948)
$\beta_{i,3}$	-0.11652	0.03070	0.01598	0.07429	0.00964	0.78870	0.00023	0.37264
	(-1.56999)	(0.14739)	(0.07388)	(0.16660)	(0.05600)	(1.28935)	(0.00172)	(2.43713)
$\beta_{i,4}$	-0.06999	-0.21346	-0.31220	-0.22768	-0.01532	-0.63246	0.21014	-0.30488
	(-1.02356)	(-1.11221)	(-3.15738)	(-1.11712)	(-0.26682)	(-3.09988)	(1.12207)	(-1.42990)
R^2	0.94959	0.96686	0.96086	0.96607	0.94363	0.96980	0.98593	0.96341
$F-stat$	923.15935	1429.84082	1203.09618	1395.22735	820.31987	1573.51186	3435.36410	1290.23061
$p-val$	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

	Ireland		Italy		Netherlands		Portugal		Spain	
BP	June 2, 2009		December 7, 2009		January 1, 2010		March 2, 2010		February 19, 2010	
$i =$	1	2	1	2	1	2	1	2	1	2
$\beta_{i,0}$	0.00015	0.05401	0.01588	0.09340	0.00652	0.02187	-0.09122	0.03756	-0.06497	0.10541
	(0.00913	(2.31437	(0.82723)	(3.12748)	(1.04694)	(0.88049)	(-5.59348)	(1.56214)	(-3.09552)	(3.20759)
$\beta_{i,1}$	0.97787	0.00099	1.00034	0.04147	0.99279	0.03120	0.92173	-0.00364	0.95150	0.03039
	(71.67948)	(0.05421)	(66.41424)	(1.77051)	(92.75596)	(0.73153)	(62.98358)	(-0.16902)	(63.43497)	(1.29411)
$\beta_{i,2}$	0.00559	0.96429	-0.01103	0.92202	-0.00357	0.92475	0.09609	0.97960	0.06249	0.90601
	(0.47770	(61.43656	(-0.67462)	(36.23653)	(-0.63008)	(40.92250)	(5.99963)	(41.48480)	(3.30411)	(30.59170)
$\beta_{i,3}$	0.28640	0.31963	-0.17054	-0.03258	-0.09011	0.20824	-0.21142	0.42349	0.96276	0.65155
	(3.92096	(3.26768	(-0.52049)	(-0.06393)	(-0.38955)	(0.22590)	(-3.67942)	(4.99899)	(5.27326)	(2.27908)
$\beta_{i,4}$	-0.22761	-0.33520	-0.00178	-0.33768	-0.05580	-0.27162	0.26220	-0.31949	-0.22012	-0.24888
	(-1.70678	(-1.87697	(-0.01175)	(-1.43232)	(-1.17015)	(-1.42914)	(1.98097)	(-1.63719)	(-1.50016)	(-1.08320)
R^2	0.95996	0.93351	0.97235	0.88055	0.94612	0.89251	0.97690	0.95659	0.98045	0.92629
$F-stat$	(1174.92830	687.96166	1723.18925	361.23680	860.49442	406.89286	2072.65352	1079.99838	2457.89022	615.78554
$p-val$	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

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Appendix

Appendix A. The First Appendix

Appendix B. Data Plots

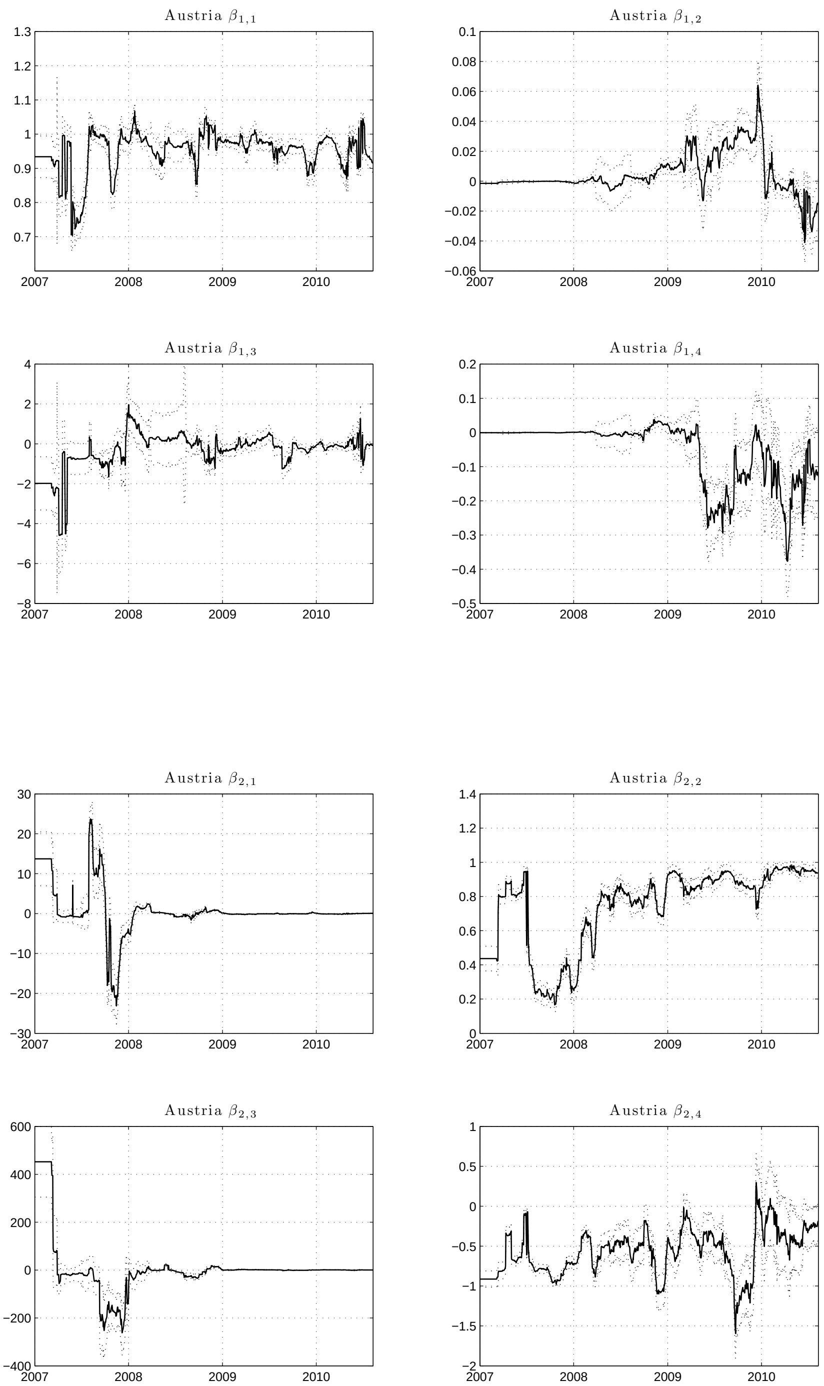

Figure A.2: Recursive Coefficients Betas: Austria

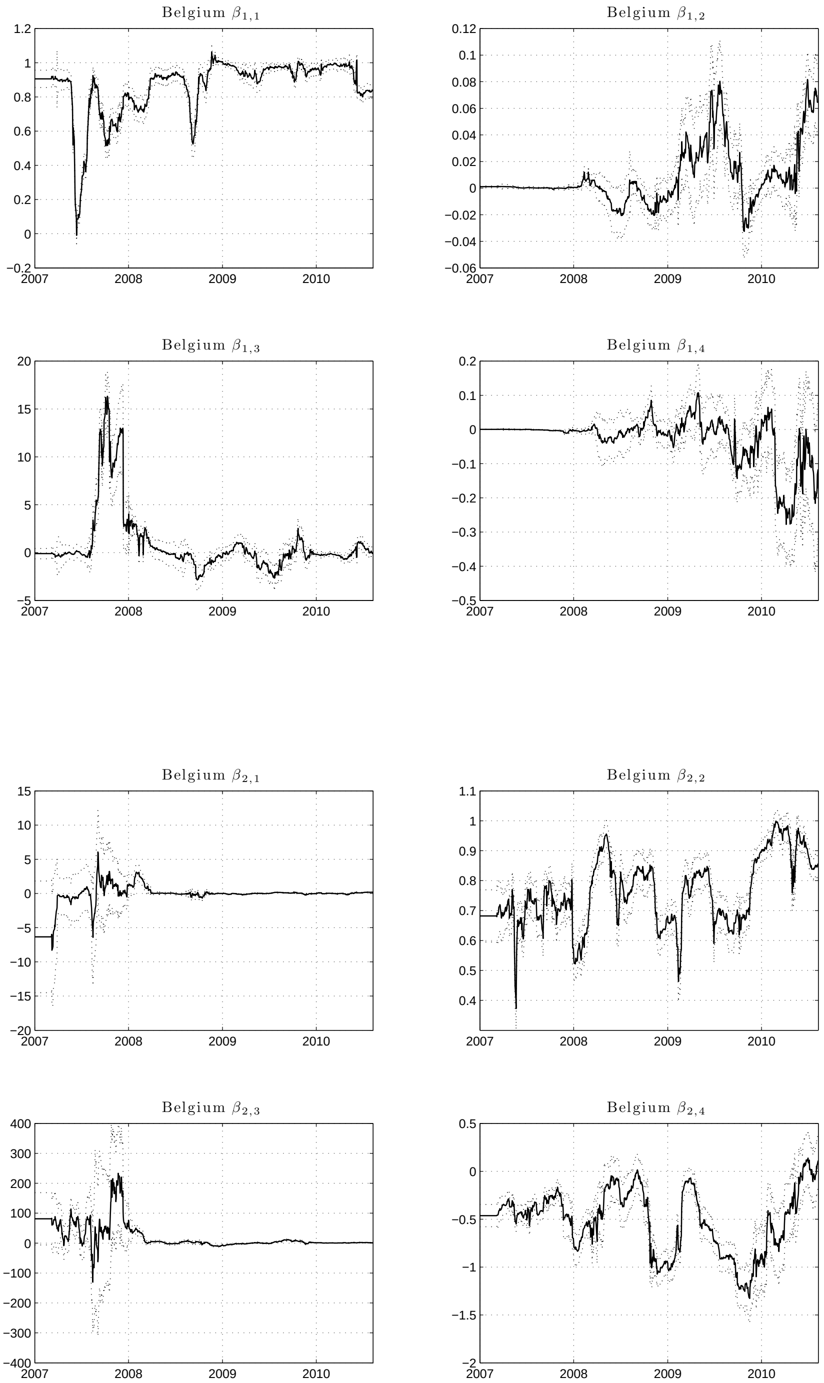

Figure A.3: Recursive Coefficients Betas: Belgium

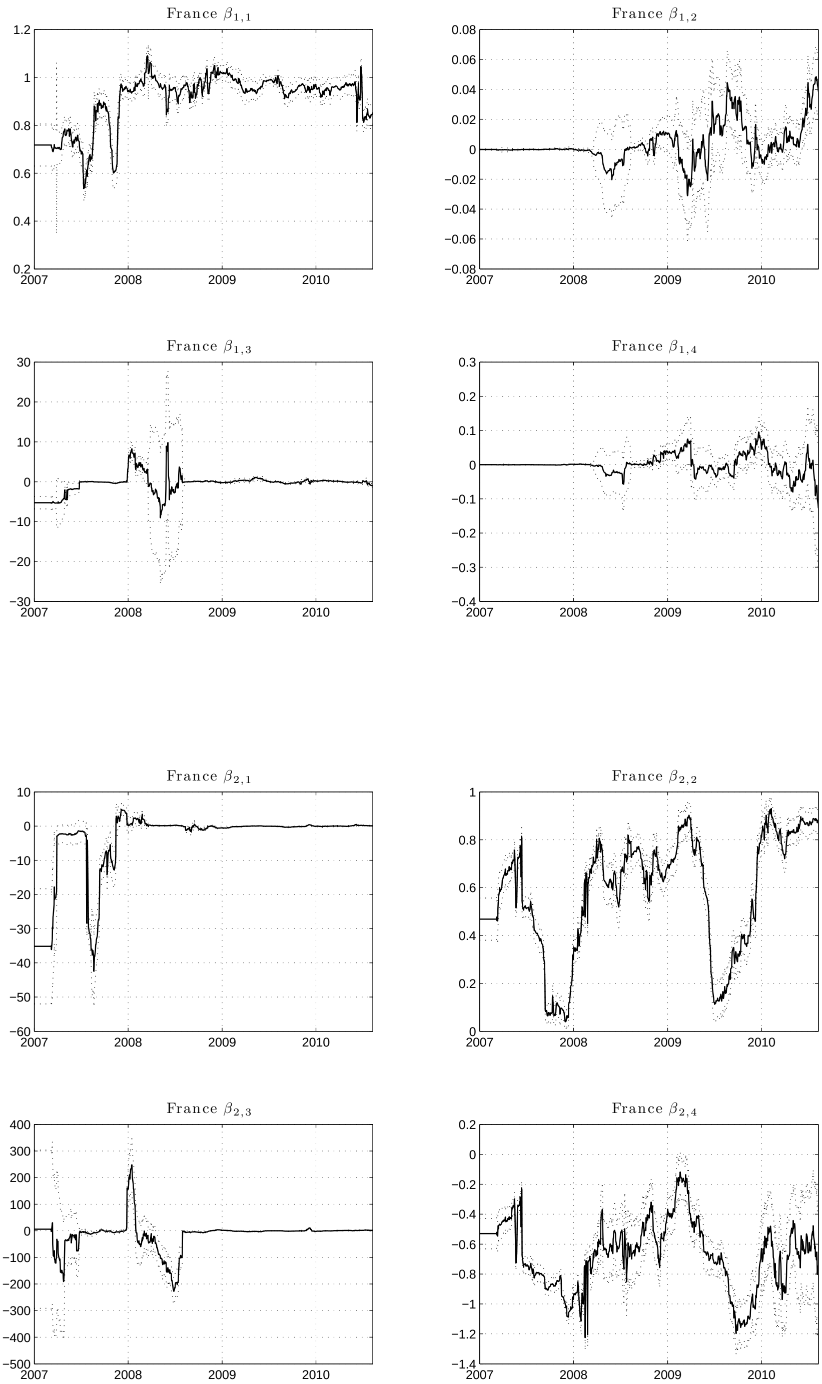

Figure A.4: Recursive Coefficients Betas: France

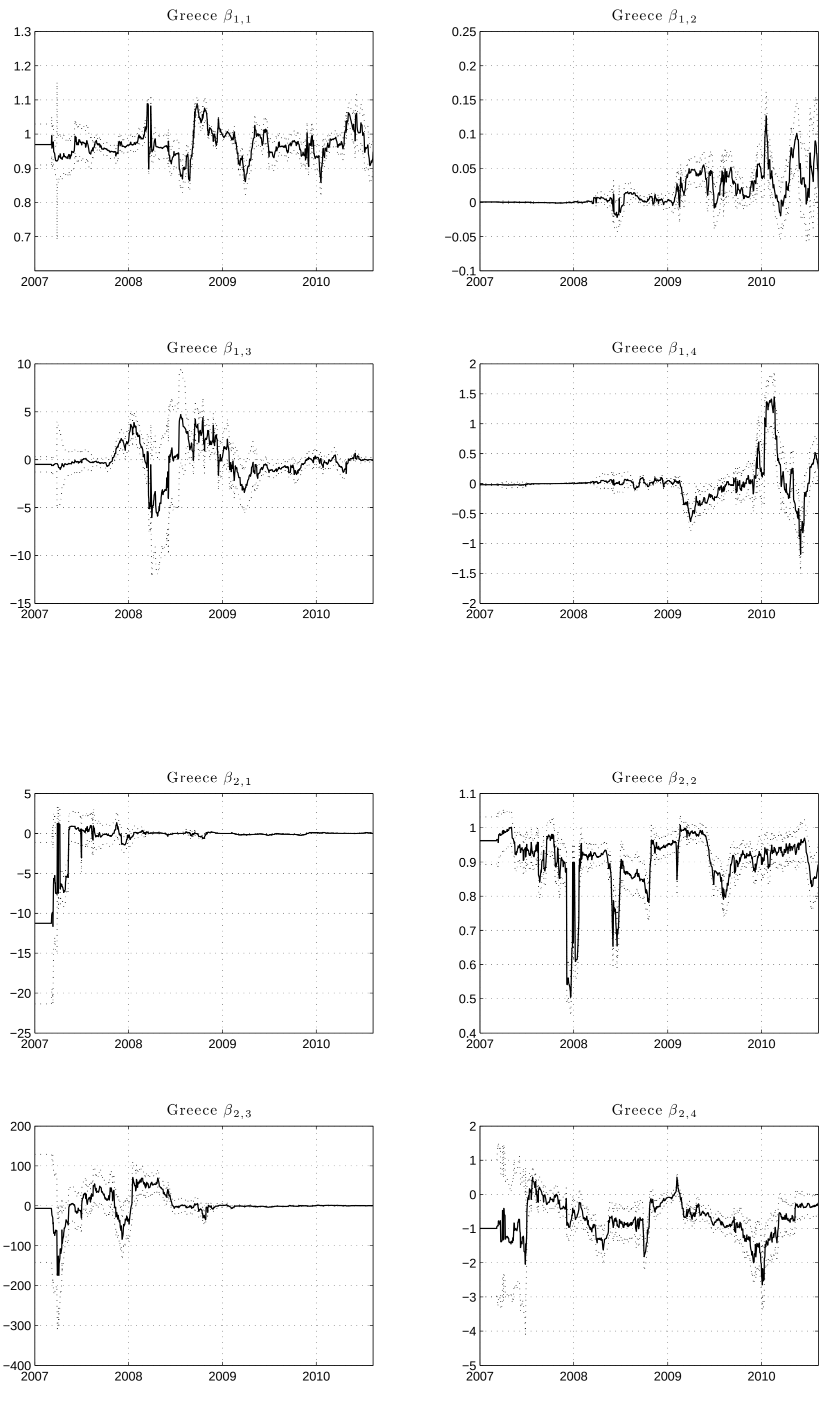

Figure A.5: Recursive Coefficients Betas: Greece

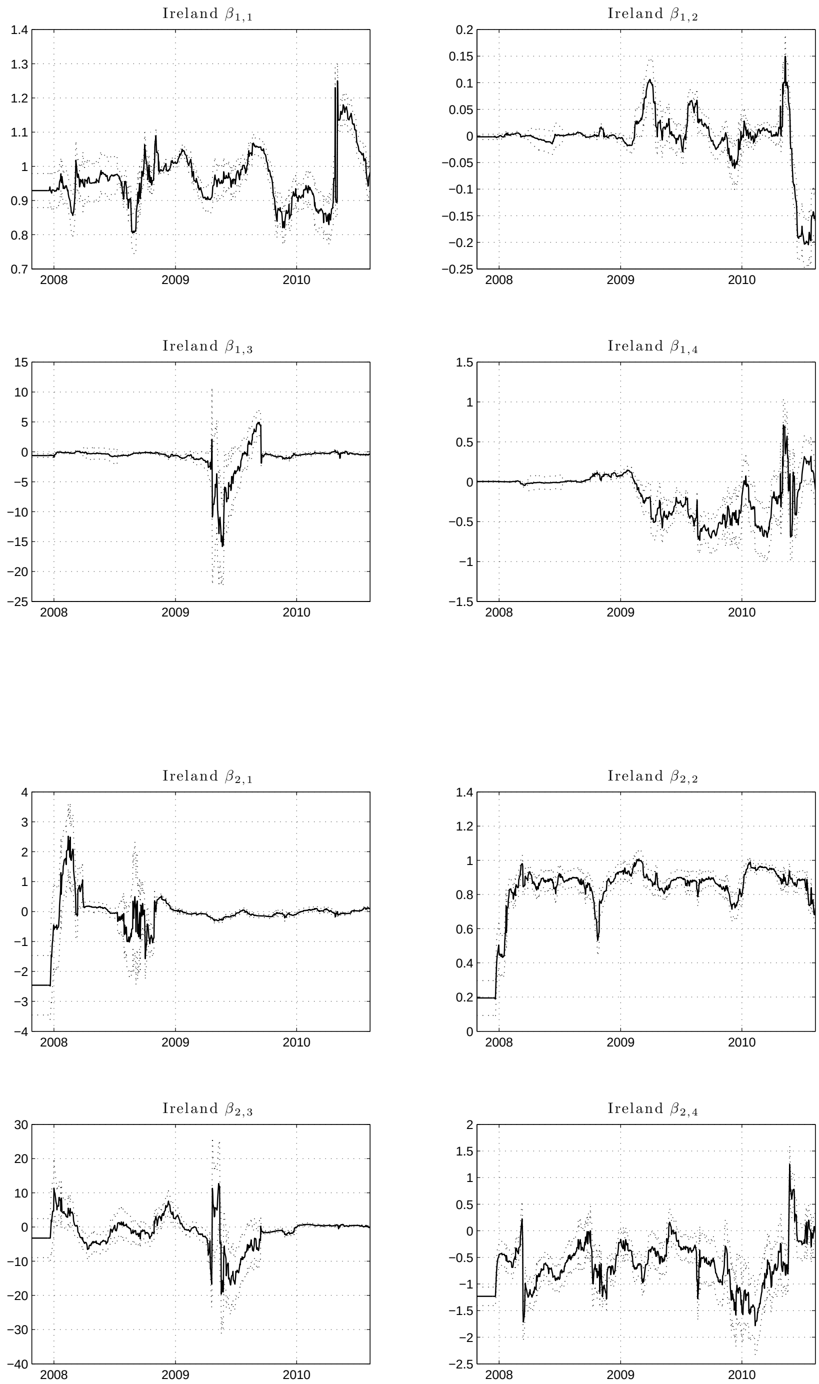

Figure A.6: Recursive Coefficients Betas: Ireland

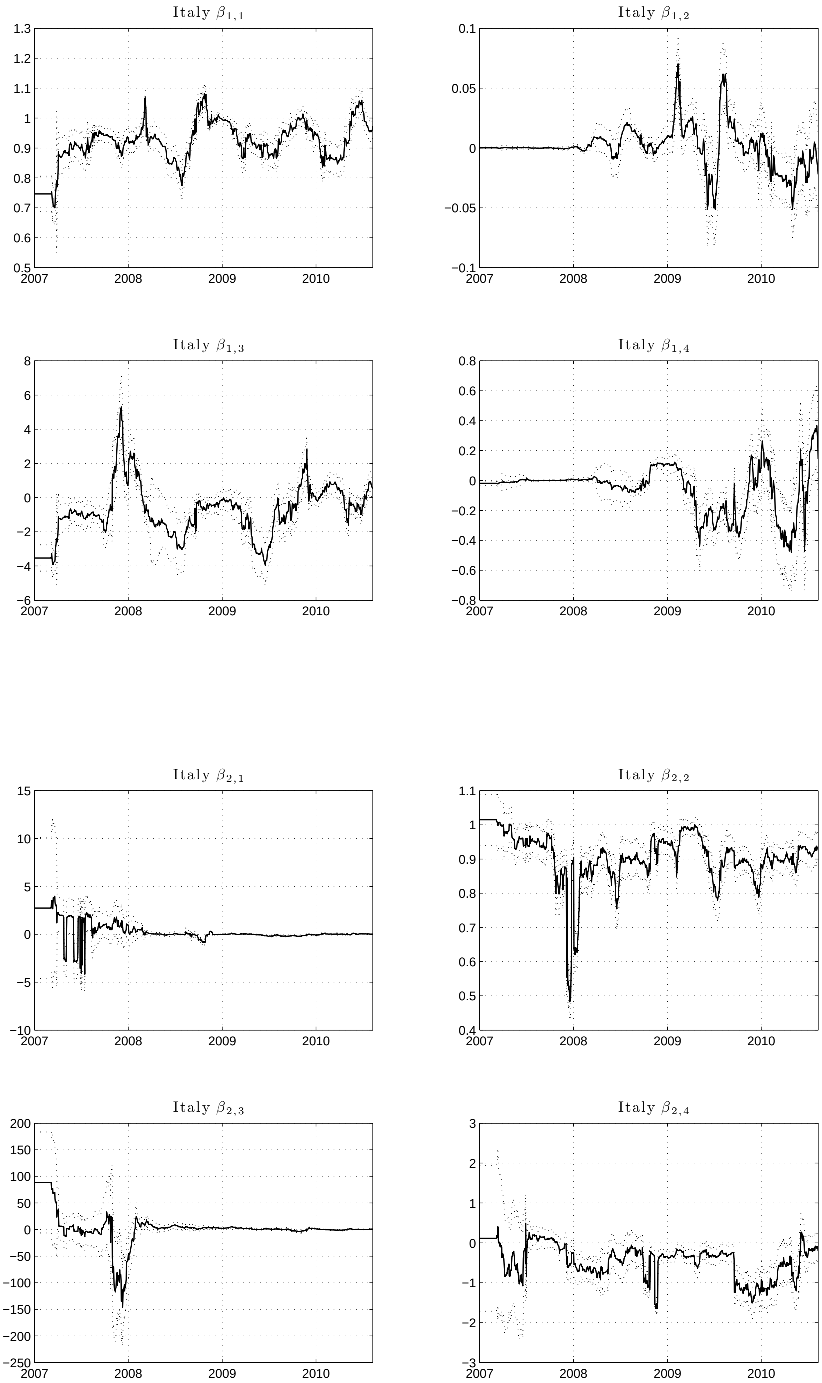

Figure A.7: Recursive Coefficients Betas: Italy

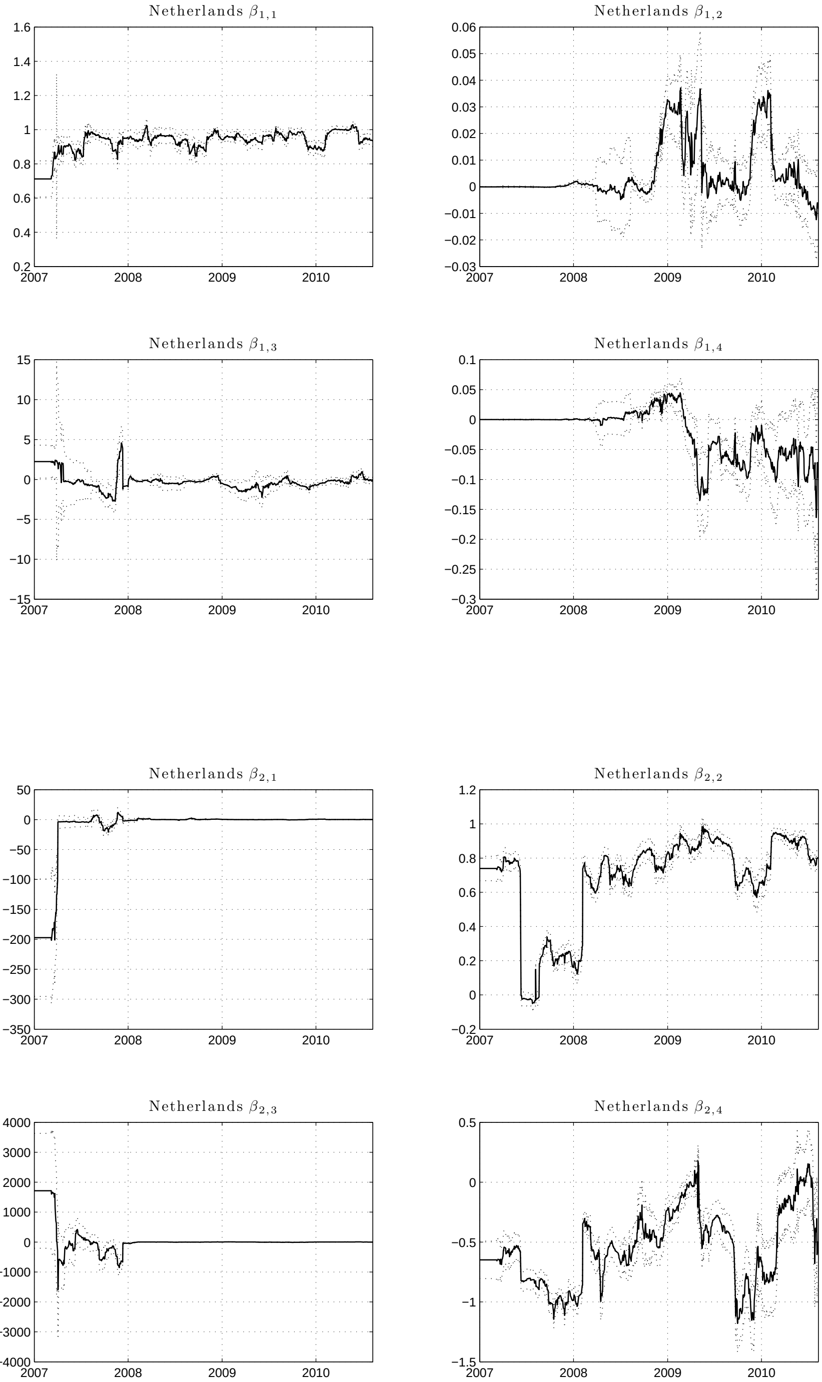

Figure A.8: Recursive Coefficients Betas: Netherlands

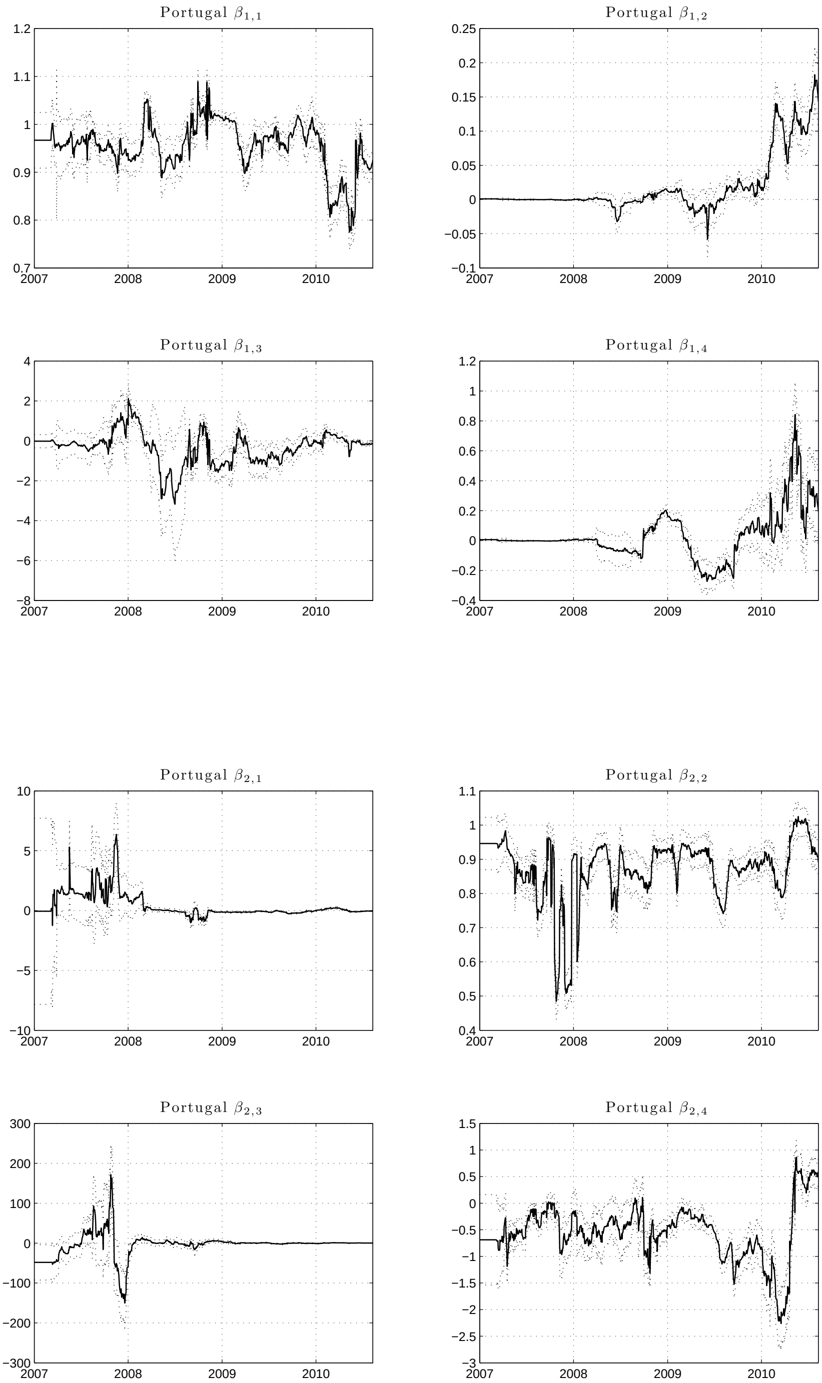

Figure A.9: Recursive Coefficients Betas: Portugal

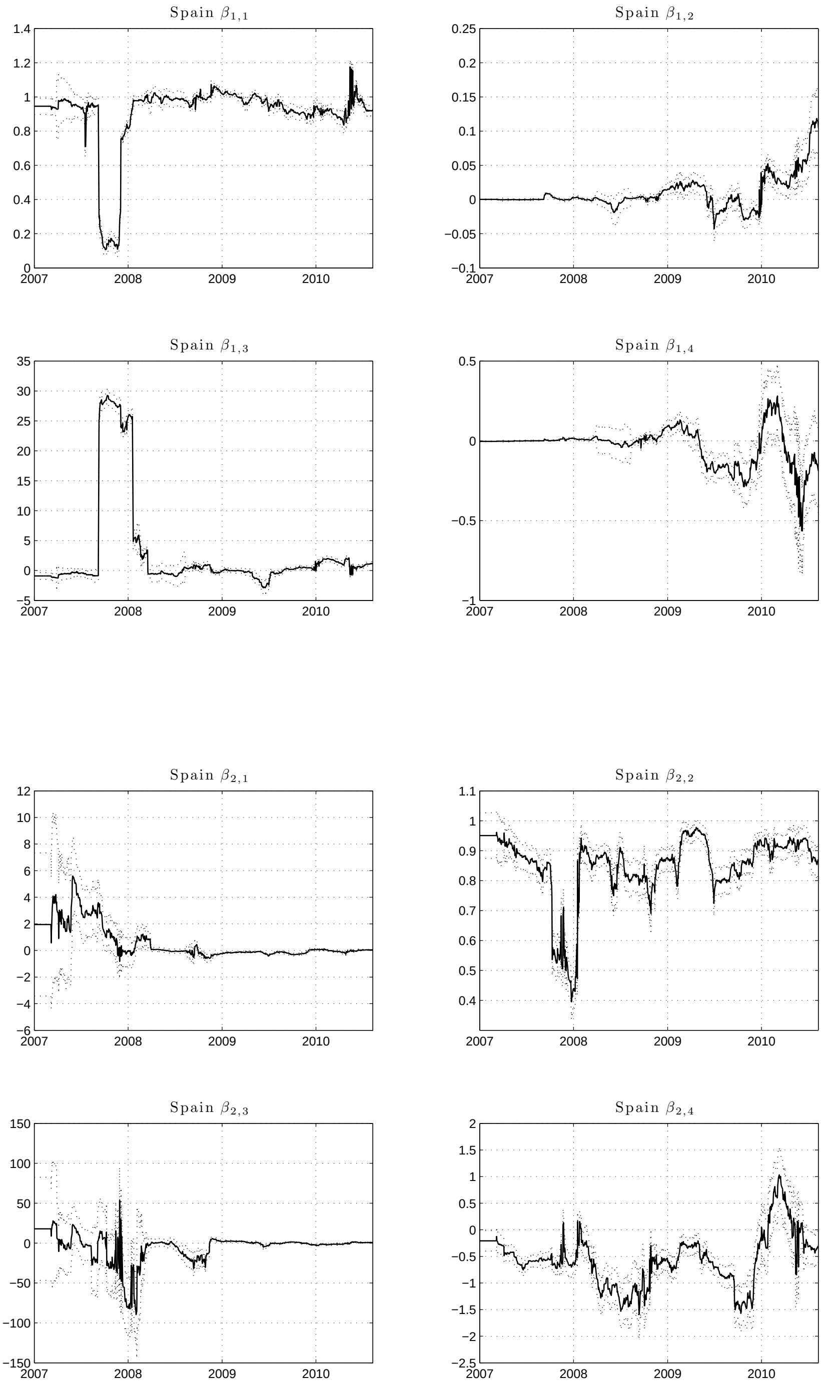

Figure A.10: Recursive Coefficients Betas: Spain

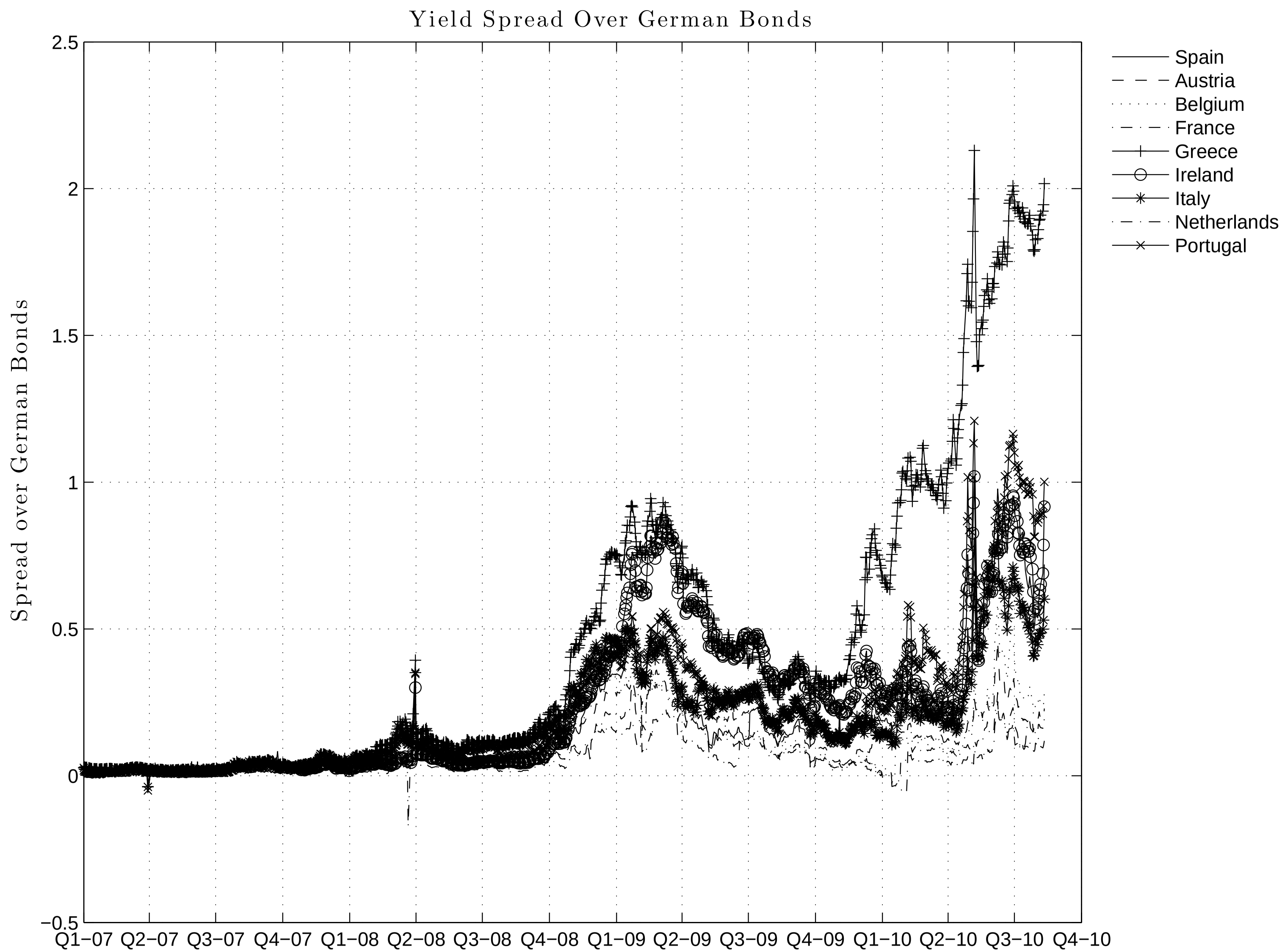

Figure B.11: Logarithmic ratio of Eurozone sovereign bond yields over German sovereign bonds yields, 5 to 10 years matched maturities

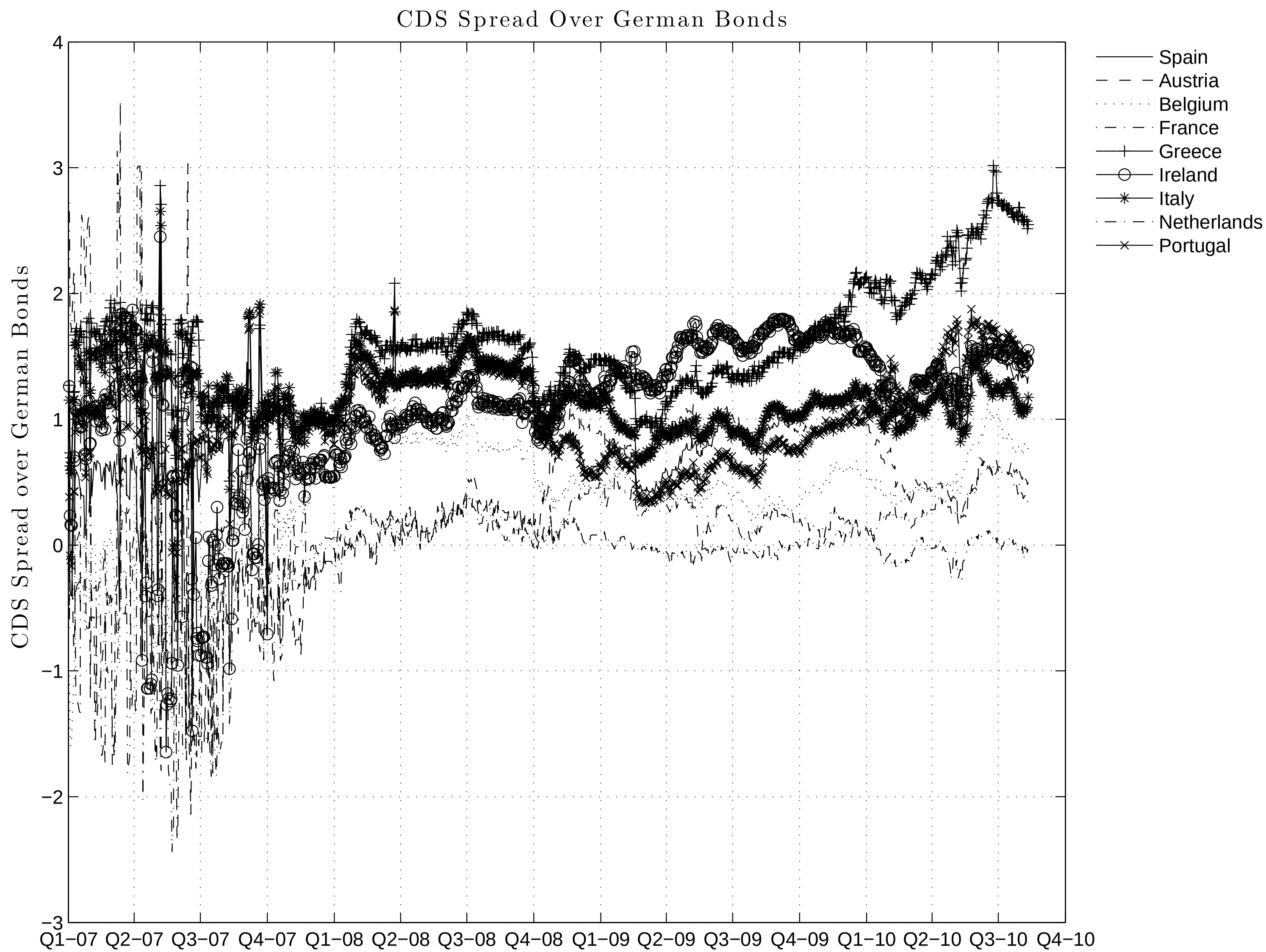

Figure B.12: Logarithmic ratio of Eurozone sovereign CDS yields over German sovereign CDS yields, 5 to 10 years matched maturities

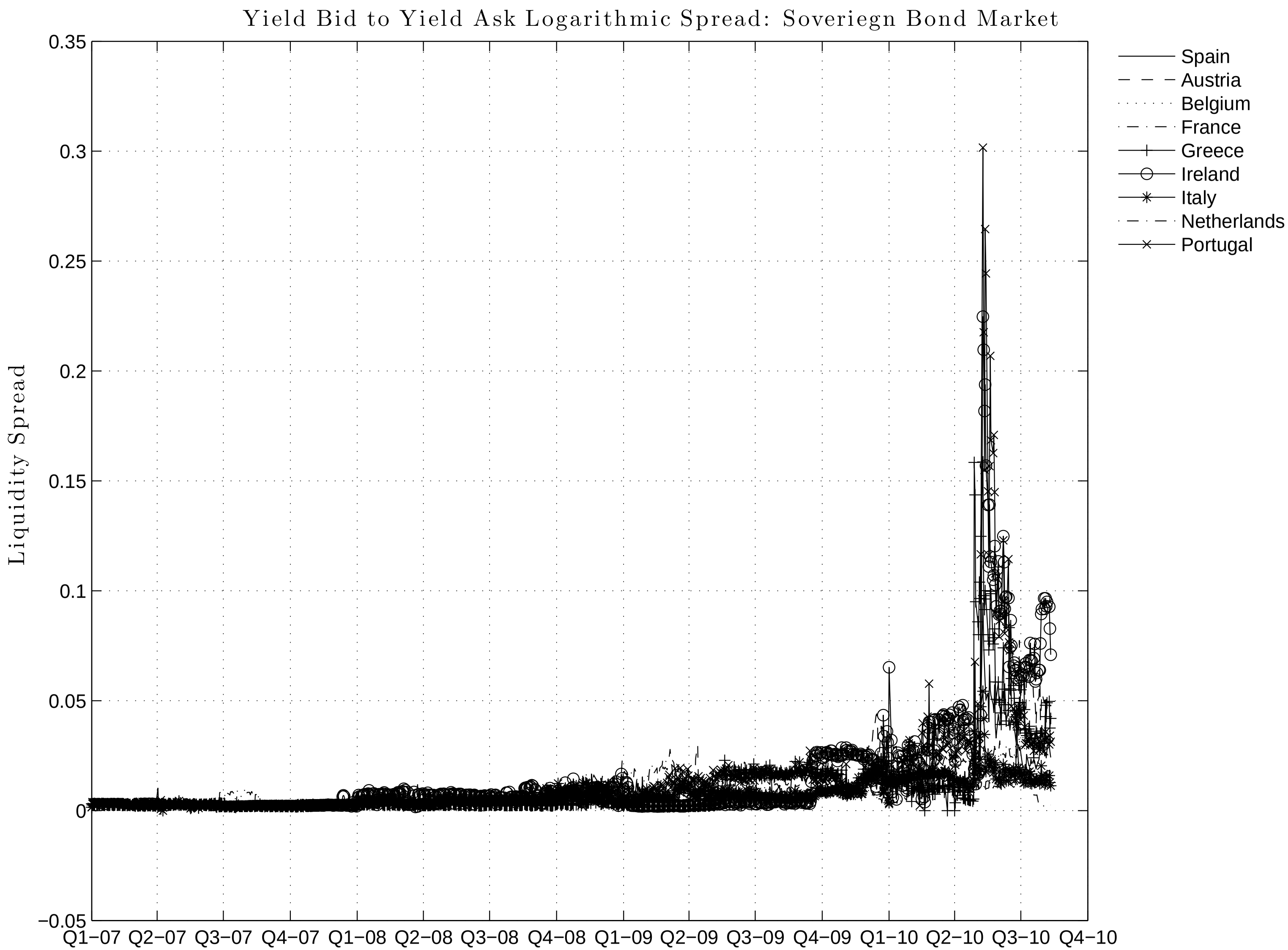

Figure B.13: Logarithmic ratio of yields bid to yields asked (offerred)

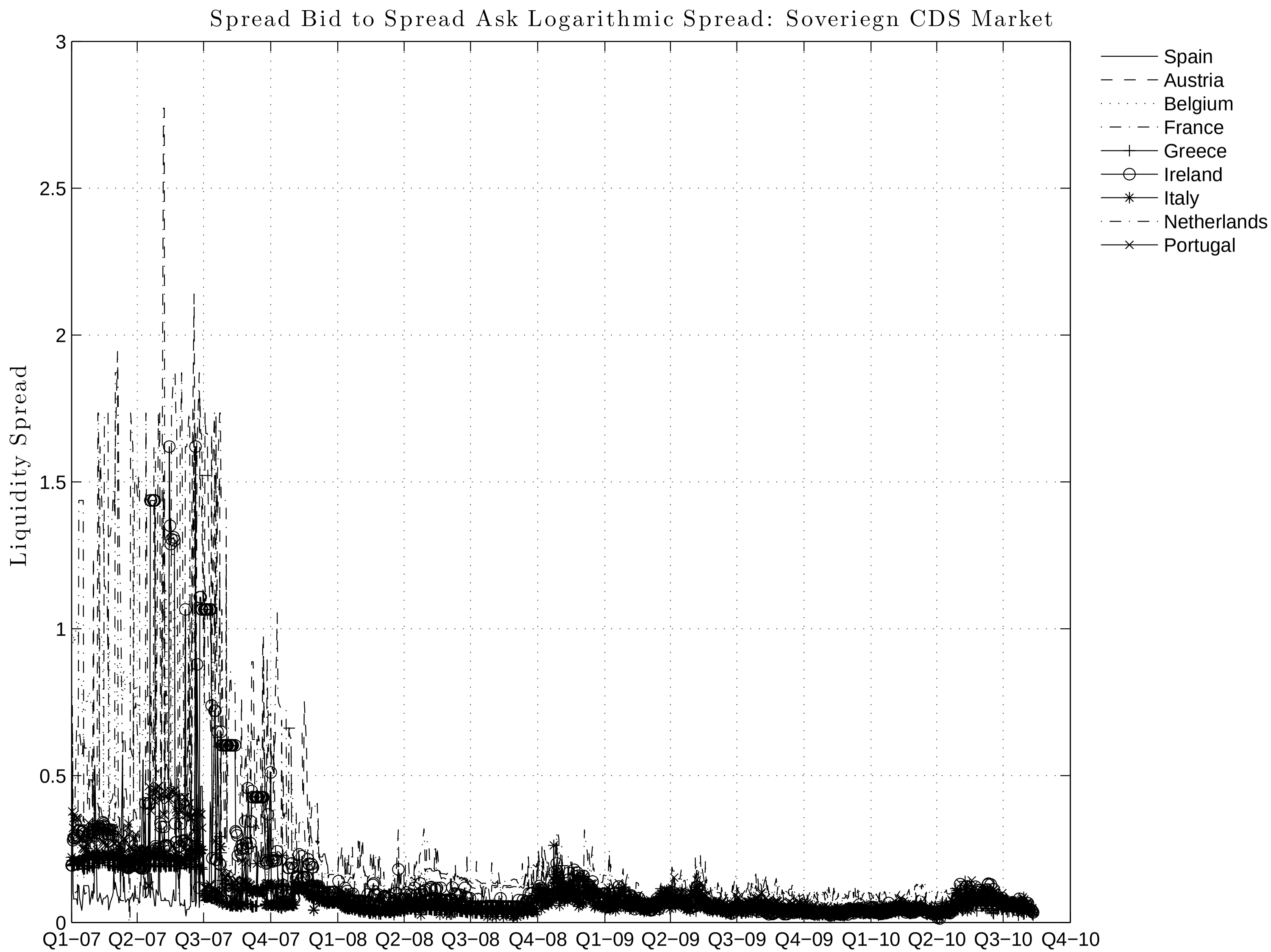

Figure B.14: Logarithmic ratio of spreads bid to spreads asked (offerred)