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Systemic risk in clearing houses: Evidence from the European repo market

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Abstract

How do crises affect Central clearing Counterparties (CCPs)? We focus on CCPs that clear and guarantee a large and safe segment of the repo market during the Eurozone sovereign debt crisis. We start by developing a simple framework to infer CCP stress, which can be measured through the sensitivity of repo rates to sovereign CDS spreads. Such sensitivity jointly captures three effects: (1) the effectiveness of the haircut policy, (2) CCP member default risk (conditional on sovereign default) and (3) CCP default risk (conditional on both sovereign and CCP member default). The data show that, during the sovereign debt crisis of 2011, repo rates strongly respond to movements in sovereign risk, in particular for GIIPS countries, indicating significant CCP stress. Our model suggests that repo investors behaved as if the conditional probability of CCP default was very large.

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1. Introduction

Central clearing counterparties (CCPs) are a fundamental component of the infrastructure of modern financial markets. In normal times, CCPs eliminate counterparty risk by inserting themselves between the buyer and the seller of an agreed-upon trade. They do so in exchange of imposing a collateral-specific haircut to member institutions, a contribution to their "default fund", and concentration limits (Duffie, 2015). As such, CCPs can help increase financial stability. But they are no panacea: While CCPs mutualize idiosyncratic counterparty risk in many ways, they remain vulnerable to financial crises. Given their size and centrality in the functioning of financial markets, their ability to withstand extreme financial shocks has become a first-order concern for all regulators around the world (e.g., Tucker, 2011; BIS, 2012; ISDA, 2013; Coeuré, 2014; DTCC, 2015). There is, however, little empirical evidence on how CCPs actually behave in times of crisis, and this study is an attempt to fill this gap.

In this paper, we examine how the CCPs backing the European repo market were affected by the Eurozone crisis of 2008-2012. In this market, sovereign bonds are used as collateral by banks to borrow overnight. This collateralized interbank lending market, which has become very large in recent years (with a daily volume of about €200bn in the Eurozone according to the 2015 ECB Money Market Survey), is crucial for the mutualization of liquidity shocks across banks. When sovereign crises arise, government bonds become worse collateral. This can affect the borrowing conditions on the repo market, which may in turn reduce interbank liquidity and weaken the banking system, as in Martin, Skeie and Von Thadden (2014). To mitigate such contagion from sovereign crises, regulators have recently encouraged market participants to systematically use CCP-cleared transactions. In the Eurozone as of 2013, such repo transactions represent 70% of the market total (ECB, 2013).

To examine whether the European sovereign debt crisis affected the European repo market through the build-up of stress in a major CCP, we focus on one large segment of repo transactions called "General Collateral" (henceforth GC). In this segment cash lenders commit to accept as collateral any bond from a given sovereign (for instance "Italian GC"). The focus on GC ensures that all market participants in our data are banks conducting similar transactions using a given sovereign as collateral. Our data cover the 2008-2012 period, and come from two trading platforms that match repo transactions anonymously. These transactions are then cleared via CCPs. Our sample account for a sizable part of the European GC repo universe: The daily volume is close to €50bn on average in our data, against a total volume of CCP-cleared European interbank repos of about €120bn (Figure 1).[1]

[Insert Figure 1 here.]

Our null hypothesis is that the CCP offers perfect protection against risk fluctuations of the underlying collateral. To test this hypothesis, we measure the extent to which shocks to sovereign collateral affect the repo rate. In a nutshell, our findings are consistent with the CCP-cleared repo market being immune against sovereign stress when the latter is moderate. In times of extreme sovereign stress, however, repo market participants appear to factor-in into their repo pricing the higher probability of CCP default conditional on sovereign default. Interestingly, increases in collateral-specific haircuts imposed by the CCP have no impact on the repo market, maybe because the instituted haircut changes are not sufficient enough.

To structure our empirical tests, we first develop a simple framework, in which cash lenders in a repo transaction have some exposure to collateral (sovereign bonds in our case). We use this framework to formalize the relation between sovereign CDS spreads and repo rates, making the simplifying assumption that the cash lender expects to *own* the sovereign

[1] The interbank market is mostly constituted of secured (i.e. repo, bilateral or trilateral) transactions. By comparison, the average daily volume on the unsecured interbank market is €40bn (ECB Money Market Study, 2015).

collateral if the CCP defaults. The model shows that this relation is stronger when (1) the default risk of CCP member financial institutions (i.e., banks that trade through the CCP) conditional on sovereign default increases, (2) CCP risk conditional on CCP member and sovereign defaults increases, and (3) haircuts are not high enough to eliminate these increases in risk. When, however, investors do not expect the CCP to default at all, the framework shows that the repo rate should not be sensitive to the sovereign CDS spread: This is our null hypothesis.

We then go to the data. In times of "moderate sovereign stress" (2009-2010), we are indeed unable to reject our null hypothesis: Repo rates are uncorrelated with the CDS spread of the underlying sovereign. In "high sovereign stress" times, however, repo rates become strongly correlated with CDS spreads. This relation is concentrated in the countries that were affected the most by the crisis, namely, Greece, Ireland, Italy, Portugal and Spain (hereafter, GIIPS countries). The same relation does not exist for the other Eurozone countries. We also find a similar negative connection, albeit weaker, between repo volume and CDS spreads. All in all, our findings suggest that in 2011 CCP default became priced by the market participants. This stopped to be the case in the first half of 2012 following the ECB's implementation of its 36-month Long-Term Financing Operation (LTRO) in December 2011.

Next, we use our simple framework to decompose the 2011 stress of the repo market into the contributions of (1) haircuts, (2) CCP members' default risk and (3) CCP default risk. Our decomposition suggests that investors perceived CCP protection to be fully effective in 2009-2010 but highly ineffective at the peak of the sovereign crisis in 2011. First, we look at the effect of haircuts, which in our framework reduce the connection between repo rates and CDS spreads. To evaluate the effectiveness of such policies, we run event studies around large changes in haircuts. We find that in 2011, haircut changes have no effect on the relation between sovereign CDS spreads and repo rates. Second, we look at changes in CCP member default risk *conditional* on sovereign default risk. We estimate this parameter by regressing bank CDS spreads on sovereign CDS spreads. We find that the risk of CCP member failure does not increase between 2010 and 2011. Hence, if the repo market appears more stressed in 2011, this does not seem to come from the fact that banks that are members of the CCP became riskier. Thus, it must be the case that investors perceived the conditional probability of CCP failure as higher in 2011 than in earlier years. In fact, our risk-neutral pricing framework suggests that market participants expected a very high probability of CCP default conditional on both CCP members and sovereign default. To confirm that the CCP was seen as offering little protection in 2011, we estimate the repo rate-to-sovereign CDS spread relation separately for a sample of bilateral trades that go through the trading platform but are not cleared by the CCP. We find that in 2011, repo rates in CCP-based trades were not less sensitive to sovereign CDS spreads than repo rates in bilateral trades. This suggests that, at that time, investors estimated the probability of CCP failure to be similar to counterparty risk in bilateral transactions.

We provide several robustness tests and examine alternative explanations for our findings. In particular, we show that the haircut policy of the ECB, which uses the repo market to conduct its monetary policy operations, does not explain our findings. We also explore a monopoly power explanation, in which concentrated lenders facing cash-short borrowers with collateral from GIIPS countries, can impose high borrowing rates on the repo market in 2011. The evidence we provide on the evolution of supply and demand on the repo market suggests that this is unlikely to be the main driver of our results.

Our paper contributes to the nascent literature on the role of CCPs, which focuses mostly on the particular case of derivative trading. CCPs provide insurance against counterparty default at lower collateral cost. This happens because CCPs are multilateral, and thus allow to internalize default externalities (Koepl, Monnet and Temzelides, 2012; Acharya and Bisin, 2014) and allow efficient use of collateral (Duffie and Zhu, 2011; Duffie, Scheicher and Vuillemey, 2014). But while CCPs provide efficient protection against idiosyncratic counterparty risk, they offer no intrinsic protection against aggregate risk and may even encourage risk-shifting (Biais, Heider, Hoereva, 2012). Due to their size and connections, they are likely to be systemically important and thus need to be monitored. Although recent papers have proposed econometric methods to estimate CCP risk, these have focused on derivative trading (Jones and Pérignon, 2013; Menkveld, 2015). Our paper develops an alternative approach to estimate the extent of CCP stress in the data, in the context of repo transactions. Our approach relies on the idea that market participants expect, in case of CCP default, that they will be exposed to the sovereign collateral. This is admittedly a strong assumption about the liquidation process, as the sharing of losses among CCP members in case of default was not very well defined during the period studied (Bank of England, 2011; Duffie, 2015; DTCC, 2015). It is however consistent with Variation Margin Gains Haircuts (VMGHs) advocated by many experts in recent years. More importantly, our assumption concerns the beliefs of market participants, rather than the actual liquidation process, and it is crucial to explain the sensitivity of repo rates to CDS spreads that we observe in 2011.

This paper also belongs to the larger literature on the repo market, in particular repo transactions motivated by cash lending or borrowing (as opposed to shorting of particular securities). Most recent work in this area has focused on the evolution of the US repo market during the 2008-2009 crisis (Gorton and Metrick, 2012; Copeland, Martin and Walker, 2014; and Krishnamurty, Nagel, and Orlov, 2014). The European repo market is different in two dimensions. First, while the US market is dominated by triparty repo (in which settlement, but not counterparty risk, is managed by a bank), transactions conducted on electronic platforms and cleared via a CCP predominate in Europe (ECB, 2013). Both markets are, however, similar in that they resisted well the financial crisis, with no significant decline in volume (see our Figure 1 and Copeland, Martin, and Walker, 2014). Second and most importantly, the European repo market is the main segment of the European interbank market, unlike in the US where the unsecured Fed Funds market dominates (Alfonso, Kovner, and Schoar, 2011). The European repo market is also where the ECB conducts its conventional and non-conventional monetary operations.[2] Importantly, it also plays a crucial role for financial stability, since it is the market where banks exchange liquidity. While several papers study stability via the network structure (see for instance Gai, Haldane, and Kapadi, 2011), our focus is different. In Europe, because public debt is the most common source of collateral on the repo market, sovereign crises have an additional power to contaminate the banking system.[3] The recent regulatory push towards centrally cleared transactions is an attempt to make this market more resilient: Our paper is a tentative evaluation of the possibility that CCPs may be a focal point of stress rather than a source of stability for the European interbank market, at least in extreme circumstances (see also Mancini, Ranaldo, and Wrampelmeyer, 2015, for a related study of a different market).

The paper proceeds as follows. Section 2 presents the institutional framework of the European repo market, data sources and the variables used in our analysis. In Section 3, we present our conceptual framework. We present our main results in Section 4, and in Section 5, we propose and test several explanations for the link between sovereign CDS spreads and repo rates. Section 6 discusses alternative explanations for our findings and concludes.

[2] Several papers focus on the microstructure of the ECB's main refinancing operations in normal times and in crisis (Bindseil, Nyborg, and Strebulaev, 2009; Cassola, Hortaçsu, and Kastl, 2013; Dunne, Fleming, and Zholos, 2011, 2013).

[3] This mechanism can contribute to the link between banks and sovereigns as more broadly discussed in several recent papers (Acharya, Dreschler, and Schnabl, 2014; Gennaioli, Marin, and Rossi, 2013), which focus on other transmission mechanisms.

2. Institutional background and data

2.1. The Repo Market

We focus on the role of CCPs in managing "General Collateral" repo transactions that are electronically and anonymously matched. We start with a brief description of this market.

A repurchase agreement (repo) is a loan collateralized with a security. Both parties (the cash lender and the security owner) agree on an interest rate, a maturity, and a haircut. The maturity is typically short (in our data, one day). The haircut is the percentage difference between the value of the security and the size of the loan (it is positive, so that the loan is overcollateralized). As a result, the interest rate is close to the safe rate of return. It may, however, fluctuate as a function of collateral risk, bank risk and insufficient haircut adjustments, as we explain in greater details below.

We restrict our analysis to "GC repos". Repo transactions are typically classified into "General Collateral" (GC) and "special". The latter are loans against a specific collateral (e.g., "Italian fixed-rate bond maturing in 2017"). Specials are often motivated by the desire to sell short a specific security in order to arbitrage the yield curve or manage dealer inventory (Duffie, 1996). In contrast, the GC repos are loans, typically short-term, whose collateral belongs to a certain predetermined list (e.g., "Italian government bonds"). The cash lender agrees to take any security from this list as collateral and is thus not looking to sell short a particular one. Instead, the objective of GC repos is to lend or borrow cash and not particular securities.

Not all repo transactions use a CCP. The repo market has several segments (Copeland et al, 2012): OTC bilateral, tri-party repos, and CCP-cleared. On the OTC market, both parties bear the counterparty risk and set the haircuts. Tri-party repos are operations in which a private bank organizes the settlement of the operations, but does not bear the counterparty risk. CCP-cleared repos are transactions in which -- besides offering settlement services -- a clearinghouse bears the counterparty risk and therefore sets the haircut centrally. The CCP inserts itself between the two counterparties: It borrows the security (and lends cash against it) from the cash-borrower, and lends the security to the cash-lender (and borrows cash in exchange). CCP clearing often comes with electronic trading services. Historically, the repo market was an OTC market intermediated by broker-dealers. Over time, electronic trading platforms that match lenders and borrowers anonymously became to dominate the market in the Eurozone. The use of these platforms often comes with attached CCP services. Our data come from such platforms.

The segmentation and motivation for repos are not the same in the US and in Europe. The two markets are of comparable size, although it is difficult to make accurate comparisons due to the presence of bilateral and triparty segments. As of May 2012, the US repo market is estimated to be $3.04 trillion (Copeland et al, 2012), while the Eurozone repo market is estimated to be €5.6 trillion as of June 2012 (based on a survey of 62 large banks by ICMA, 2013). These measures are subject to double-counting but they suggest similar sizes. However, the US market is dominated by triparty repos, which account for 53% of the market as of May 2012. In Europe, CCP-cleared repos dominate: According to a survey of 149 banks by the ECB (ECB, 2015), CCP-cleared repos account for 66% of the total in 2012. Another important difference between the European and US markets is that, while the US repo market is mostly used to finance the shadow banking system (Krishnamurthy, Nagel, and Orlov, 2014), banks are very active in European repo markets (Mancini, Ranaldo, and Wrampelmeyer, 2015). This difference can be explained by European banks' tendency to hold more government bonds in their securities portfolios. The repo market is also where the ECB tends to conduct its routine monetary policy operations (see for instance Cassola, Hortacsu and Kastl, 2013).

2.2. Data

2.2.1. Transaction data

Our data come from two large electronic platforms (ICAP BrokerTec and MTS repo) and cover the period from January 1st, 2008 to June 30, 2012. ICAP BrokerTec provides us with the bulk of the data, but does not cover repos based on Italian government collateral. For Italian GC, we thus rely on data from MTS Repo, which is the main electronic repo platform for that country. For both platforms, our raw data contains all repo transactions. For each transaction, our data report (1) whether the transaction is GC or special, (2) the nature of the underlying collateral (say, German vs French government debt), (3) whether the transaction is CCP-cleared or not, (4) the date of the repo transaction and its maturity, and (5) the interest rate and the amount.

We restrict our analysis to GC repo transactions that use sovereign bonds from Eurozone countries as collateral. In these transactions, the lender is allowed to provide any collateral from the GC list, which is considered to be safe enough to warrant cash lending at the repo rate. The GC list is country-specific, that is, in an Italian GC repo contract the collateral has to be an Italian sovereign bond. As shown in Figure 1, MTS and ICAP GC repos represent a daily volume of little less than €50bn during the period, which is estimated by the ECB to reach an overall daily volume of approximately €200bn.

Since our focus is on the role of CCPs, in most of our analysis we restrict the sample to CCP-cleared transactions. Sometimes, counterparties choose to sign bilateral contracts rather than going through CCPs, but this is not the norm. Most of the time, electronic transactions are CCP-cleared. Counterparties trading through ICAP need to clear transactions through LCH.Clearnet Ltd.[4] Counterparties trading Italian GC through MTS have to use Cassa di Compensazione e Garanzia SpA (CC&G). The fact that in our data Italian GC is cleared via a different CCP does not seem to play a role: We have checked that our main results are not affected when we exclude Italy from the tests. We can distinguish CCP-based and bilateral transactions in the ICAP database and in the MTS database in 2010-2012. The MTS dataset does not allow this distinction in 2008 and 2009. We thus simply assume that all pre-2010 Italian repo transactions are CCP-based.[5] Based on this convention, we find that 85% of the transactions turn out to be CCP-cleared in our data over the entire period (and 80% in the post-2009 period, in which the exact information is available for both MTS and ICAP). We focus on these transactions for our main results (in Section 4), but we return to the bilateral / CCP distinction in additional tests (in Section 5).

In terms of maturity, we restrict our analysis to one-day repo transactions, which represent about 97% of total volume in our data.[6] These one-day transactions are denoted as "overnight", "tomorrow next" and "spot next" depending on the day of delivery.

[Insert Table 1 here.]

We collapse our trade data into daily observations of GC rates per sovereign collateral. We have GC trades for 11 countries (Greece, Ireland, Italy, Portugal, Spain; Austria, Belgium, Germany, Finland, France, the Netherlands). For each day and each country, we compute two variables. The daily country-level repo rate is the volume-weighted average interest rate on one-day, CCP-cleared, repo transactions. The GC volume is the sum of all

[4] The only exception is French GC, which is cleared via LCH.Clearnet SA, but this CCP is itself an affiliate of LCH.Clearnet Ltd.

[5] This assumption seems reasonable given the increasing predominance of CCP-based over bilateral transactions, but it inevitably makes our data noisier. To ensure that this does not affect our results, we present our main results excluding Italy in a robustness test (in appendix Table 1, Panel B). Doing so does not affect our conclusions.

[6] There are no maintenance margins for 1-day repos, for which only the initial haircuts matter. Moreover, in one-day repos the uncertainty regarding default premium of the underlying sovereign bond is also reduced to a minimum (compared to, say, 1- or 3-month repos).

transactions for a given country. In subsequent tests, we ignore daily observations with missing repo rates, except in the tests of Section 4.3, in which we analyze repo volume and assign a volume of 0 to days with missing repo rates. Table 1 reports summary statistics for repo rates and volume for the entire sample period (January 2008 to June 2012) and for the four subperiods we consider in our tests: "Normal times" (January 2008 to Lehman Brothers' bankruptcy on September 15, 2008); "Sovereign stress times" (January 2009 to December 2010); "Sovereign crisis times" (January 2011 to the day before the 36-month LTRO on December 20, 2011); and "post-LTRO period" (January to June 2012).

[Insert Figures 2 and 3 here.]

Figure 2 presents the evolution of daily volumes (averaged by month) of repo transactions for two groups of countries: GIIPS countries (Greece, Italy, Ireland, Portugal, and Spain), and non-GIIPS countries (Austria, Belgium, Finland, France, Germany, and the Netherlands). The average daily volumes have the same order of magnitude, but the volume of GIIPS repos goes down from about €35bn in 2008-2009 to about €20bn in June 2012. Non-GIIPS repo volumes are stable at around €20bn. Figure 3 provides a more detailed breakdown by country (note that each panel uses a different scale). Panel A reports trading volume for Italy, France and Germany. These three countries are over-represented in our dataset. Altogether, the total trading volume on their repo markets is about €30bn per day. Panel B of Figure 3 reports numbers for Austria, Belgium, Spain, Finland and the Netherlands. In this second panel, trading volume is never zero but it is of smaller scale (approximately €1bn per day on average, with peaks at about €4bn to €6bn for Belgium, Spain and the Netherlands). Panel C shows volume for the three countries that eventually went through a bailout program (in March 2010 for Greece, November 2010 for Ireland, and April 2011 for Portugal). These countries' repo markets shut down entirely as soon as their banks obtain financial assistance.

For countries that enter a bailout program during our sample period, we exclude all observations in and after the month of the bailout program.

2.2.2. Sovereign and bank risk data

We match our repo data with each country's daily credit default swap (CDS) rates from Datastream using the five-year senior CDS series (*Sovereign CDS* in our tables). We also estimate default risk for banks in a given country using the simple average of (five-year) individual bank senior CDS rates to the extent they are available on Datastream. We report summary statistics on bank and sovereign CDS spreads in Table 1, for the entire period and for each subperiod separately.

2.3. The unfolding of the Euro crisis in our sample

This section provides a short description of the data and preliminary evidence that the repo market was affected by the developments of the European sovereign crisis. This is in spite of the fact that the segment we consider is backed by a CCP supposed to insulate market participants from default risks that affect similar OTC transactions. This observation, which we refine in the subsequent sections, constitutes our main finding.

[Insert Figure 4 here.]

We report in Figure 4 the repo rates of GIIPS and non-GIIPS transactions over the period that we study (2008-mid 2012). For comparison purposes, we also reproduce the ECB rate corridor (the deposit rate, which is the lower bound, and the lending facility rate, which is the upper bound). In normal times, the repo rate follows the main ECB policy rate, because the ECB's interventions (called Main Refinancing Operations, or MROs for short) are auctions with partial allotment whose goal was to align the repo rate with the main policy rate (see Cassola, Hortaçsu, and Kastl, 2013, for a description). After October 2008, the ECB greatly expands the size of its interventions (auctions change from partial to full allotment), so that the repo rate converges quickly to the deposit rate. In mid-2010, the Greek sovereign crisis becomes more acute, and all repo rates increase again, up to 50bp above the ECB deposit rate although the ECB does not scale down the size of its MROs. In the summer of 2011, the sovereign crisis spreads to Italy and Spain, and the repo market separates into two: GIIPS repos remain about 50bp higher than the deposit rate, while non-GIIPS repos fall. This situation lasts for about half a year, until the two rates become realigned with the lower bound of the corridor at the end of 2011 (we argue in Section 5.4 that the timing coincides with the implementation of the 36-month LTRO of December 2011).

Over the entire period, the average repo rate is not stationary (the Dickey-Fuller test fails to reject the unit root hypothesis at 89%). In our empirical analysis, we deal with the non-stationary nature of the series using two approaches. First, our focus on four separate subperiods (2008-Lehman, 2009-2010, 2011, 2012S1) helps. During each of these subperiods except the first one (which is not the focus of our paper), Dickey-Fuller statistics clearly reject the unit root hypothesis, and the time series show no statistically significant trend. Second, in all our specifications we use the difference between the repo rate and the ECB deposit rate. This difference is theoretically motivated (see our next section), and is stationary both within each subperiod and over the entire period.

[Insert Figure 5 here.]

Figure 5 displays the evolution of average sovereign CDS spreads of GIIPS and non-GIIPS countries. In line with the evolution of the repo market, CDS spreads for the two groups of countries move very closely until the Greek crisis erupts in the beginning of 2010. The two groups start to drift apart but the difference remains moderate until the spring of 2011 (when Portugal officially requires EU assistance to fund its sovereign borrowing). Between mid-2011 and the end of 2011, GIIPS CDS spreads increase from 5 to 25%, while non-GIIPS CDS remain essentially flat. The divergence in CDS rates coincides with the divergence in repo rates during this period.

[Insert Figure 6 here.]

The above observations suggest a correlation between CDS spreads and repo rates, at least in GIIPS countries. This is surprising, given that all transactions that we consider are CCP-cleared and therefore in principle insulated from default risks. Before we investigate this more deeply, we note that this finding is not present in aggregate data, which justifies our analysis at the country-level. In Figure 6, we show how the average repo rate and the average CDS spread correlate. We take the difference between the repo rate and the ECB deposit rate to make the series stationary. Then, we compute the average sovereign CDS spread and the average adjusted repo rate, each day, across all 11 countries in our sample. We obtain a time series of 1,149 daily observations, which we plot in Figure 6. We find that the time-series relationship between repo rates and sovereign risk is actually negative and statistically significant (in particular in 2009 and 2011). Hence, aggregate repo rates do not seem to react to sovereign stress. If anything, they react negatively, i.e., repo borrowing becomes cheaper in times of stress. This happens because the aggregate repo rate in our data mixes GC rates on GIIPS and non-GIIPS countries.

In subsequent tests we exploit the country-by-country variation to refine the test on aggregate data. As it turns out, we find a sharp contrast between the reactions of repo markets to the Eurozone sovereign crisis in GIIPS vs. non-GIIPS countries. Our conceptual framework suggests a channel that is consistent with these results: during periods of significant sovereign stress, the probability of CCP insolvency (conditional on sovereign and member banks defaults) increases.

3. Explaining repo rates: A conceptual framework

3.1. Assumptions

To analyze the pricing of repo loans, we start from a stylized risk-neutral no-arbitrage model. Assume that cash lenders arbitrage between overnight lending on the repo market at r^{REPO} and lending with no risk to the ECB at the deposit rate r^{ECB}. Repo lending of P(1-h)€ is collateralized with P€ of sovereign bonds, where *h* is the haircut and P the price of the bond. The sovereign bond defaults with probability π, in which case the bondholder incurs a loss given default (LGD) of *x*, which is a random variable with c.d.f. F().

In the data, repo rates and collateral risk are strongly related in times of crisis. For such a link to arise, we need to assume that the cash lender is exposed to the collateral in some states of nature. These states of nature necessarily happen when the CCP defaults. To see this, imagine that the CCP never defaults. In this case, repo lending is always safe and at equilibrium $r^{REPO} = r^{ECB}$. Such a model cannot explain the repo rate-to-sovereign CDS spread sensitivity that we document in Section 4. By contrast, if the cash lender becomes exposed to the collateral when the CCP defaults, then she will price this exposure and the repo rate will be sensitive to collateral risk.

To rationalize the results, we thus need to make the following assumption:

Assumption 1. In case of CCP failure, the lender owns the collateral.

During the period of our study (2008-2012S1) liquidation in case of CCP failure is not very well defined, but the practitioner literature, as well as informal interviews with CCP employees, suggest that this is a credible assumption. We defer the discussion on the plausibility of this assumption to Section 3.3.

3.2. Set-Up

In the absence of sovereign default, the lender is made whole as long as daily fluctuations of the bond price are below the haircut. We assume, accordingly, that the haircut policy is set conservatively enough to absorb such price movements. However, in the alternative scenario, conditional on sovereign default, the expected LGD on 1/(1-h) € of bond is thus $\int_h^1 (x-h)dF(x)/(1-h) = G(h)$. G(.) is a decreasing function of h: bigger haircuts allow to minimize the loss in case of default.

Denote p the probability of CCP member default *conditional* on sovereign default. "CCP member default" is a general term that means the default of one or several banks that trade through the CCP and that are big enough to require a large-scale intervention by the CCP to settle their transactions, which can ultimately cause the failure of the CCP itself.[7] This probability p can be estimated for instance by regressing bank CDS spreads on sovereign CDS spreads as in Acharya, Dreschler and Schnabl (2014), something we also do in Table 7. Finally, we denote λ the probability that the CCP defaults, *conditional* on both CCP members and sovereign defaults. As in Krishnamurthy, Nagel, and Vissing-Jorgensen (2013), we rely on risk-neutral probabilities rather than the true physical probabilities of default.

Because lenders always have the choice to lend to ECB at the deposit rate, a no-arbitrage condition implies:

$$r^{ECB} = (1-p\lambda\pi)\, r^{REPO} - p\lambda\pi G(h) \qquad (1)$$

which, after straightforward manipulation and first order approximation, leads to:

[7] Modelling the conditional failure of member banks is not necessary since these do not directly affect the cash lender, as counterparty failure would in a bilateral transaction. However, considering the failure of CCP members allows us to describe more realistically the chain of events leading to the failure of the CCP - from sovereign default to member defaults to CCP default. Moreover, this allows us to motivate the tests of Section 5, in which we consider separately the change in bank risk and the change in perceived CCP risk as possible factors driving the strong link between sovereign CDS spreads and repo rates in 2011.

$$r^{REPO} = r^{ECB} + (p\lambda G(h)/G(0)).(\pi G(0)) \quad (2)$$

Equation (2) is a no-arbitrage condition that allows us to think about the pricing of repo lending. It states that the repo rate should be a function of the sovereign's probability of default π.

This simple framework allows us to interpret the results of our regressions, in which we regress the repo rate on sovereign CDS spread. The sovereign CDS spread measures $\pi G(0)$, i.e., the probability of default π times the expected loss given default $\int_0^1 x dF(x) = G(0)$ for €1 of bond. As a result, our regressions allow us to obtain an estimate of $p\lambda G(h)/G(0)$, which measures the conditional probabilities of default of the CCP and its member banks, as well as the LGD given the haircut. This will be our main empirical strategy.

Finally, note that our framework only allows us to measure the market's perception. The repo rate to CDS sensitivity may increase because market participants become more risk averse. It may also increase because traders hold excessive beliefs that the CCP may fail. Thus, we cannot discard "behavioral" explanations, although we cannot prove them either. It is important to bear in mind, however, that λ is a *conditional* probability. It is closer to a correlation (between CCP failure and sovereign default) than to the unconditional belief that the CCP will fail.

3.3. What happens in case of CCP failure?

We discuss here our assumption 1 that, in case of CCP default, the lender becomes owner of the collateral. First, notice that CCP failure is a plausible event. When one or several members default, CCPs typically have buffers that consist of default funds and capital reserves (equity). As long as these buffers are sufficient, non-defaulting members face no loss on their margin accounts. Such events correspond to CCP "non-failure" in the model, since lenders get repaid fully. But in case of a major crisis, these buffers quickly become too small. For instance, as of December 2011, LCH.Clearnet (which clears all non-Italian repos in our data) only had a single default fund, of approximately €680m, for all its clearinghouse activities (both repo and derivatives). This is to be compared with an average daily volume of €17bn on the repo market in our data, excluding Italy. Assuming that 8% of the transactions default, and a 50% haircut on their collateral, the entire default fund would be wiped out.[8] Hence, the default of two medium-sized members concurrent with the default of their related sovereign is a shock big enough to exhaust the default fund of LCH.Clearnet.

Second, in case of CCP default, lenders get a fraction of the value of their collateral. This is called "end of waterfall loss sharing". When default funds are insufficient to absorb all losses, the remaining contracts are "torn up" (see for instance Table A.1. in Elliott, 2013). Then, a haircut is applied to all positions. This haircut reflects the mismatch between positive and negative positions due to the default of some members. It is also a function of the value of the underlying collateral of each lender. Lenders with worse collateral receive a smaller fraction of their claim, which is the spirit of VMGH for derivatives (see Eliott, 2013 or Duffie, 2015). This makes the payoff of lenders sensitive to the value of the collateral in case of default. This allocation rule was confirmed to us by a risk manager at LCH.Clearnet.

Finally, our assumption (that the cash lender becomes exposed to collateral in the event of CCP default) can be understood as a way to incorporate *beliefs* of market participants about the resolution procedure, rather than the procedure itself. For instance, end-of-waterfall

[8] A similar order of magnitude is valid for CC&G, the CCP clearing Italian repos in our data. At the end of 2011, CC&G had a default fund for bonds of €1.1bn. With an average daily volume of Italian repo of €26bn, defaults on about 9% of the transactions along with 50% haircuts on collateral would be enough to exhaust the default fund.

loss sharing rules were not precisely codified in 2011.[9] So it seems reasonable to assume that market participants were behaving as if lenders would be exposed to the collateral in case of CCP default, as it is the case today. Several informal conversations that we had with repo traders suggested that they were subject to sovereign exposure limits set by their institutions' risk management departments (for instance, "not more than €500m of Italian paper"). Such anecdotal evidence suggests that risk managers of, at least, several large repo dealers, thought that lending cash against a particular sovereign collateral exposed the bank to this country's debt, which is consistent with our assumption 1.

4. Main results

4.1. Sovereign default risk and repo rates

In the spirit of Eq. (2) we run the following regression, for country c, at date t:

$$r^{\mathrm{Repo}}_{c,t} - r^{\mathrm{ECB}}_{t} = \alpha_c + \delta_t + \delta_{c,m} + \beta.\mathit{Sovereign\ CDS}_{c,t} + \varepsilon_{c,t} \qquad (3)$$

where the dependent variable is the spread between the repo rate of country c and the ECB deposit rate, which is our measure of the safe rate of return. The coefficient of interest is β, the sensitivity of the repo rate to the sovereign CDS spread. According to the no-arbitrage equation (2), β contains the *joint* effect of (i) the conditional default probability of the CCP (λ), (ii) the conditional default probability of CCP member banks (p), and (iii) the haircut policy (h). Our null hypothesis is that haircuts are conservative even in case of sovereign default, and/or that the CCP is resilient enough to ensure that β=0.

[9] For instance, the Bank of England acknowledged in 2011 that "CCPs do not generally have formal arrangements for allocating losses that exceed their default resources […] If a CCP were to fail, residual losses would fall on participants (as creditors) and it is likely any allocation would occur in a way that was difficult to predict with certainty and could take a considerable period of time." (Financial Stability Report, December 2011, p.53).

In our baseline specification, the regression also includes country fixed effects (α_c) and time fixed effects (δ_t) to account for movements in the common factors affecting the European repo market. We cluster error terms $\varepsilon_{c,t}$ at the daily level across countries. To make sure we are identifying β on high-frequency comovements of sovereign CDS spreads and repo rates, we also report regressions with country-month fixed effects $\delta_{c,m}$. This allows us to force identification on daily variations within the month. Finally, note that the average excess repo rate (the average of $r^{Repo}{}_{c,t} - r^{ECB}{}_t$ across countries) is a stationary variable, in particular if we focus on the post-Lehman period. The Dickey-Fuller (DF) statistic over the entire period is -2.9, which allows us to reject the unit root hypothesis at the 4%-level. If we focus on 2009-2012S1, the DF statistic becomes -4.8, which rejects the unit root hypothesis at less than 0.01%. As we discussed in Section 2.3, the monetary policy of the ECB in normal times implies a large difference between the repo rate and the ECB deposit rate, which explains the relative weakness of the DF test over the entire period. This large difference disappears and the results of the DF test improve in the period following Lehman's bankruptcy, which is the period the paper mostly focuses on.

[Insert Table 2 here.]

The results appear in Panel A of Table 2. In the first column of Panel A, we consider the entire period (2008 to mid-2012). The link between sovereign CDS spreads over the entire time period and across countries is significantly positive: the coefficient estimate for *Sovereign CDS* is equal to 0.065 and statistically significant at the 1%-level. Our null hypothesis, that in CCP-cleared transactions repo rates should be insensitive to sovereign risk, is rejected. The effect is economically sizable: a one-standard deviation increase in the sovereign CDS spread (95bp) leads to an average increase of 6 basis points in the repo rate (compared to a sample mean of 31bp and standard deviation of 40bp). Thus, repo markets were pricing-in a non-negligible risk of default of the CCP during the period we examine.

We then look at changes in this implicit belief over the period. We split our sample into the four sub-periods described in Section 2.3: “Normal times”, “sovereign stress times”, “sovereign crisis times”, and “post-LTRO period”. In columns 2 to 5 of Panel A in Table 2, we run the same regression as in the first column separately for each of the sub-periods. In “normal times”, i.e., before September 15, 2008 (in column 2), the coefficient estimate for *Sovereign CDS* is equal to -0.023 and is statistically insignificant. In other words, during this first period, the repo market was not stressed. Markets did not expect any CCP or member bank default.

When the crisis hits, however, the relation between GC-repos and sovereign CDS rates appears, and it becomes stronger, both economically and statistically, as the sovereign debt crisis worsens, in 2011. In “sovereign stress times”, the coefficient estimate for *Sovereign CDS* (in column 3) is equal to 0.016 and is statistically significant at the 1%-level: a one standard-deviation increase in the sovereign CDS rate leads to an average increase of about 1 basis point (=0.016×76) in the GC-repo rate for all Eurozone countries considered together. The effect is statistically significant but modest economically. In column 4, however, during “sovereign crisis times” (during 2011) the coefficient estimate is much higher, 0.192, and statistically significant at the 1%-level: a one standard-deviation increase in the sovereign CDS spread has a much bigger impact. It leads to an average increase of almost 22 basis points in the repo rate (=0.192×113).

The stress sharply decreases with the implementation of the 36-month LTRO of December 21, 2011. Post-LTRO, during the first six months of 2012, the coefficient estimate for *Sovereign CDS* goes back down to 0.033 (still statistically significant at the 1% level), suggesting that following LTRO implementation, the stress that had built up in the repo market abated but did not disappear.

To make sure we identify coefficients on high frequency co-movement between CDS spreads and repo rates, we replicate the above regressions including country-month fixed effects. This approach allows us to control for slower movements in country-specific risk factors.[10] We report the results in Table 2, Panel B.

In this very demanding specification, the link between GC-repo rates and CDS spreads becomes insignificant in all the columns, except in column 4, in which we examine the "sovereign crisis" period (2011). The coefficient estimate is reduced to 0.076 but it is still statistically significant at the 5%-level: a one-standard deviation increase in the CDS spread leads to an average increase of almost 9 basis points (=0.076×113) for all one-day Eurozone GC-repo rates combined across countries. The coefficient is significant, but significantly weaker than in the baseline specification with only market-wide pricing factors. However, as we see in the next section, this finding conceals a large amount of heterogeneity between GIIPS and non-GIIPS countries.

4.2. Sovereign default risk and repo rates in GIIPS vs. non-GIIPS countries

In our framework, the coefficient β corresponds to $p\lambda G(h)/G(0)$, which represents the joint conditional default of the CCP and member banks, as well as the effect of the haircut. In this section, we investigate whether β is the same in GIIPS and non-GIIPS countries. A difference may arise because haircuts are too low in transactions using riskier GIIPS collateral, i.e., because $G(h)/G(0)$ is larger in GIIPS countries. In Table 3, we test whether the sensitivity of repo rates to sovereign risk differs between GIIPS and non-GIIPS countries. We create an indicator variable named *GIIPS*, which is equal to one for countries in the GIIPS

[10] An alternative way to control for such slow movements in country-specific factors is to include time trends in the regressions. Doing so yields the same results as including country-month fixed effects.

category, and zero otherwise. Then, we add an interaction term *GIIPS×Sovereign CDS* to Eq. (3). The coefficient on this interaction term measures the extent to which repo rates are differentially sensitive to sovereign CDS spreads across the two groups of countries.

[Insert Table 3 here.]

We report regression results in Table 3. As before, Panel B includes country-month fixed effects, while panel A does not. Altogether, these results suggest that the positive sensitivity of repo rates to CDS spreads is mostly driven by GIIPS countries. In fact, looking across the two panels, for the entire 2008-2012 period (column 1), this relation is statistically significantly negative for non-GIIPS countries: the coefficient on *Sovereign CDS* (the non-interacted term) is -0.023 (significant at 1%-level) in Panel A, and -0.051 (significant at 1%-level) in the more demanding specification of Panel B. This is evidence of flight to quality. An increase in non-GIIPS CDS spreads indicates general stress on EU sovereigns.[11] In which instance, the CDS spreads of GIIPS countries go up even more, which increases the relative attractiveness of safe haven sovereign debt as collateral. Consistent with this and as expected, the coefficient estimates for the interacted variables *GIIPS×Sovereign CDS* are positive and statistically significant at 1% in column 1 of both panels. Said differently, when perceived sovereign risk measured by CDS spreads on sovereign debt increases, a divide appears across the repo markets of Eurozone countries: Repo investors escape the repo markets from GIIPS countries and fly to quality, i.e., to the repo markets of the safest countries of the Eurozone. The statistically significant estimate of Panel B (0.066) indicates that a 120bp increase in sovereign CDS spreads (a one-standard deviation increase) for GIIPS countries raises the related repo rates by some 8bp on average. But this relatively modest effect conceals the fact that the effect was concentrated during the sovereign crisis.

[11] This is apparent from Figure 5. Average CDS spreads of GIIPS and non-GIIPS countries co-move strongly. Over the entire period that we study, the correlation between the two series is 0.77. In 2011, the peak of the sovereign crisis, it reaches 0.85.

Consistent with our previous findings from Table 2, the relation between sovereign CDS spreads and repo rates becomes more pronounced at the peak of the crisis, as does the divergence between GIIPS and non-GIIPS countries. In Table 3, the coefficients on the two variables *Sovereign CDS* and *GIIPS×Sovereign CDS* are insignificant before November 2008 (column 2). They start diverging in 2009-2010 (column 3), even though they remain insignificant in our most demanding specification (Panel B). At the peak of the crisis (in 2011, column 4), the divergence becomes strongly significant in all specifications. Taking estimate of 0.208 for the interaction term (which is statistically significant at the 1%-level) from Panel B, in 2011, a one-standard deviation increase in the sovereign CDS spread of GIIPS countries (120bp) is associated with a 0.208×120=25bp relative increase in the GC repo rate of these countries. Consistent with our previous findings, this relation between underlying sovereign-debt risk and GC repo rates decreases only after the introduction of the first 36-month LTRO in December 2011, when the coefficient estimate for the interacted term becomes negative but statistically insignificant (column 5 of Panel B).

We rule out the possibility that our results are somehow linked to the maturity mismatch between overnight repo rates and the 5-year sovereign CDS rates (Augustin, 2013, documents the term structure of CDS spreads). When we replace the latter with the one-year sovereign CDS rates (the shortest sovereign CDS maturity available to us), we obtain very similar results. We report the comparable results in Appendix Table A1, Panel A. In column 4, the coefficient estimate for *GIIPS×Sovereign CDS* during 2011 (0.180) is statistically significant at the 1% level and comparable to the corresponding estimate in Table 3, Panel B.

Second, we explore whether our results are CCP-dependent, and find that they are not. As we explain above, Italian GC repo transactions are cleared by CC&G, while all other repos are traded via ICAP and cleared via LCH.Clearnet. One interpretation of our results is that the default probability of CC&G went up, while the default probability of LCH.Clearnet remained stable. It would explain why repo rates became more sensitive to CDS spreads for GIIPS countries, of which Italian repo represents a large share. To explore this possibility, we repeat the same regressions excluding Italian transactions. The results are presented in Panel B of Appendix Table A1. Our findings remain unchanged when we exclude Italian repos from our sample.

4.3. Repo volume and sovereign risk

In this section, we ask whether sovereign risk affects trading volume on the repo market. To do this, we run variants of Eq. (3), in which the dependent variable is the daily volume traded instead of the repo rate. We take the logarithm of 1+volume, and we attribute a volume of 0 to days with no transactions. Our results are not sensitive to this convention, and carry through when we exclude days with missing observations instead. Regression results are reported in Tables 4 and 5, which are structured exactly like Tables 2 and 3, respectively, for the ease of reading.

[Insert Table 4 here.]

Table 4 shows that repo volume is, on average across countries, quite sensitive to local sovereign risk. Panel A shows a strong negative relationship between CDS spreads and repo volume over the entire period (column 1), but also in 2009-2010, in 2011 and even in the first semester of 2012 (in columns 3, 4 and 5, respectively). In 2011, a one-standard deviation increase in CDS spreads (113bp) leads to a volume reduction of about 37% ($=1-e^{-0.413\times1.13}$). At the average volume level (€6.02bn), this corresponds to a drop of €2.2bn in daily trading volume. From Panel A the impact thus looks large.

However, the results in Panel B show that this effect is identified on low (monthly) frequency movements in country-level factors. Once we include country-month dummies, the average effect becomes statistically insignificant in all periods, including 2011 (Table 4, Panel

B). We notice, however, that the coefficient is not driven to zero, it only becomes more noisily estimated. It is thus impossible to reject the hypothesis that the effect uncovered at low frequencies also holds at the daily frequency. We also note that these results are opposite to what Mancini, Ranaldo, and Wrampelmeyer (2015) find on the GC pooled (GCP) repo market. This is probably due to the higher resilience of the GCP market - though the reason behind this resilience remains somewhat of a mystery, since the larger collateral base in GCP repo is likely to generate more substitution towards relatively lower quality collateral when closing the transaction.

We then look at the differential impact of sovereign stress on repo volume between GIIPS and non-GIIPS countries. To do so, we add to the regression an interaction term *GIIPS×Sovereign CDS*. The coefficient on this interaction term indicates the differential impact of sovereign stress on repo volume for GIIPS countries.

[Insert Table 5 here.]

The results reported in Table 5 indicate that volume seems to be negatively affected by sovereign stress, but the coefficient is noisily estimated. In column 1 of Panel A, the simple specification with daily fixed effects delivers a strong positive coefficient on the interaction term, which is difficult to interpret. It is however mostly due to the presence of Spain in the sample, whose volume traded surges in the later part of 2011 (see Figure 3), precisely when the Spanish CDS spread is at its highest. When we run the regression of column 1 excluding Spain, the coefficient on the interaction term becomes negative. To make sure we are identifying our coefficient on higher frequency movements, we then move to panel B, in which we include country-month fixed effects. In this second specification, the coefficient on the interaction term is equal to -0.523 and is significant at the 10% level. The effect is strongest during the 2009-2010 period: A one-standard deviation increase in CDS spreads of

GIIPS countries (83bp) leads to a 53% (=1-$e^{-0.523\times0.83}$) reduction in daily volume. In 2011 the coefficient estimate of the interaction term is also negative but it is not statistically significant, probably because daily volume fluctuates a lot in this period.

5. The transmission channel between sovereign CDS spreads and repo rates

Our next objective is to understand how shocks to GIIPS CDS spreads are transmitted to repo rates. To do this, we use the model of Section 3. If we take Eq. (2) literally, the sensitivity of repo rates to CDS spreads should be equal to $p\lambda G(h)/G(0)$. It means that sovereign stress transmits to repo rates more when (1) haircuts are set less conservatively, (2) the conditional probability of CCP member failure increases or, (3) the conditional probability of CCP failure increases. In this section, we investigate the relative importance of these determinants.

5.1. Haircuts

A conservative haircut policy has the potential to eliminate, or at least attenuate, the effect of stress on repo rates. However big the increase in default probabilities of the CCP or some of its members, a high enough haircut h leads to a negligible conditional loss given default G(h), thereby breaking the link between sovereign CDS spreads and repo rates. Our previous findings show that this link is present in 2011, indicating that haircuts are not high enough at that time. To investigate the effect of haircuts on repo rates, we focus on three instances in which haircuts were increased sharply, and ask whether the repo rate-to-CDS sensitivity was affected by these changes in haircuts. Clearly, haircut modifications are themselves endogenous and are adjusted in response to heightened sovereign stress. To deal with this concern, we focus on short periods around haircut changes, but we acknowledge this method is imperfect.

[Insert Figure 7 here.]

Haircut changes for France, Spain and Italy, available from the website of LCH.Clearnet, are shown in Figure 7. These haircuts are averaged across maturity groups (below and above 7 years). We focus on three episodes in which LCH.Clearnet raises haircuts by more than 100bp. The first two haircut changes occurred in Spain (December 16, 2010 and September 21, 2011), the last one in Italy (November 10, 2011). For the two Spanish haircut changes, we focus on a 3-month window around the haircut change, because the haircut follows a relatively neat "step function". The downside of these two "experiments" is that they correspond to relatively modest haircut rises (about 100bp). The Italian shock of 2011 is much more dramatic since the haircut goes up from approximately 6% to 10%. The problem with this change is that it only lasted a month, after which the haircut went back to 7%. We thus restrict ourselves to a 1-month window around November 10 for the Italian test.

[Insert Table 6 here.]

The results are reported in Table 6. For each shock, we run a variant of Eq. (3) in which we interact all terms with a *POST* dummy variable equal to one after the haircut change, and zero before. We report the results of these regressions in columns 1, 3 and 5. These regressions are similar to "simple diffs" in which we look at the change in repo rate-to-CDS spread sensitivity before and after the haircut change. In this case, the coefficient of interest is the interaction term *POST×Sovereign CDS*. We, then, extend the sample to all other countries and add to the specification the *HC Country* dummy variable, which is equal to one if the country experiences a haircut change (the "treatment" country), and zero otherwise. These regressions are "diff-in-diff" tests, which allow us to compare the change in repo-to-CDS spread sensitivity in treated countries relative to other Eurozone countries around the haircut change. The coefficient of interest in these regressions is the triple interaction *POST×HC Country×Sovereign CDS*. We report the results of these regressions in columns 2, 4 and 6 of Table 6.

Overall, the results are consistent with haircuts being effective in "normal times", but not in the second half of 2011, the peak of the sovereign crisis in Europe. The first Spanish haircut seems to have been effective at reducing stress on the repo market. In column 1, the sensitivity of Spanish repo rates to Spanish CDS spreads goes down by 0.209 after the haircut change. In column 2 (the difference-in-differences estimation), the excess sensitivity of Spanish repo rates to CDS spreads goes down from a statistically positive 0.209 before the haircut change to 0.209-0.236 = -0.027, i.e., close to zero, after the change. By contrast, for the two shocks occurring in 2011, the sensitivity increases strongly after the shock, which we interpret as evidence that the haircut increase was not large enough to insulate the repo market from sovereign stress. In the Italian case of November 10, 2011 (column 5), the repo rate-to-CDS spread sensitivity increases by 0.357 after the haircut change. This coefficient is significant at the 1% level and corresponds approximately to a 17bp increase in repo rates for a one-standard deviation increase in Italian CDS spreads. This finding carries out in the diff-in-diff exercise of column 6. The Spanish case of September 21, 2011, is similar (columns 3 and 4). In sum, haircut changes seem to have the power of calming market stress in "normal times", but not during the worst of the sovereign crisis.

5.2. CCP members risk

When CCP member risk (*p* in our model) goes up, we also expect the repo-to-CDS sensitivity $p\lambda G(h)/G(0)$ to increase. In this section, we propose a measure of *p* and investigate how it changes over time. We show that, if anything, *p* decreased in 2011, a result coherent with the fact that banks in the Eurozone decreased their exposure to their own sovereigns in 2011 as Angeloni and Wolff (2012) and Acharya and Steffen (2015) show.

To measure p, we regress the average CDS spread of CCP members on the CDS spread of GIIPS countries. Note that p is the probability of default of the average member *conditional* on sovereign default. As such, it may differ substantially from an unconditional default probability. To estimate it, we exploit Bayes' law and assumptions about stationarity. Let t be a time index. P_t is the unconditional probability that the average CCP member defaults at t; π_t is the sovereign default probability; ρ is the probability of member default conditional on GIIPS non-default. According to Bayes' law:

$$P_t = p\, \pi_t + \rho\,(1 - \pi_t) = (p - \rho)\, \pi_t + \rho \qquad (4)$$

where we assume that both conditional member default probabilities p and ρ are stationary. By regressing P_t on π_t, we obtain an estimate of the difference between the two default probabilities ($p - \rho$), which is a lower bound for p.

Relying on this insight, we estimate ($p - \rho$) using data on CDS spreads to measure CCP member and sovereign default probabilities. In principle, we could estimate one regression (4) per sovereign, but reporting results would be cumbersome. To simplify presentation, we only run one regression with π_t measuring average GIIPS sovereign default risk.[12] We use the following first-difference version of (4):

$$\Delta CDS_t^{members} = \alpha + \beta.\Delta CDS_t^{GIIPS\ sov.} + \gamma.F_t + \varepsilon_t \qquad (5)$$

where Δ represents daily differences. We use first difference because DF tests cannot reject the possibility that the series have unit roots, even within the various subperiods that we analyze. We also checked that first-differenced variables are indeed stationary. $CDS_t^{GIIPS\ sov}$ corresponds to the average change in 5-year CDS on all available GIIPS sovereigns on day t.

[12] As we have seen earlier, repo rates respond more to the CDS spreads of sovereign bonds from GIIPS countries, therefore we focus on CDS spreads of these sovereigns only. Considering average CDS spreads of all countries in the sample yields the same results.

$CDS_t^{members}$ is the average spread of CCP members on day *t*. We look at three groups of members separately: Members of both LCH.Clearnet and CC&G, members of LCH.Clearnet only, and members of CC&G. We obtain the current list of members from LCH.Clearnet and CC&G from their websites.[13] Finally, F_t is a risk factor for the CDS market, designed to capture fluctuations in spreads that do not come from Eq. (4). We include this factor in the specification because we have only one observation per day and thus we cannot include day fixed effects as we do in our previous tests. To construct this factor, we follow Pan and Singleton (2008) and compute the first principal component of CDS changes of 5 large European sovereigns (Belgium, France, Germany, Italy and Spain) that are chosen because their CDS spreads are continuously available over the entire period. The resulting factor loads positively on all five sovereigns. We have experimented with alternative measures of the risk factor, without a material change in our results.[14] Obviously, the inclusion of the risk factor F_t in our regression leads us to underestimate (p - ρ) as some of the comovement of P_t and π_t will be picked up by the factor.

[Insert Table 7 here.]

Table 7 reports the results. In Panel A, the dependent variable is the average CDS spread of members of CC&G and LCH.Clearnet, which are the two CCPs clearing trades on the MTS and ICAP platforms, respectively. In panels B and C, we explore the average default probabilities of LCH.Clearnet and CC&G members separately. Looking first at panel A, over the entire period the coefficient β is equal to 0.00123 and is insignificant. Members' CDS

[13] The full list of CC&G's members is available at: http://www.lseg.com/post-trade-services/ccp-services/ccg/membership/members. The list of LCH.Clearnet's members is available at: http://www.lchclearnet.com/fr/members-clients/members/current-membership. Pulling these information from the current website may expose us to some form of look ahead bias, although it is not entirely clear how it affects our results.

[14] For instance, we have added the second principal component as an additional control, but it was most of the time insignificant, consistent with the findings of Pan and Singleton (2008). We have also computed the average sovereign CDS spread, and a change in the VSTOXX index, which measures the implicit volatility on the EUROSTOXX 50. None of these alternative approaches yield materially different results.

fluctuations are not particularly sensitive to changes in GIIPS default probabilities, beyond their comovement with the CDS risk factor (which is strongly significant). During the pre-sovereign crisis period (from 2009 to 2010), the coefficient is equal to 3.4% and it is significant at the 5% level. But during the sovereign crisis period and later (from 2011 to mid-2012), the coefficient goes down to zero. Next we examine separately members of the two CCPs, LCH.Clearnet and CC&G. We do so because members of the two CCPs may have different characteristics and sensitivities to sovereign risk. In particular, many CC&G members are banks from a GIIPS country (Italy, to be precise) that could be more sensitive to sovereign risk than non-GIIPS banks. The tests, which are reported in panels B and C of Table 7, lead to the same conclusion for the two CCPs: During the sovereign crisis, the probability of member default conditional on GIIPS default does not seem to increase. If anything, it decreases. This evolution is consistent with the findings of earlier papers on the Euro crisis, which show that banks in GIIPS countries reduced exposure to their own sovereigns in 2011 (Angeloni and Wolff, 2012, and Acharya and Steffen, 2015).[15]

Overall, the evolution of our estimates of CCP member risk p during the crisis does not match the evolution of the repo rate-to-sovereign CDS spread found in earlier tables: Repo stress is the highest in 2011, but this is precisely the moment when member risk is decreasing. There are two potential explanations for this: (1) market participants' perception that CCP failure risk increased (λ increased) or (2) market participants' perception that sovereign risk increased while haircuts did not increase enough to compensate increased sovereign bond risk, leading to an increase in expected loss given default G(h). Note that in both cases, $\lambda>0$, i.e., the possibility that the CCP fail *conditional* on sovereign default, is necessary to obtain a positive relation between repo rates and sovereign CDS spreads. While it is impossible to discard explanation (2), we offer below evidence that (1) holds.

[15] In fact, this reduction in exposure to GIIPS sovereign debt in 2011 is observed for nearly all Eurozone banks (Popov and Van Horen, 2015).

5.3. CCP default pricing

This Section discusses the possibility that the increase in repo rates-to-CDS spread sensitivity in 2011 may be explained by an increase in (real or perceived) risk of CCP failure. There is anecdotal evidence that financial regulators and market participants were worried about a large CCP default. For example, Paul Tucker, deputy governor at the Bank of England warned in June 2011 that: "Central counterparties need to adopt prudent collateral policies, but also to monitor the robustness of their clearing members and risks from the business that they are bringing to the CCP, … I am not convinced that that is sufficiently recognised by clearing houses or by standard setters." (Financial Times, June 2, 2011). Few months later, Paul Tucker stated that "There is a big gap in the regimes for CCPs – what happens if they go bust? I can tell you the simple answer: mayhem. As bad as, conceivably worse than, the failure of large and complex banks." (Financial Times, October 24, 2011). The market participants whom we spoke with also explained that many perceived a large-scale series of defaults of banks and sovereigns as likely at the end of 2011. As a consequence, the amount of GIIPS collateral that they could take was severely limited by risk management, in spite of the risk-protection of the CCP. This is consistent with the view that this protection was considered imperfect at that time.

Note also that the key parameter λ in our model is the probability of CCP default *conditional* on sovereign default, which is a priori much higher than the unconditional probability. One possible reason is that sovereigns are themselves a possible backstop liquidity provider for CCPs. As discussed in Section 3.3, for instance, the default fund of LCH.Clearnet was not large enough to accommodate the default of more than two average size members in a situation where their collateral would take a 50% haircut. This in itself is an unlikely event, but not *conditional* on sovereign default.

To test whether the market participants perceived the risk of repo transactions going through CCP to be lower than that of a relevant benchmark, we exploit the fact that a non-negligible fraction of the trades on our two platforms are bilateral and therefore not CCP-cleared. We ask whether the repo to CDS sensitivity is lower among CCP-cleared trades.

[Insert Figure 8 here.]

We use data on GC repo bilateral transactions between January 2011 and June 2012 on all non-GIIPS markets, Italy, Portugal and Spain.[16] Bilateral transactions are similar to CCP-based ones in that they use the same GC list and haircuts, but they are not anonymous. Thus, bilateral transactions that go through trading platforms are very similar to OTC transactions, although they represent much smaller volumes. Figure 8 presents the monthly trading volumes of CCP-based and bilateral transactions in our sample. In non-GIIPS countries, bilateral trades represent about 15% of CCP-cleared trades and are quite stable over time. In Portugal and Spain, they represent much smaller volumes, in particular in the last four months of 2011, when they virtually disappear.

Because bilateral trades are less frequent than CCP-cleared ones, many days have no transaction, and therefore no bilateral repo rate. To get around this data limitation, we aggregate the rates at the monthly level, taking the average monthly rate for the two series, and replacing country-month fixed effects by separate country fixed effects and month fixed effects.[17] We then repeat the tests of Table 3 separately for CCP-based and bilateral repo rates.

[Insert Table 8 here.]

[16] These data exclude Greece and Ireland, as the repo markets of these two GIIPS countries shut down before January 2011.
[17] Our results are the same if we use daily rates and keep only days with non-zero bilateral trade volume.

Table 8 reports the results. In column 1 of Panel A, in which the dependent variable is the CCP-cleared repo rate in year 2011, the coefficient on *Sovereign CDS* is negative but statistically insignificant. The coefficient on *GIIPS×Sovereign CDS* is statistically positive and, reassuringly, of the same magnitude as the coefficient we obtain on the same interaction variable in Table 3. In column 2, a similar result holds for bilateral rates but the coefficient on *GIIPS×Sovereign CDS* is smaller than in column 1. This suggests that in 2011 repo rates are not less sensitive to sovereign stress in the CCP-based segment of the market. They are in 2012 (Panel B), when the coefficient on *GIIPS×Sovereign CDS* becomes smaller for CCP-based repo than for bilateral repo, although both coefficients are statistically insignificant. These results have to be interpreted with care, however, because when sovereign stress rises, the pool of banks that have access to the bilateral market may shrink to only the safest ones. Thus, the test on bilateral repo rates probably underestimates their sensitivity to sovereign stress.

6. Alternative hypotheses

6.1. Market Power of Lenders

An alternative explanation of our findings is that the second half of 2011 was a period of increased market power of investors willing to lend cash against stressed sovereign collateral. The intuition is that during this phase of intense sovereign stress, most cash-rich banks refused to increase their exposure to GIIPS sovereign risk. At the same time, banks in the periphery had few alternatives sources of funding and were thus ready to accept higher rates to borrow from the repo market. As a result, the increase in the repo rates-to-CDS spreads sensitivity that we document could come from a handful of cash-rich banks willing to lend against bonds that few wanted as collateral.

The demand and supply for repo transactions are hard to estimate, but a few elements suggest that shifts in the demand and supply curves on the repo market cannot fully explain our main finding. On the borrowing side, July-December 2011 is a period during which the supply of GIIPS collateral from potentially risky counterparties was going *down*, not up. Angeloni and Wolff (2012) show that between July and December 2011, holdings of their own sovereign bonds by Italian, Spanish, Irish and Portuguese Banks went down in absolute terms. Acharya and Steffen document that, over 2011, own-sovereign holdings of GIIPS banks went down by about 3%. If anything, it looks like GIIPS banks had less GIIPS collateral to supply, not more, in the second half of 2011.

On the lending side, we could not find evidence of weaker competition between lenders in 2011S2. Our transactions data do not contain counterparty IDs so that we cannot measure lender concentration directly. But some aggregate data are available, and these do not show evidence of increased concentration on the repo market. We show this evidence in Figure A.1. First, the ECB Money Market study reports annually the percentage of reverse repos accounted for by the top 5, 10 and 20 largest European banks in this market. Over time, the market share of the largest banks did not increase but instead *decreased* (Panel A). Second, we went directly to Bankscope and pulled data on reverse repos from the balance sheets of banks. The evolution of the Herfindahl – Hirschman Index based on this variable suggests that over time, the lending side of the repo market becomes *less*, not more, concentrated, with no breakdown of this trend in 2011 (Panel B of Fig. A.1). Unfortunately, we cannot observe this concentration separately for each type of sovereign collateral, so we cannot rule out the possibility that the lending side of the repo market became more competitive on some bonds and less competitive on others. However, increased overall competition in this market suggests that arising opportunities should have been arbitraged away more easily in 2011 than earlier in our study period.

6.2. Haircut policy of the ECB

In this section, we explore the possibility that the ECB's haircut policy may drive our results. The ECB does most of its monetary policy interventions on the repo market, so it has the power to affect repo rates. Conventional monetary policy operations are not country specific, so they should be absorbed in the day fixed effects of our regressions. But since the crisis, the ECB has started to intervene through its collateral list, by changing the haircuts that it takes on specific collateral. It could be the case that the ECB responds to increased sovereign risk by differentially increasing the haircuts it demands on riskier sovereigns. If the CCPs in our data fail to react by aligning their haircuts on the ECB, lending cash against stressed collateral through the CCP becomes less attractive to investors, and rates should increase. Thus, if the ECB increases haircuts on stressed sovereigns, our estimates would be biased upward. If, on the contrary, the ECB reduces haircuts on stressed sovereigns, they are biased downward.

To implement this test, we add the ECB's haircut as an additional control to Eq. (3) and we estimate the following equation:

$$r^{\text{Repo}}{}_{c,t} - r^{\text{ECB}}{}_{t} = \alpha_c + \delta_t + \delta_{c,m} + \beta.\textit{Sovereign CDS}_{c,t} + \gamma.\textit{ECB HC}_{c,t} + \varepsilon_{c,t} \qquad (6)$$

where $ECB\ HC_{c,t}$ is the average haircut taken by ECB on sovereign bonds of country c at date t. We compute this measure using the publicly available collateral list of the ECB.[18] A natural hypothesis is that $\gamma>0$: When the ECB increases its haircut on country c, lending to the ECB becomes relatively more attractive (safer), and lending through the platform requires a higher risk premium. If however, $ECB\ HC_{c,t}$ and $CDS_{c,t}$ are positively correlated, and the haircut is omitted from the equation, the OLS estimate of β is biased upward.

We report estimates of regression (6) in Appendix Table A.2. We only report results including country-month fixed effects though results without them deliver the same message. In both specifications (with sovereign CDS as in Table 2, or sovereign CDS interacted with the GIIPS dummy as in Table 3), controlling for the haircut of the ECB does not change our results.

6.3 Accounting for Country-Specific Risk Exposure

In Eq. (3), we control for common factors on the repo market through the inclusion of a day fixed effect. The limitation of this approach is that it assumes that all repo rates have the same exposure to the risk factors. However, it is reasonable to think that some countries have different exposures to the same risk factor. Our main specification partially deals with this issue with month-country fixed effects, but these can only capture slow-moving factors. Given the data available to us, we cannot identify the effect of the sovereign CDS if we introduce country-level day-fixed effects as well. In this section, we adopt a different approach: We focus on a specific risk factor (the Vixx), and allow for different country-specific exposures across country-level repo rates. We implement this by estimating the following version of our basic Eq. (3):

$$r^{Repo}_{c,t} - r^{ECB}_{t} = \alpha_c + \delta_t + \delta_{c,m} + \beta.\mathit{Sovereign\ CDS}_{c,t} + \gamma_c.\mathit{Vixx}_t + \varepsilon_{c,t} \qquad (7)$$

[18] We are grateful to Guillaume Vuillemey for sharing his data with us.

where $Vixx_t$ is the Vixx, obtained at the daily frequency from Datastream. γ_c captures the country-specific exposure to volatility risk. This equation is identified because we fix the factor structure of repo rates. There is no clear consensus about this factor structure. We take the Vixx as a first pass measure of "risk aversion" like Mancini, Ranaldo, and Wrampelmeyer (2015).

We run Eq. (7) and report the results in Table A.3. We only report results including country-month fixed effects though results without them deliver the same message. In both specifications (with sovereign CDS as in Table 2, or sovereign CDS interacted with the GIIPS dummy as in Table 3), controlling for differential country exposures to Vixx does not change our results.

7. Conclusion

We analyze the sensitivity of repo market rates to sovereign default risk during the Eurozone crisis. This sensitivity is very high, even for CCP-cleared repos, in which lenders are in principle protected against default risks. We propose a simple framework that allows us to decompose this sensitivity into (1) CCP default risk, (2) CCP members default risk, and (3) haircut policy effectiveness. In 2009-2010, the sensitivity is low, in spite of significant bank risk. One haircut increase experience seems to have been effective at reducing repo stress. Overall, markets behave as if the CCP was able to insulate the repo market from stress in 2009-2010. In 2011, however, attempts at raising haircuts prove ineffective. The repo-to-sovereign risk sensitivity increases strongly, despite the fact that bank default risk decreases somewhat during that period.

Our results are consistent with CCP failure being perceived as a reality and being priced in repo rates. Given how crucial the repo market is for banks, such failure needs to be dealt with through ex ante regulation. Until 2011, explicit resolution frameworks (especially end of waterfall loss sharing rules) were lacking because CCPs were perceived as solid and unlikely to fail. 2011 has proved that this was not the case and central banks began to push much harder for explicit CCP resolution frameworks.

An important outcome of the paper is that central banks have the power to alleviate stress on CCPs through massive intervention. After the December 2011 LTRO announcement by the ECB, repo rates to CDS sensitivity went down dramatically, indicating that market participants have stopped to price CCP default risk. There are many possible channels through which this may be the case. For instance, by making large long-term loans to borrowers, the ECB may have made it much less risky for lenders to lend through private CCP-cleared platforms, but this is only one of the channels.

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Figure 1: Average daily trading volume in the Eurozone interbank repo market

This figure presents the evolution of different segments of the Eurozone interbank repo market between 2008 and 2012. Interbank Secured, Interbank Secured Bilateral and Interbank Secured Bilateral CCP based, Eurex GC Pooling are from Mancini, Ranaldo, and Wrampelmeyer (2015). MTS/ICAP GC is the sum of one day GC repo trades in our dataset. All numbers are in €bn of average daily volume.

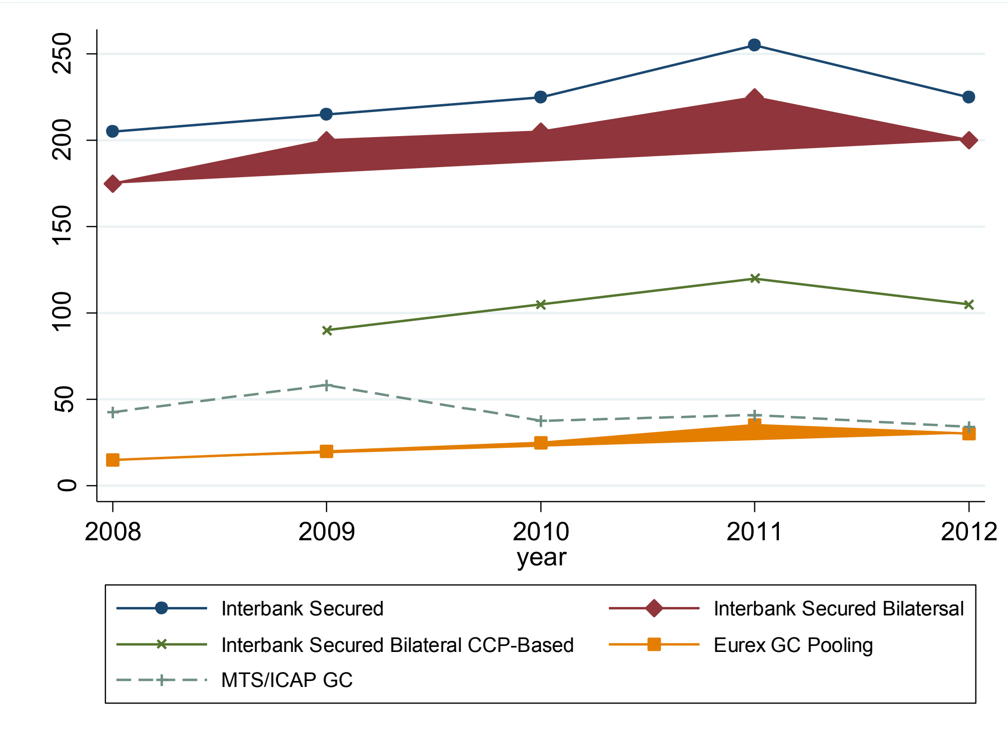


Figure 2: Evolution of the volume of repo transactions in the Eurozone, GIIPS vs Non GIIPS, 2008-2012 S1

This figure presents the monthly evolution of the average daily volume of General Collateral (GC) repo in the Eurozone between January 2008 and June 2012, for GIIPS countries (Greece, Ireland, Italy, Portugal and Spain) and the six non-GIIPS countries in our sample. The scale of the y-axis is in €bn.

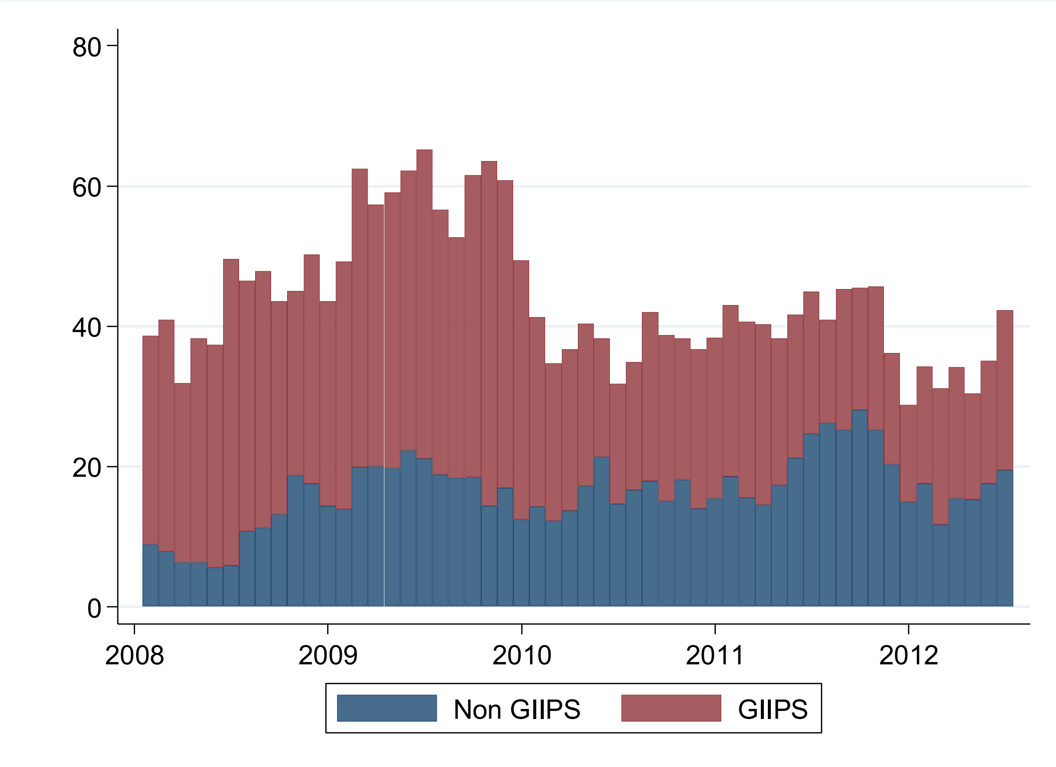
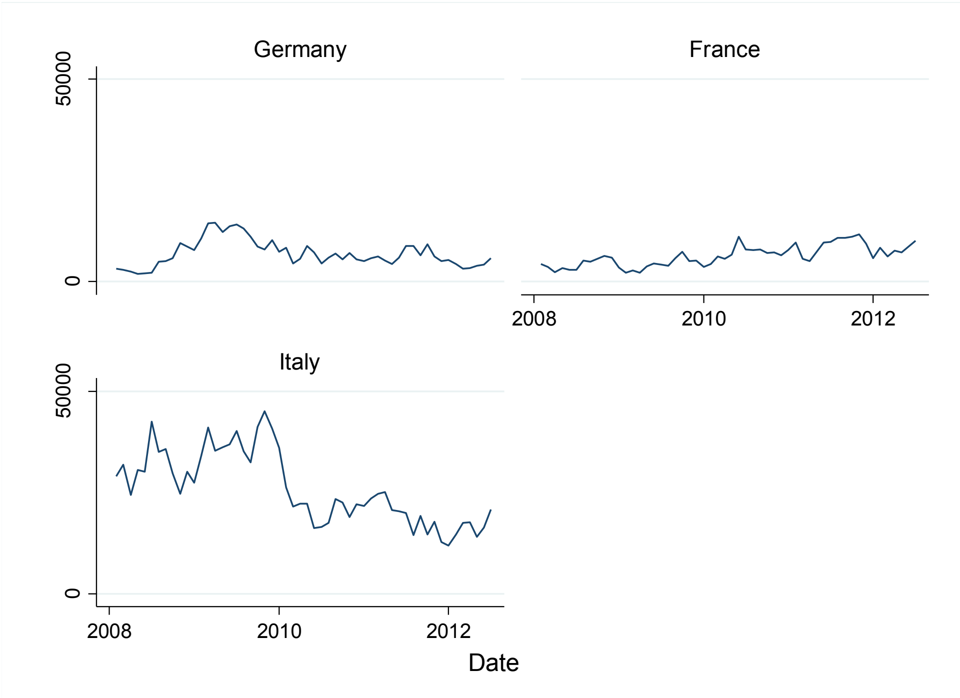


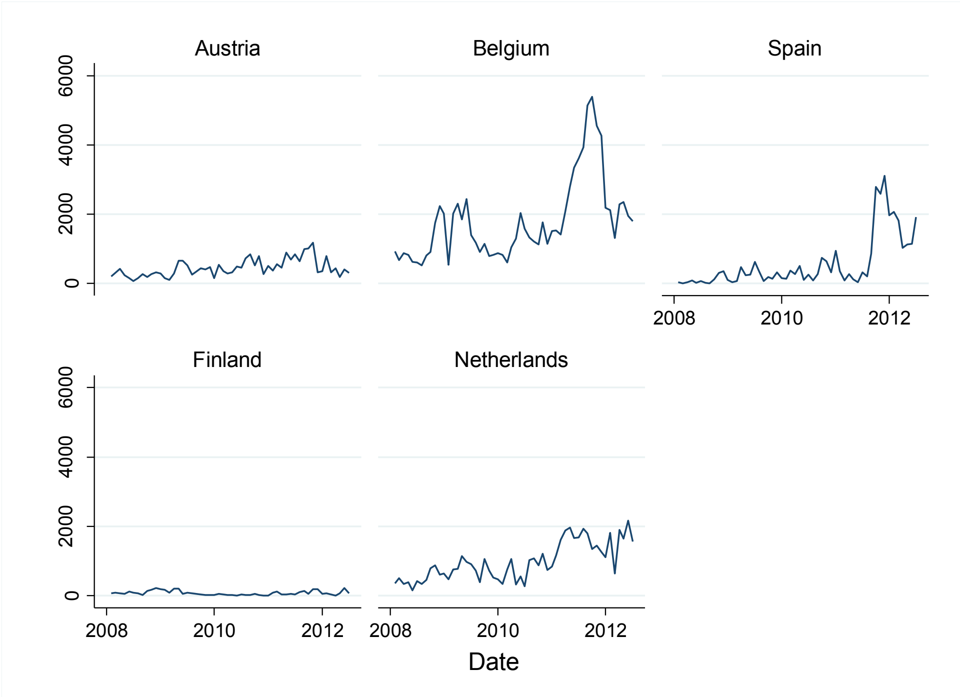
Figure 3: Evolution of the volume of repo transactions in the Eurozone by country, 2008-2012 S1

This figure presents the evolution of the average daily volume of General Collateral (GC) repo in the Eurozone over our sample period, between January 2008 and June 2012, by country. All amounts are in €m, but each panel uses a different scale. Panel A is restricted to Germany, Italy and France. Panel B presents all other countries that did not seek foreign assistance through a bailout program. Panel C is restricted to countries that entered assistance programs (Ireland, Portugal and Greece). The start dates of bailout programs are indicated by vertical lines.

Panel A: Germany, France, Italy



Panel B: Austria, Belgium, Spain, Finland, the Netherlands



Panel C: Greece, Ireland, Portugal

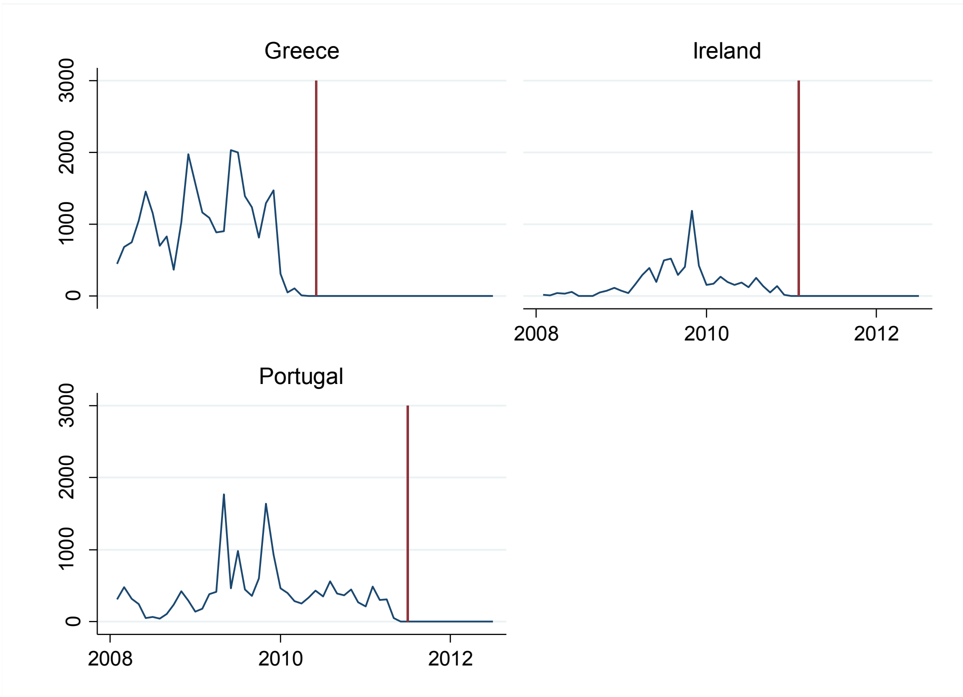


Figure 4: Interest rates, 2008-2012 S1

This figure presents the evolution of the ECB marginal lending and deposit rates, as well as the average General Collateral (GC) repo rate for GIIPS (Greece, Ireland, Italy, Portugal and Spain) and non-GIIPS Eurozone countries between January 2008 and June 2012. Interest rates are expressed in percent.

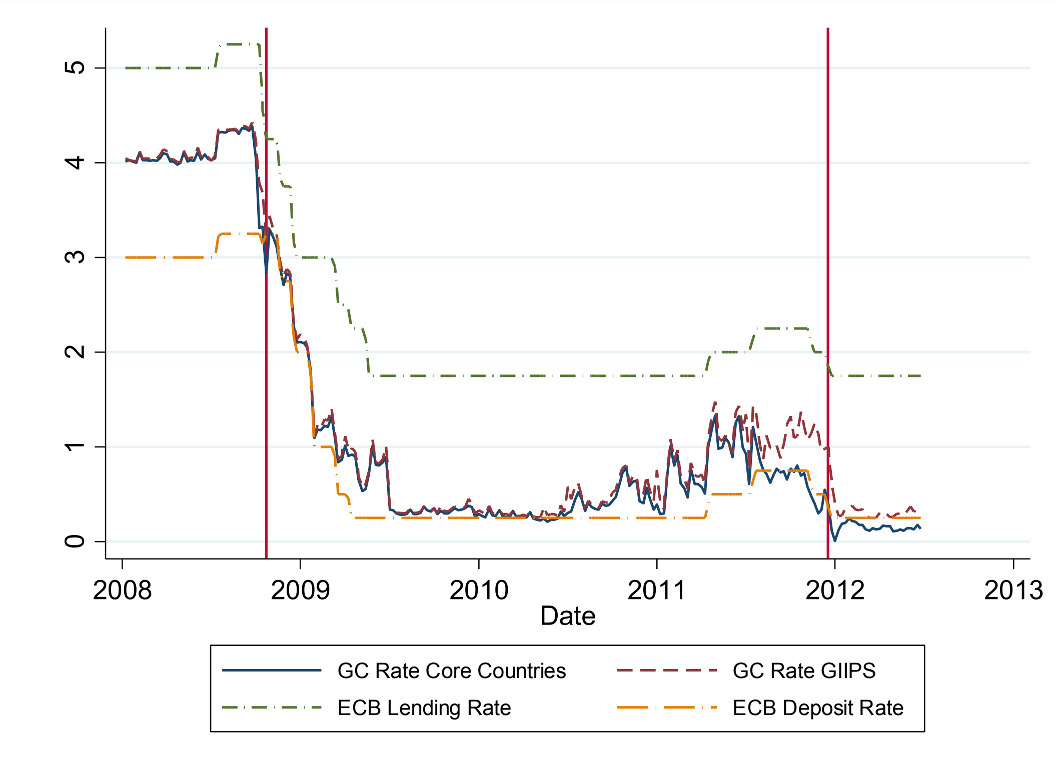


Figure 5: Sovereign CDS spreads, 2008-2012 S1

This figure presents the evolution of weekly average sovereign CDS spreads for GIIPS (Greece, Ireland, Italy, Portugal and Spain) and non-GIIPS Eurozone countries between January 2008 and June 2012. CDS spreads are in percent.

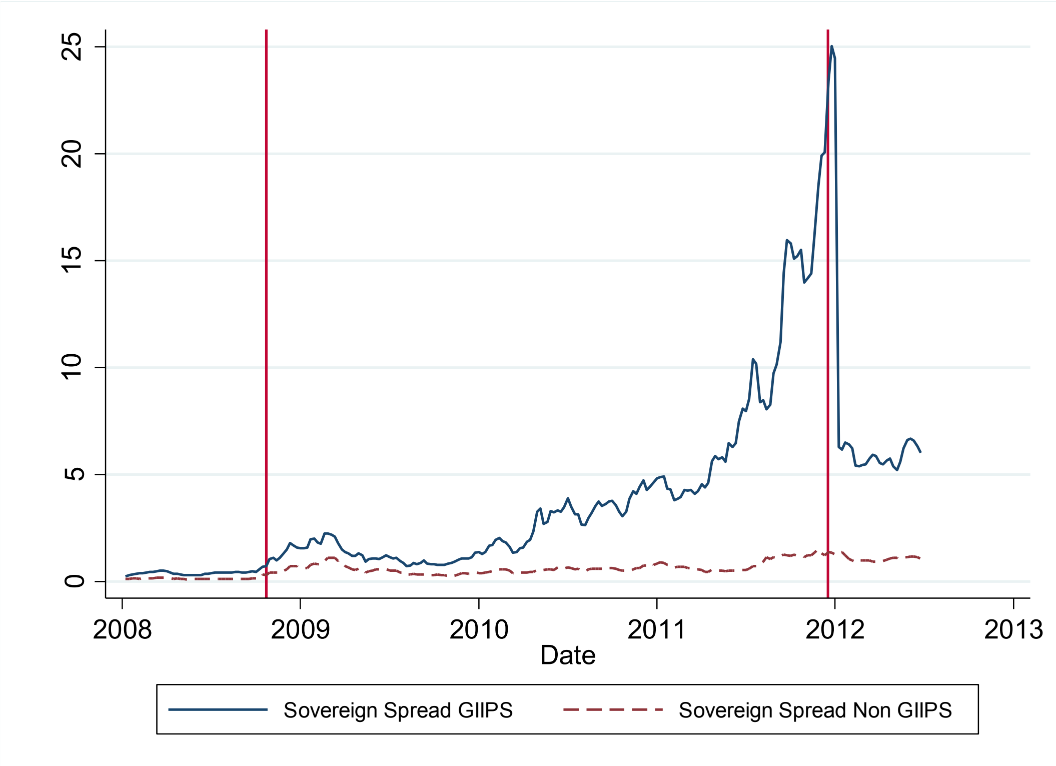


Figure 6: Relationship between repo rates and sovereign CDS spreads

This figure presents a scatter plot of the relationship between the average daily repo rate and the average daily sovereign CDS spread, across the 11 repo markets in our data. Each dot corresponds to one day. On the x-axis, we report the average sovereign CDS spread across the 11 countries. On the y-axis, we report the average difference between the repo rate and the ECB deposit rate across the same 11 countries. Our data has 1,149 observations, corresponding to all days between Jan 1, 2008 and June 30, 2012. The coefficient of the regression of repo rates on CDS spreads is -0.06, with an heteroskedacity-adjusted t-statistic of -14.01.

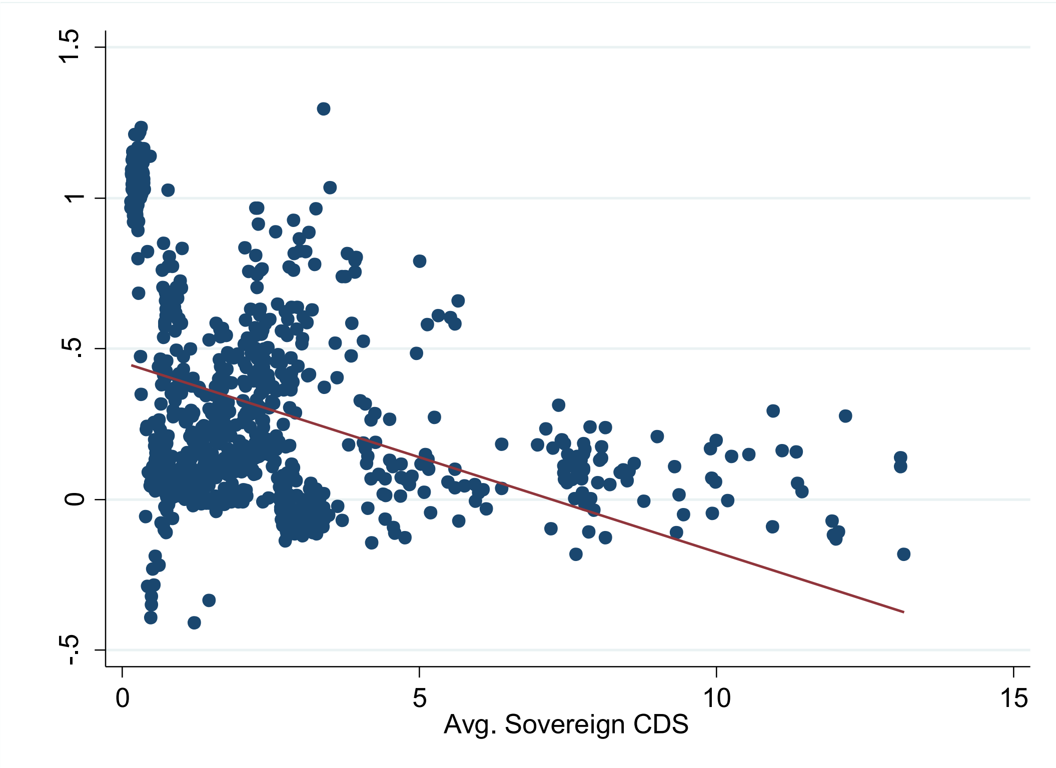


Figure 7: The evolution of haircuts

This figure presents the evolution of haircuts applied to General Collateral (GC) repo transactions by ICAP BrokerTec in France, Italy and Spain between 2008 and June 2012. Haircuts are averaged across maturity groups (below and above 7 years) and are expressed in percent.

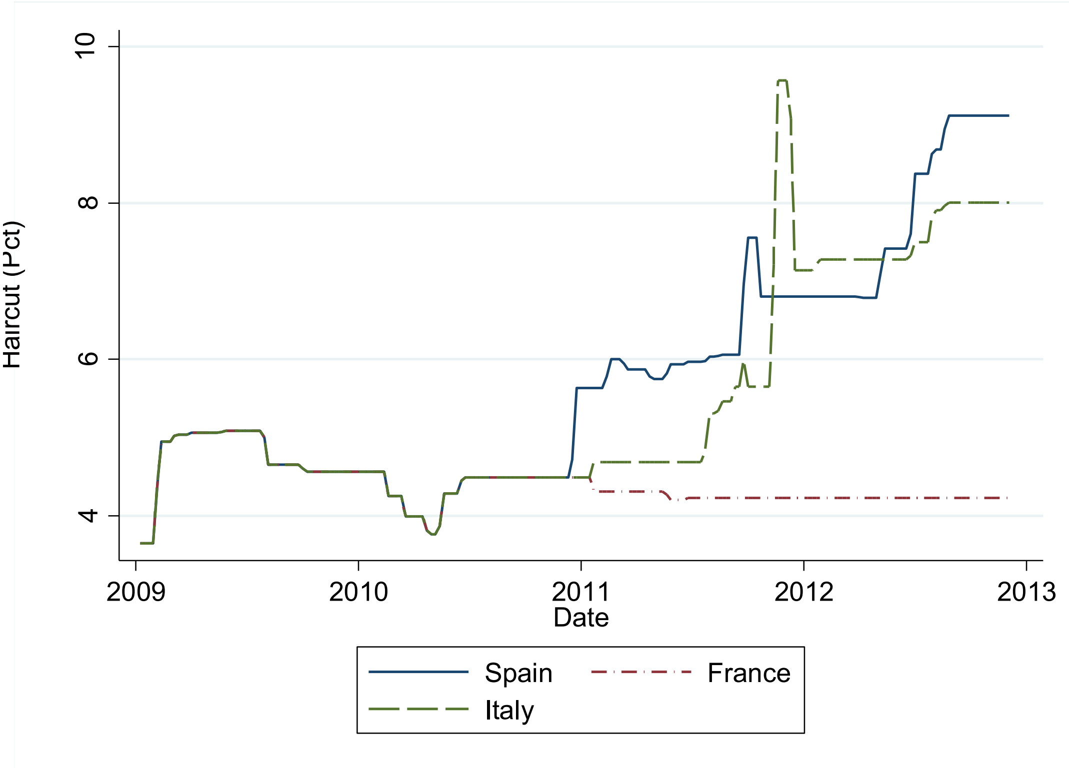
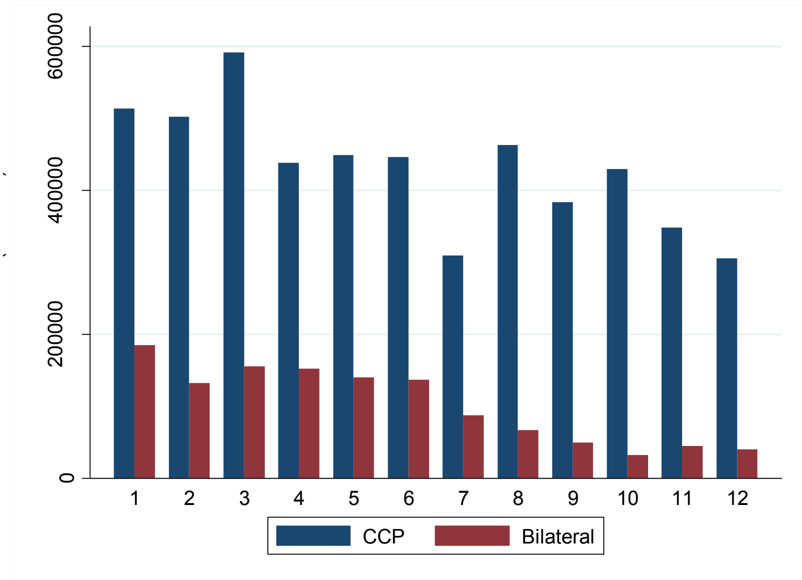


Figure 8: Monthly volumes of CCP-cleared versus bilateral repo transactions in 2011

This figure presents volumes of CCP-based and bilateral GC repo transactions in the Eurozone for each month of 2011. Panel A presents volume for GIIPS countries for which data are available (Italy, Portugal and Spain). Panel B presents volume for all Non-GIIPS countries in our dataset. All amounts are in €m.

Panel A: Italy, Portugal, and Spain



Panel B: Non-GIIPS Countries

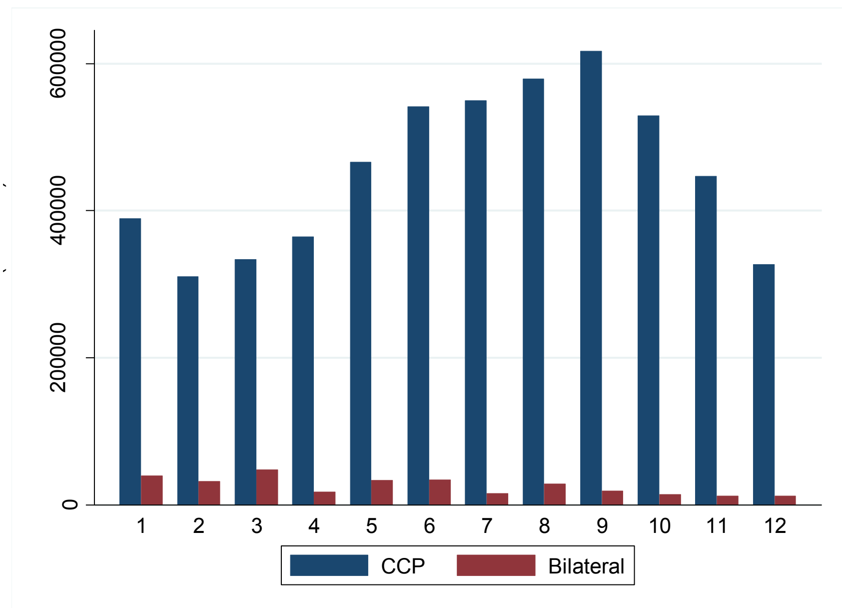


Table 1: Summary statistics

This table reports summary statistics over the entire sample period, and over each of the four sub-periods we consider in subsequent tests. *Repo Rate-ECB Deposit Rate* is the annualized country-level average daily general collateral (GC) repo rate for one-day repo contracts minus the ECB deposit facility rate. *Daily Volume* is the country-level total daily trading volume of such repo contracts. *Sovereign CDS Spread* is the country-level daily 5-year sovereign credit default swap rate. *CCP Member CDS Spread* is the average daily 5-year CDS spread of all financial institutions that are members of the CCPs in the sample.

	Number of observations	Mean	Median	Std. Dev.	Min.	Max.
Jan. 2008 to June 2012						
Repo Rate-ECB Deposit Rate (Pct)	8,814	0.31	0.14	0.40	-0.65	1.88
Daily Volume (€bn)	8,814	5.80	1.65	9.44	0.03	61.77
Sovereign CDS Spread (Pct)	8,471	1.04	0.68	0.95	0.05	5.22
CCP Members CDS Spread (Pct)	8,814	1.78	1.53	0.89	0.46	4.52
Jan. 2008 to Lehman's bankruptcy						
Repo Rate-ECB Deposit Rate (Pct)	1,218	1.06	1.06	0.06	0.74	1.46
Daily Volume (€bn)	1,218	6.17	1.05	11.62	0.03	53.27
Sovereign CDS Spread (Pct)	989	0.24	0.20	0.15	0.05	0.64
CCP Members CDS Spread (Pct)	1,218	0.89	0.90	0.24	0.46	1.68
Jan. 2009 to Dec. 2010						
Repo Rate-ECB Deposit Rate (Pct)	4,190	0.19	0.10	0.21	-0.45	1.63
Daily Volume (€bn)	4,190	5.92	1.17	10.35	0.03	61.77
Sovereign CDS Spread (Pct)	4,134	0.97	0.68	0.76	0.17	4.81
CCP Members CDS Spread (Pct)	4,190	1.41	1.41	0.35	0.83	2.32
Jan. 2011 to Dec. 2011 LTRO						
Repo Rate-ECB Deposit Rate (Pct)	1,857	0.30	0.29	0.33	-0.43	1.88
Daily Volume (€bn)	1,857	5.80	3.10	6.78	0.03	38.51
Sovereign CDS Spread (Pct)	1,857	1.36	1.00	1.13	0.23	5.22
CCP Members CDS Spread (Pct)	1,857	2.60	2.19	0.84	1.53	4.52
Jan. 2012 to June 2012						
Repo Rate-ECB Deposit Rate (Pct)	882	-0.05	-0.07	0.08	-0.21	0.22
Daily Volume (€bn)	882	4.85	2.30	5.80	0.03	27.18
Sovereign CDS Spread (Pct)	882	1.77	1.22	1.20	0.28	4.73
CCP Members CDS Spread (Pct)	882	3.25	3.26	0.42	2.55	3.93

Table 2: GC repo rates and sovereign CDS spreads

This table report estimates of fixed-effect panel regressions in which the dependent variable is the daily country-level average general collateral (GC) repurchase agreement rate minus the ECB deposit facility rate (*Repo Rate-ECB Deposit Rate)* and the explanatory variable is the daily country-level 5-year sovereign credit default swap rate (*Sovereign CDS*). All regressions include day fixed effects. Moreover, Panel A regressions include country fixed effects and Panel B regressions include country-month fixed effects. t-statistics are presented in parentheses. Standard errors are clustered at the daily level. *, **, and *** denote statistical significance at the 10%-, 5%-, and 1%-level, respectively.

Panel A: Fixed-effect regressions

	(1) 2008-2012 S1	(2) 2008-Lehman	(3) 2009-2010	(4) 2011	(5) 2012 S1
Sovereign CDS	0.065***	-0.023	0.016***	0.192***	0.033***
	(14.54)	(-0.58)	(6.34)	(16.53)	(6.78)
Day FE	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes
Country-month FE	No	No	No	No	No
Number of observations	8,471	989	4,174	1,817	882
R^2	0.959	0.739	0.941	0.922	0.850

Panel B: Fixed-effect regressions with country-month fixed effects

	(1) 2008-2012 S1	(2) 2008-Lehman	(3) 2009-2010	(4) 2011	(5) 2012 S1
Sovereign CDS	0.015	-0.010	0.002	0.076**	0.007
	(1.19)	(-1.30)	(0.21)	(2.28)	(0.57)
Day FE	Yes	Yes	Yes	Yes	Yes
Country FE	No	No	No	No	No
Country-month FE	Yes	Yes	Yes	Yes	Yes
Number of observations	8,471	989	4,174	1,817	882
R^2	0.980	0.785	0.950	0.949	0.946

Table 3: GC repo rates and sovereign CDS spreads – GIIPS vs. non-GIIPS countries

This table reports the estimates of fixed-effect panel regressions in which the dependent variable is the daily country-level average general collateral (GC) repurchase agreement rate minus the ECB deposit facility rate (*Repo Rate-ECB Deposit Rate).* The explanatory variables are the daily country-level 5-year sovereign credit default swap rate (*Sovereign CDS*), and its interaction with an indicator variable that is equal to one for Greece, Ireland, Italy, Portugal and Spain, and zero otherwise (*GIIPS*). All regressions include day fixed effects. Moreover, Panel A regressions include country fixed effects, and Panel B regressions include country-month fixed effects. t-statistics are presented in parentheses. Standard errors are clustered at the daily level. *, **, and *** denote statistical significance at the 10%-, 5%-, and 1%-level, respectively.

Panel A: Fixed-effect regressions

	(1) 2008-2012 S1	(2) 2008-Lehman	(3) 2009-2010	(4) 2011	(5) 2012 S1
Sovereign CDS	-0.023***	-0.119	-0.022***	0.016	0.043***
	(-5.81)	(-1.06)	(-4.74)	(1.29)	(5.88)
GIIPS×Sovereign CDS	0.082***	0.084	0.038***	0.158***	-0.010
	(14.47)	(1.01)	(7.41)	(10.73)	(-1.15)
Day FE	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes
Country-month FE	No	No	No	No	No
Number of observations	8,471	989	4,174	1,817	882
R^2	0.961	0.740	0.941	0.931	0.933

Panel B: Fixed-effect regressions with country-month fixed effects

	(1) 2008-2012 S1	(2) 2008-Lehman	(3) 2009-2010	(5) 2011	(6) 2012 S1
Sovereign CDS	-0.051***	-0.130	-0.030	-0.108***	0.016
	(-2.87)	(-0.58)	(-1.23)	(-3.36)	(1.13)
GIIPS×Sovereign CDS	0.066***	0.028	0.030	0.208***	-0.009
	(3.43)	(0.15)	(1.32)	(5.24)	(-0.48)
Day FE	Yes	Yes	Yes	Yes	Yes
Country FE	No	No	No	No	No
Country-month FE	Yes	Yes	Yes	Yes	Yes
Number of observations	8,471	989	4,174	1,817	882
R^2	0.981	0.785	0.950	0.950	0.946

Table 4: GC repo volume and sovereign CDS spreads

This table reports the estimates of fixed-effect panel regressions in which the dependent variable is the logarithm of the daily country-level general collateral (GC) repurchase agreement volume in €bn (*ln(Daily Volume+1)*) and the explanatory variable is the daily country-level 5-year sovereign credit default swap rate (*Sovereign CDS*). All regressions include day fixed effects. Moreover, Panel A regressions include country fixed effects, and Panel B regressions include country-month fixed effects. t-statistics are presented in parentheses. Standard errors are clustered at the daily level. *, **, and *** denote statistical significance at the 10%-, 5%-, and 1%-level, respectively.

Panel A: Fixed-effect regressions

	(1) 2008-2012 S1	(2) 2008-Lehman	(3) 2009-2010	(4) 2011	(5) 2012 S1
Sovereign CDS	-0.368***	-0.160	-0.900***	-0.413***	-0.412***
	(-8.27)	(-0.10)	(-17.42)	(-4.77)	(-3.94)
Day FE	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes
Country-month FE	No	No	No	No	No
Number of observations	10,135	1,263	5,053	2,117	989
R^2	0.174	0.207	0.198	0.180	0.320

Panel B: Fixed-effect regressions with country-month fixed effects

	(2) 2008-2012 S1	(3) 2008-Lehman	(4) 2009-2010	(5) 2011	(6) 2012 S1
Sovereign CDS	-0.183	4.088	-0.107	-0.302	-0.443
	(-1.23)	(1.12)	(-0.59)	(-0.98)	(-1.39)
Day FE	Yes	Yes	Yes	Yes	Yes
Country FE	No	No	No	No	No
Country-month FE	Yes	Yes	Yes	Yes	Yes
Number of observations	10,135	1,263	5,053	2,117	989
R^2	0.811	0.851	0.791	0.828	0.849

Table 5: GC-repo volume and sovereign CDS spreads – GIIPS vs. non-GIIPS countries

This table reports the estimates of fixed-effect panel regressions in which the dependent variable is the logarithm of the daily country-level general collateral (GC) repurchase agreement volume in €bn (*ln(Daily Volume+1)*). The explanatory variables are the daily country-level 5-year sovereign credit default swap rate (*Sovereign CDS*) and its interaction with an indicator variable that is equal to one for Greece, Ireland, Italy, Portugal and Spain, and zero otherwise (*GIIPS*). All regressions include day fixed effects. Moreover, Panel A regressions include country fixed effects, and Panel B regressions include country-month fixed effects. t-statistics are presented in parentheses. Standard errors are clustered at the daily level. *, **, and *** denote statistical significance at the 10%-, 5%-, and 1%-level, respectively.

Panel A: Fixed-effect regressions

	(2) 2008-2012 S1	(3) 2008-Lehman	(4) 2009-2010	(5) 2011	(6) 2012 S1
Sovereign CDS	-0.609***	0.688	0.395**	-2.215***	0.145
	(-7.62)	(0.17)	(2.28)	(-10.14)	(0.52)
GIIPS×Sovereign CDS	0.227***	-0.748	-1.288***	1.682***	-0.583**
	(3.66)	(-0.23)	(-7.73)	(10.65)	(-2.10)
Day FE	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes
Country-month FE	No	No	No	No	No
Number of observations	10135	1263	5053	2117	989
R^2	0.697	0.817	0.724	0.739	0.817

Panel B: Fixed-effect regressions with country-month fixed effects

	(1) 2008-2012 S1	(2) 2008-Lehman	(3) 2009-2010	(5) 2011	(6) 2012 S1
Sovereign CDS	0.345	-0.645	1.433**	0.128	-0.533
	(1.10)	(-0.09)	(2.34)	(0.31)	(-1.03)
GIIPS×Sovereign CDS	-0.523*	4.396	-1.489**	-0.471	0.098
	(-1.73)	(0.78)	(-2.53)	(-1.08)	(0.20)
Day FE	Yes	Yes	Yes	Yes	Yes
Country FE	No	No	No	No	No
Country-month FE	Yes	Yes	Yes	Yes	Yes
Number of observations	10135	1263	5053	2117	989
R^2	0.811	0.851	0.791	0.828	0.849

Table 6: The impact of haircuts on the repo rate-to-CDS spread sensitivity

This table reports the estimates of OLS regressions explaining the daily country-level general collateral (GC) repo rate minus the ECB deposit facility rate (*Repo Rate-ECB Deposit Rate)* around the haircut changes on Spanish repos of December 16, 2010 and September 21, 2011 and around the haircut change on Italian repos of November 10 2011. The explanatory variables are the daily country-level 5-year sovereign credit default swap rate (*Sovereign CDS*), an indicator variable equal to one after the haircut change (*POST*), an indicator variable equal to one for Spain or Italy (*HC COUNTRY*), and interactions between these variables. Columns 1 and 3 present the results for Spanish repo rates only in a 6-month window around the haircut change, respectively for the December 2010 and the September 2011 increases. Column 5 presents the results for Italian repo rates only in a two-month window around the haircut change of November 2011. Columns 2 and 4 present the results for Spanish repo using a difference-in-differences estimation using repo rates from all Eurozone countries as the control group in a 6-month window around the two Spanish haircut changes. Column 6 presents the results for Italian repo using a difference-in-differences estimation using repo rates from all Eurozone countries as the control group in a two-month window around the November 2011 haircut change. In columns 1, 3 and 5, standard errors are corrected using the Newey-West procedure with a 5-day lag. In columns 2, 4 and 6, standard errors are clustered at the daily level. t-statistics are in parentheses. *, **, and *** denote statistical significance at the 10%-, 5%-, and 1%-level, respectively.

	Spain December 2010 haircut change		Spain September 2011 haircut change		Italy November 2011 haircut change	
	(1) Spain only	(2) Spain and others	(3) Spain only	(4) Spain and others	(5) Italy only	(6) Italy and others
Sovereign CDS	-0.082	-0.291***	-0.385***	-0.245***	-0.095	-0.111
	(-1.47)	(-5.98)	(-3.51)	(-6.24)	(-1.01)	(-1.53)
POST	0.586***	0.068*	-1.501***	-0.340***	-1.289***	-0.095**
	(2.79)	(1.70)	(-3.73)	(-8.48)	(-3.00)	(-2.04)
POST× Sovereign CDS	-0.209**	0.027**	0.524***	0.203***	0.357***	0.059***
	(-2.26)	(2.07)	(4.01)	(9.88)	(3.30)	(2.76)
HC Country× Sovereign CDS		0.209***		-0.140		0.017
		(4.24)		(-1.05)		(0.16)
POST×HC Country		0.518***		-1.161**		-1.172**
		(2.68)		(-2.32)		(-2.21)
POST×HC Country ×Sovereign CDS		-0.236**		0.320**		0.291**
		(-2.58)		(2.06)		(2.22)
Constant	0.524***	0.644***	1.498***	0.580***	0.851**	0.272**
	(4.19)	(11.25)	(4.52)	(6.12)	(2.36)	(2.27)
Country FE	No	Yes	No	Yes	No	Yes
Number of obs.	88	997	111	951	44	333
R^2		0.148		0.571		0.803

Table 7: GIIPS sovereign CDS spreads and the CDS spreads of CCP members

This table reports OLS regressions of changes in CCP members' CDS spreads on changes in GIIPS sovereign CDS spreads, controlling for a CDS risk factor. *Change in GIIPS Sovereign CDS* is the average daily change in the spread of the 5-year sovereign CDS across all 5 GIIPS countries. *CDS common risk factor* is the first principal component of the vector of CDS changes of all sovereign CDS. In panel A, the dependent variable is the average change of CDS of LCH.Clearnet and CC&G members. In Panel B, we use the average CDS change of LCH.Clearnet members only. In Panel C, we use the average CDS change of CC&G members only. t-statistics are presented in parentheses. GIIPS countries are Greece, Ireland, Italy, Portugal and Spain. Standard errors are robust to heteroskedasticity. t-statistics are in parentheses. *, **, and *** denote statistical significance at the 10%-, 5%-, and 1%-level, respectively.

Panel A: ΔCDS of all CCP members

	(1) 2008-2012 S1	(2) 2008-Lehman	(3) 2009-2010	(4) 2011	(5) 2012 S1
ΔGIIPS sovereign CDS	0.00123	0.796**	0.0335**	0.00412	0.000239
	(0.80)	(2.39)	(2.33)	(0.76)	(0.57)
CDS common risk factor	0.0246***	0.0834***	0.0227***	0.0222***	0.0285***
	(24.88)	(4.01)	(14.10)	(17.35)	(12.08)
Number of observations	1,075	136	486	243	125
R^2	0.482	0.241	0.597	0.689	0.612

Panel B: ΔCDS of members of LCH.Clearnet

	(1) 2008-2012 S1	(2) 2008-Lehman	(3) 2009-2010	(4) 2011	(5) 2012 S1
ΔGIIPS sovereign CDS	0.00116	0.815**	0.0344**	0.00404	0.000174
	(0.79)	(2.37)	(2.21)	(0.79)	(0.47)
CDS common risk factor	0.0236***	0.0847***	0.0224***	0.0209***	0.0269***
	(23.11)	(4.10)	(14.01)	(16.29)	(11.69)
Number of observations	1,075	136	486	243	125
R^2	0.461	0.237	0.596	0.682	0.612

Panel C: ΔCDS of members of CC&G

	(1) 2008-2012 S1	(2) 2008-Lehman	(3) 2009-2010	(4) 2011	(5) 2012 S1
ΔGIIPS sovereign CDS	0.000531	0.781*	0.0196	0.00161	0.000453
	(0.35)	(1.98)	(1.29)	(0.26)	(0.89)
CDS common risk factor	0.0269***	0.0915***	0.0235***	0.0256***	0.0332***
	(28.61)	(3.50)	(12.74)	(19.79)	(13.74)
Number of observations	1,075	136	486	243	125
R^2	0.481	0.219	0.536	0.733	0.621

Table 8: Repo-to-CDS spread sensitivity in CCP-cleared vs. bilateral transactions

This table reports the estimates of fixed-effect panel regressions in which the dependent variable is the monthly country-level volume-weighted average general collateral (GC) repo rate minus the ECB deposit facility rate (*Repo Rate-ECB Deposit Rate*) in column 1 and the monthly country-level volume-weighted average bilateral repo rate minus the ECB deposit facility rate in column 2. The explanatory variables are the volume-weighted average monthly country-level 5-year sovereign credit default swap rate (*Sovereign CDS*), and its interaction with an indicator variable that is equal to one for Portugal, Italy and Spain, and zero otherwise (*GIIPS*). Observations are limited to countries for which both bilateral and GC repo transactions are observed in a given month. The regressions include month fixed effects and country fixed effects. t-statistics are presented in parentheses. Standard errors are clustered at the monthly level. *, **, and *** denote statistical significance at the 10%-, 5%-, and 1%-level, respectively.

Panel A: 2011

	(1) CCP	(2) Bilateral
Sovereign CDS	-0.018	-0.003
	(-0.31)	(-0.05)
GIIPS×Sovereign CDS	0.186***	0.141**
	(4.57)	(2.66)
Month FE	Yes	Yes
Country FE	Yes	Yes
Number of observations	84	84
R^2	0.942	0.882

Panel B: 2012

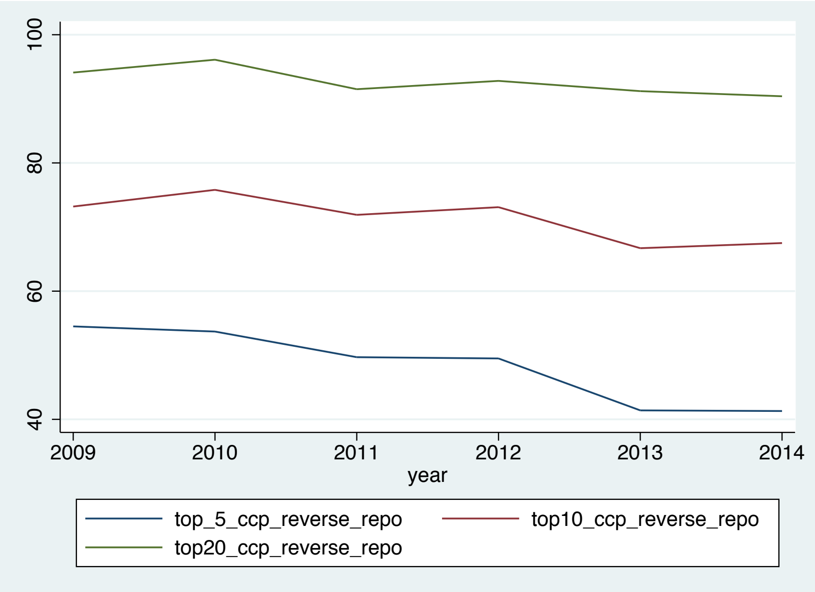
	(1) CCP	(2) Bilateral
Sovereign CDS	0.038**	0.019
	(2.86)	(0.50)
GIIPS×Sovereign CDS	-0.016	0.018
	(-1.12)	(0.54)
Month FE	Yes	Yes
Country FE	Yes	Yes
Number of observations	38	38
R^2	0.985	0.944

APPENDIX A: SUPPLEMENTARY TABLES AND FIGURES

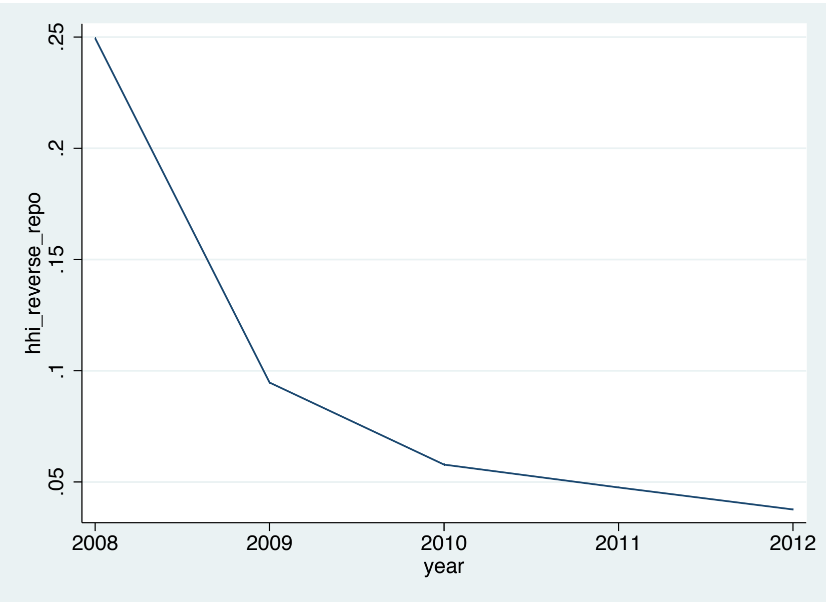
APPENDIX FIGURE A.1: Concentration on the CCP cleared Repo Market

Panel A presents the annual percentage share of reverse repos by the top 5, 10 and 20 largest European banks as reported in the ECB Money Market Study. Panel B presents, the evolution of the Herfindahl-Hirschman Index, which is calculated based on reverse repo data from Bankscope.

Panel A: Share of largest participants to CCP-cleared repo (source: ECB Money Market Study)



Panel B: Herfindahl-Hirschman Index of reverse repo market concentration (source: Bankscope)



Appendix Table A.1: GC repo rates and sovereign CDS spreads – Robustness checks

This table reports the estimates of fixed-effect panel regressions in which the dependent variable is the country-level average daily general collateral (GC) repurchase agreement rate minus the ECB deposit facility rate (*Repo Rate-ECB Deposit Rate)*. In Panel A, the explanatory variable is the daily country-level one-year sovereign credit default swap rate (*Sovereign CDS*) and its interaction with an indicator variable that is equal to one for Greece, Ireland, Italy, Portugal and Spain, and zero otherwise (*GIIPS*). In Panel B, we run the same regression with the 5-year sovereign CDS rate (as in Table 3, Panel B) excluding Italy from the sample. All regressions include day and country-month fixed effects. t-statistics are presented in parentheses. Standard errors are clustered at the daily level. *, **, and *** denote statistical significance at the 10%-, 5%-, and 1%-level, respectively.

Panel A: Repo-to-CDS spread sensitivity with one-year sovereign CDS

	(1) 2008-2012 S1	(2) 2008-Lehman	(3) 2009-2010	(4) 2011	(5) 2012 S1
Sovereign CDS	-0.032**	-0.350	-0.017	-0.064**	0.005
	(-2.10)	(-1.41)	(-0.72)	(-2.30)	(0.45)
GIIPS×Sovereign CDS	0.055***	0.122	0.022	0.180***	-0.012
	(3.20)	(0.52)	(1.02)	(5.40)	(-0.79)
Day FE	Yes	Yes	Yes	Yes	Yes
Country-month FE	Yes	Yes	Yes	Yes	Yes
Number of observations	7151	846	3653	1460	716
R^2	0.979	0.793	0.947	0.944	0.945

Panel B: Fixed-effect regressions with country-month fixed effects excluding Italy

	(1) 2008-2012 S1	(2) 2008-Lehman	(3) 2009-2010	(5) 2011	(6) 2012 S1
Sovereign CDS	-0.037**	-0.108	-0.033	-0.089***	0.009
	(-2.52)	(-0.44)	(-1.26)	(-3.49)	(0.68)
GIIPS×Sovereign CDS	0.032*	0.007	0.034	0.129***	-0.009
	(1.93)	(0.03)	(1.39)	(3.03)	(-0.46)
Day FE	Yes	Yes	Yes	Yes	Yes
Country-month FE	Yes	Yes	Yes	Yes	Yes
Number of observations	7324	813	3918	1564	760
R^2	0.983	0.766	0.948	0.960	0.950

Appendix Table A2: Controlling for ECB haircut policy

This table reports the estimates of equation (6). All regressions include day and country-month fixed effects. The average ECB haircut (*ECB HC*) is computed as the average prevailing haircut on all sovereigns of the country. t-statistics are presented in parentheses. Standard errors are clustered at the daily level. *, **, and *** denote statistical significance at the 10%-, 5%-, and 1%-level, respectively.

Panel A: Sensitivity of repo rates to sovereign CDS spreads

	(1) 2010-2012 S1	(2) 2010	(3) 2011	(4) 2012 S1
Sovereign CDS	0.033**	0.00123	0.076**	0.007
	(2.31)	(0.13)	(2.28)	(0.56)
ECB HC	-0.0003	-0.013	-0.009	0.002
	(-0.05)	(-0.34)	(-0.39)	(0.51)
Day FE	Yes	Yes	Yes	Yes
Country-month FE	Yes	Yes	Yes	Yes
Number of observations	4,173	1,462	1,809	875
R^2	0.957	0.923	0.949	0.946

Panel B: Sensitivity of repo rates to sovereign CDS spreads – GIIPS vs. non-GIIPS

	(1) 2010-2012 S1	(2) 2010	(3) 2011	(4) 2012 S1
Sovereign CDS	-0.090***	-0.138***	-0.108***	0.016
	(-4.34)	(-4.10)	(-3.35)	(1.18)
ECB HC	-0.004	-0.005	-0.008	0.003
	(-0.51)	(-0.14)	(-0.29)	(0.61)
GIIPS×Sovereign CDS	0.128***	0.135***	0.208***	-0.010
	(5.57)	(4.18)	(5.23)	(-0.52)
Day FE	Yes	Yes	Yes	Yes
Country-month FE	Yes	Yes	Yes	Yes
Number of observations	4,173	1,462	1,809	875
R^2	0.957	0.924	0.950	0.946

Appendix Table A3: Controlling for country-level exposure to risk

This table reports the estimates of equation (7). All regressions include day fixed effects and country-month fixed effects. We also include the Vixx Interacted with country fixed effects. t-statistics are presented in parentheses. Standard errors are clustered at the daily level. *, **, and *** denote statistical significance at the 10%-, 5%-, and 1%-level, respectively.

Panel A: Sensitivity of repo rates to sovereign CDS spreads

	(1) 2008-2012 S1	(2) 2008-Lehman	(3) 2009-2010	(4) 2011	(5) 2012 S1
Sovereign CDS	0.016	-0.149*	-0.001	0.073**	0.012
	(1.32)	(-1.69)	(-0.16)	(2.09)	(0.85)
Day FE	Yes	Yes	Yes	Yes	Yes
Country-Month FE	Yes	Yes	Yes	Yes	Yes
Country FE×Vixx	Yes	Yes	Yes	Yes	Yes
Number of obs.	8,437	989	4,156	1,817	882
R^2	0.981	0.786	0.951	0.949	0.946

Panel B: Sensitivity of repo rates to sovereign CDS spreads – GIIPS vs. non-GIIPS

	(1) 2008-2012 S1	(2) 2008-Lehman	(3) 2009-2010	(4) 2011	(5) 2012 S1
Sovereign CDS	-0.060***	-0.089	-0.028	-0.121***	0.023
	(-3.30)	(-0.28)	(-1.01)	(-3.81)	(1.61)
GIIPS×Sovereign CDS	0.079***	-0.056	0.026	0.225***	-0.014
	(4.05)	(-0.21)	(0.96)	(5.60)	(-0.63)
Day FE	Yes	Yes	Yes	Yes	Yes
Country-Month FE	Yes	Yes	Yes	Yes	Yes
Country FE×Vixx	Yes	Yes	Yes	Yes	Yes
Number of obs.	8,437	989	4,156	1,817	882
R^2	0.981	0.786	0.951	0.951	0.946

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