School of Finance

University of St.Gallen

THE FORWARD PREMIUM IN SHORT-TERM RATES

ANGELO RANALDO
MATTHIAS RUPPRECHT

WORKING PAPERS ON FINANCE NO. 2016/19

SWISS INSTITUTE OF BANKING AND FINANCE (S/BF – HSG)

OCTOBER 2016
THIS VERSION: SEPTEMBER 5, 2019

The Forward Premium in Short-Term Rates*

Angelo Ranaldo
University of St. Gallen†

Matthias Rupprecht
University of St. Gallen‡

September 5, 2019

*We thank Farshid Abdi, Alexander Bechtel, Martin Brown, Markus Brunnermeier, Pasquale Della Corte, Phillipe Mueller, Lucio Sarno, Patrick Schaffner, Paul Söderlind, Dimitri Vayanos, Andrea Vedolin, Jan Wrampelmeyer, and Shengxing Zhang, as well as participants of the 2017 European Finance Association, the Bank of England, University of Zurich, and the Swiss National Bank for helpful comments. This work was supported by the grants 165002 and 154445 (Sinergia) from the Swiss National Science Foundation.

†Angelo Ranaldo, University of St. Gallen, Swiss Institute of Banking and Finance, Unterer Graben 21, CH-9000 St. Gallen, Switzerland. E-mail: angelo.ranaldo@unisg.ch.

‡Matthias Rupprecht, University of St. Gallen, E-mail: matthias.rupprecht@unisg.ch.

The Forward Premium in Short-Term Rates

September 5, 2019

This paper provides the first systematic study of the temporal and cross-sectional variation in the forward premium in very short-term rates. Using a unique and comprehensive data set of European repurchase agreements (repo), we find that the forward premium varies significantly with the (net) demand for borrowing and funding risk. Conditional tests of the unbiasedness hypothesis reveal that the Expectations Hypothesis (EH) cannot be rejected when funding liquidity risk is low and the demand is balanced. Overall, funding liquidity risk is the main driver affecting the short end of the term structure, and the validity of the EH depends on funding risk premiums and demand for funding immediacy.

Keywords: Expectations hypothesis, repo, forward premium, interest rates

JEL Codes: D01, E43, E52, G10, G21

Since Fisher (1896), the expectations hypothesis (EH) has been a pivotal theory for interest rates, affecting all areas in financial economics and, in particular, asset pricing in bond and foreign exchange (FX) markets. Postulating that the long-term rate is purely determined by the current and expected future short-term rates plus a constant risk premium, the EH has mostly been rejected empirically[1]. Even at the very short end of the term structure, where Longstaff (2000b) first tested the EH using general collateral (GC) repo rates, Della Corte, Sarno, and Thornton (2008) reject it statistically, yet confirm the theory's economic validity.

In this paper, we approach the EH from a new angle, asking whether the time variation of funding risk can explain the EH's failure. Specifically, by funding risk we mean immediacy and costs of raising short-term liquidity in the repo market, which has become the main source of funding in the economy. Most importantly, the overnight repo rate not only constitutes the short rate of the term structure, as introduced by Longstaff (2000b), it also serves as the main funding rate for investors' bond positions along the entire yield curve. As the most prevalent repo maturity and policy target rate, the overnight repo rate is where funding risk materializes, spreading across the term structure through investors' bond trading, and deterring the relation between long- and short-term interest rates as postulated by the EH.

We analyze the impact of funding risk on the forward premium in overnight repo rates, expressed as the spread between the forward and spot rate. Both repos are overnight loans secured with various collateral securities that are ideal to identify any temporal and cross-sectional variation in funding risk. To the extent that the forward rate is an unbiased predictor of the future spot rate, the unbiasedness hypothesis holds in the absence of time-varying risk premiums. Using unique transaction-level data, we find that the unbiasedness hypothesis is statistically rejected when funding risk is high, but cannot be rejected when funding risk is absent.

A better understanding of the forward premium and its impact on the EH is important to policy makers and investors for at least three reasons. First, investment decisions and economic output are

[1] An exhaustive survey goes beyond the scope of this paper. Former studies on the EH include, e.g., Roll (1970), Fama (1984a), Fama and Bliss (1987), Frankel and Froot (1987), Stambaugh (1988), Froot (1989) Campbell and Shiller (1991), Bekaert, Hodrick, and Marshall (1997), and Bekaert and Hodrick (2001).

determined by short-term market expectations, which are commonly retrieved from the yield curve and require a separation of the effects coming from risk premiums (Keynes, 1936). Second, an effective and timely implementation of economic and monetary policies needs a thorough understanding and accurate interpretation of interest rates, agents' expectations, and risk premiums. Time and cross-sectional variations of short-term rates can indeed obstruct the pass-through efficiency of monetary policy (Duffie and Krishnamurthy, 2016). Third, among the first symptoms of a financial crisis are a sudden increase in risk premiums and quantity rationing of money market liquidity that can generate bank runs, rollover risk, and system-wide financial contagion. Thus, a better understanding of time-varying risk premiums is crucial for market regulators (e.g., Financial Stability Board, 2012).

We argue that investigating the forward premium in overnight repo rates allows isolating the main assumptions behind the unbiasedness hypothesis, namely, rational expectations and constant risk premiums. First, the use of overnight repos allows removing various sources of (time-varying) risk. Since funding concentrates in very short-term maturities, this reduces term premiums and uncertainty over longer horizons (Hicks, 1946). Additionally, overcollateralization of repos removes or reduces credit risk, making loans inherently informationally insensitive (Holmstrom, 2015) and the nominal repayment virtually certain when secured by safe assets such as European government bonds (Gorton and Ordonez, 2014).[2]

Second, the European repo market studied in this paper provides the ideal institutional setting to form rational expectations on short-term interest rates. The determination of European repo rates benefits from various money market index rates and, most importantly, from the Euro system's official target rate for main refinancing operations (MRO), thus facilitating an efficient price discovery process and the reduction of search costs (Duffie, Dworczak, and Zhu, 2017). In addition, the European repo market is an interbank market populated by professional agents who trade on anonymous, transparent, and liquid platforms cleared by central counterparties (Mancini, Ranaldo, and Wrampelmeyer, 2016), which reduce and homogenize counterparty credit risk (e.g., Duffie and Zhu, 2011; Acharya and Bisin, 2014) and

[2]Specifically, a repo is a sale (to the lender) and repurchase (of the borrower) of the collateral asset for an amount smaller than its market value, providing the lender with strong protection against credit risk.

determine ex ante margins that are exogenous to market participants, contrary to the prevalent practice in repo markets in the United States (Gorton and Metrick, 2012; Copeland, Martin, and Walker, 2014). Such a trading environment reduces possible arbitrage opportunities and many kinds of frictions that can bias the formation of rational expectations (Longstaff, 2000a).

Another important characteristic of the European repo market is the wide range of eligible collateral assets, which also differ in terms of sovereign credit quality (Mancini, Ranaldo, and Wrampelmeyer, 2016; Boissel et al., 2017). Repos can be secured by general collateral (GC), i.e., a wide range of securities with similar characteristics, or limited to a specific collateral security ("specials", SC). GC repos benefit from risk diversification, while special repos inherit idiosyncratic risk from the collateral security (Duffie, 1996). Importantly, GC and in particular special repos are used to fund investors' long and short positions across the term structure of bond maturities, providing a direct link between the analysis of the overnight forward premium and its implications for the validity of the EH.

Our analysis proceeds in two steps. First, we analyze the repo forward premium with respect to its variation with funding risk. To do this, we compute the daily forward premium as the spread between the daily forward and spot rates, using the "tomorrow-next" (TN) rate as the forward rate and the overnight (ON) rate as the spot rate. The only difference between the two repos is the settlement time, i.e., ON repos provide immediate funding settled same-day, while TN repos are settled one business day later. Both contracts have the same maturity, which ensures that the time frame for which the EH should hold and the return measurement period are identical, thus providing a consistent framework to analyze the time variation in term premiums (Longstaff, 1990). Given the contract and institutional design, we hypothesize that, if anything, the variation of the forward premium can be explained by time-varying funding risk. We measure funding risk at two levels: aggregate and repo-specific. The former is represented by the Libor-OIS spread, which is a commonly used proxy capturing money market uncertainty and constraints. The latter is new and is based on the order flow of a given repo contract, computed as the difference between (aggressive) borrower-initiated and lender-initiated trading volumes. A higher value of ON order flow signals funding demand pressure and thus funding immediacy, i.e., the urgency to raise funding capital. We conduct panel regressions of the forward premium with aggregate and specific measures of time-varying risk as explanatory variables. Moreover, we control for other possible determinants including calendar effects, such as the end of the monetary policy's "maintenance period" and quarter-ends that can affect repo markets (e.g., Munyan, 2017; BIS, 2017).

In the second part of our paper, we perform various conditional tests of the EH across time and collateral securities. Since we effectively analyze one-day differences in repo rates, we employ the vector autoregression (VAR) framework proposed by Bekaert and Hodrick (2001) and used in, e.g., Della Corte, Sarno, and Thornton (2008), which proves particularly suitable in detecting very small deviations. In particular, we examine whether today's forward premium is an efficient predictor of tomorrow's ON spot spread, and test the resulting restrictions imposed by the EH on the VAR parameters using a recursive iterative procedure developed by Bekaert and Hodrick (2001) and further investigated by Sarno, Thornton, and Valente (2007). We conduct conditional analyses based on the results obtained from the panel regressions. That is, we run the EH tests on sample periods conditioned on our funding risk variables. Specifically, we test the EH on sample periods when the funding risk variables were in their highest to lowest quartiles.

We use a unique and comprehensive data set representing the vast majority of the European repo market. Our data set spans from 2006 to 2016, including pre-crises as well as crises periods. We access every trade executed on the three main automated trading systems: BrokerTec, Eurex Repo, and MTS Repo, which together represent more than 67% of the entire European repo market in 2014 (ECB, 2014), covering a total trading volume of EUR 601 trillion, i.e., on average more than EUR 54 trillion per year. These numbers give an idea about the importance and the size of the European repo market, which is larger than the estimated size of the repo market in the United States.[3] Given the information granularity of our data, we provide the first systematic study of the temporal and cross-sectional variation in GC and special repo rates across heterogeneous collateral securities.

Several clear results emerge from our study. First, we find compelling evidence that the forward

[3]Estimates of the size of the U.S. repo market range from USD 5.5 trillion (Copeland et al., 2012) to USD 10 trillion (Gorton and Metrick, 2012).

premium is mainly driven by time-varying risk. For GC repos, the variation of aggregate funding risk and repo-specific order flow have a significant effect on the forward premium, even after controlling for time and repo-specific characteristics. This means, tighter funding constraints measured by money market risk premiums (e.g., Libor-OIS spread) increase the forward spread. Also, a stronger demand for funding immediacy in ON (TN) repos decreases (increases) the forward premium. For special repos, we test whether their forward premiums can also be affected by collateral issues. Following the previous literature, we measure "specialness" as the daily spread between countries' volume-weighted GC and special rates (Duffie, 1996). We find that aggregate funding risk and specialness increase the forward premium of special repo rates. We further test for the impact of funding risk by controlling for calendar effects arising from the European Central Bank's (ECB) monetary policy schedule and financial regulation. The results are robust and deliver consistent findings, in that the GC and special forward premiums depend on aggregate funding risk as well as ON net demand and specialness, respectively.

Second, we find that the statistical rejection of the EH for GC repo rates moves inversely with funding risk, suggesting that without risk variations, expectations about future short-term rates are in line with what the theory predicts. By contrast, the EH is typically rejected for specials. For GC, the EH finds support when aggregate funding risk and demand for funding immediacy is negligible. In the cross-section, the rejection of the EH is more evident when collateral securities bear sovereign risk premiums, such as for EU non-core countries' (i.e., Italian and Spanish) government bonds, or idiosyncratic risks as for specials.

Our paper contributes to three strands of the literature. First, we contribute to the forward premium literature. Whereas the forward premium has been predominantly studied in FX and longer interest rates, we provide the first study analyzing forward premiums in very short-term interest rates and show that they are determined by time-varying funding risk.

Second, we contribute to the literature on the EH. As a simple but general theory, the EH has attracted an enormous deal of attention in the literature. The most important contributions closest to our paper are Longstaff (2000b) and Della Corte, Sarno, and Thornton (2008), both providing a thorough empirical analysis of the EH using U.S. repo data. Contrary to prior research, Longstaff (2000b) shows that the EH holds for very short maturities, from overnight up to several weeks. Della Corte, Sarno, and Thornton (2008) provide evidence against the EH, but their rejection is insignificant from an economic point of view. Our paper reconciles this mixed evidence by explaining *why* the EH can fail, that is, the fundamental role of the time-varying funding risk premium. While the time-series approach has dominated prior research on the EH, none of the previous papers provides (i) a comparative analysis over different repo collateral securities and rates, and (ii) conditional EH analyses on funding risk and calendar effects.

Third, we contribute to the growing empirical literature on repo markets. Gorton and Metrick (2012), Krishnamurthy, Nagel, and Orlov (2014), and Copeland, Martin, and Walker (2014) analyze the effects of the recent financial crisis on U.S. repos. Mancini, Ranaldo, and Wrampelmeyer (2016) document the overall resilience of the European repo market during the recent financial crisis, while Boissel et al. (2017) show that repo rates collateralized by government bonds of GIIPS countries were affected by sovereign risk. Focusing on specials, Jordan and Jordan (1997) and Buraschi and Menini (2002) provide evidence that (liquidity) risk premiums affect repo rates. We contribute to the extant literature by examining whether and how time-varying (funding) risk and demand for funding immediacy, measured by the repo order flow, affect expectations on the pricing of GC and special repo rates. To do this, we analyze the largest and most comprehensive transaction-based data set of the European repo market studied so far.

The paper proceeds as follows. In the next section, we present the data set. Section 2 performs panel regressions of the forward premium. The econometric procedure of the EH tests is explained in Section 3, and the conditional test results are presented in Section 4. Section 5 concludes.

1. Data

Our data set contains every repo transaction executed on the three major European electronic trading platforms from 2006 to 2016: BrokerTec, Eurex Repo, and MTS Repo, which together represent more than 67% of the entire European repo market in 2014 (ECB, 2014).[4] There are two important distinguishing

[4]Other platforms exist (e.g., SENAF/MEFF Repo, TulletPrebon), but their volumes for CCP-based repo transactions are much smaller. For instance, the total repo volume on MEFF Repo between 2011 and 2014 is less than EUR 4.5 trillion (MEFF, 2014).

characteristics across European repos: First, the geographical origin of the collateral securities, which can be a country or a pool of countries: Belgium, France, Germany, Italy, Netherlands, and Spain, or GC Pooling ECB basket (henceforth "GCP") and GC Pooling ECB Extended basket ("GCX"). Second, a repo can be collateralized either more generally by a pre-specified basket of collateral securities (e.g., the same country issuing the collateral securities, or certain eligibility criteria as required for GCP vs. GCX), or limited to only a specific security (i.e., an unique ISIN). The former is called "general collateral" (GC) and the latter is a "special". The motives to enter a GC or special differ, in that GC repos are generally meant to be cash- or funding-driven, while specials can be used for trading purposes.[5]

Every trading platform is important for some segments of the European repo market. For instance, BrokerTec operates a large panel of specials and GC repos of various countries including Belgium, France, Germany, Netherlands, and Spain. Eurex Repo exclusively provides the GCP, in which only very safe collateral securities are eligible, and the sibling basket GCX, which extends the list of eligible assets to some riskier securities.[6] An important share of German GC repos is also traded on Eurex. MTS Repo is the predominant trading platform for Italian repos and runs a non-negligible share of specials.[7]

In total, our database includes 23'698'541 transactions and about EUR 601'009'581 million of (one-sided) traded volume. These data offer at least three improvements to the data used in previous tests of the EH. First, our sample is very large and economically relevant. It comprises various collateral securities providing cross-sectional heterogeneity in our analysis. Moreover, the sample period spans from January 2006 to December 2016, including pre-crises and crises periods. Second, risks in the repo market crucially depend on the market structure (Martin, Skeie, and von Thadden, 2014). In contrast to bilateral or

[5]For example, a bank in need of cash will pledge its government securities as collateral to obtain a repo loan, for which it pays the GC repo rate. Since the motive is funding, the type of collateral security makes no difference as long as it belongs to the pre-specified basket. In contrast, a specific repo is often used for trading, in particular for short-selling, for which the delivery of a specific collateral security is required.

[6]The GCP basket consists of the safest, very high quality collateral securities, including those securities admitted for collateralization of open market operations by the ECB that have been rated at least A-/A3. The GCP Extended basket consists of a larger subset of the securities admitted at the ECB, i.e., potentially riskier, but still safe securities (Mancini, Ranaldo, and Wrampelmeyer, 2016).

[7]MTS Repo provides transaction data starting only from 2010.

triparty repos that proved to be fragile[8], all repos in our sample are traded anonymously via a central counterparty (CCP), which protects lenders from counterparty credit risk. Moreover, the collateral assets used in the European CCP-based repo market are likewise eligible for refinancing operations at the central bank, making the ECB the (repo) lender of last resort. Due to this risk mitigation, some of our repo data are effectively riskless interest rates and thus particularly suitable for testing the EH at the extreme short end of the term structure. Third, the data structure allows us to properly align investors' expectations by considering the exact settlement times of each repo contract. Specifically, all spot (ON) repos are settled immediately, while "tomorrow-next" (TN) repos entered today are settled at 11 a.m. on the next business day, thus representing one-day forward rates.[9] For the two contracts to become real substitutes, we compute the daily ON repo rate as the average of all ON rates from opening to 11 a.m., and the daily TN rate as the average of all TN rates from opening to closing. Therefore, our repo rates differ from previous studies of the EH using daily closing rates (e.g., Longstaff, 2000b; Della Corte, Sarno, and Thornton, 2008).

Table 1A reports the descriptive statistics of European repo rates. Panel A of Table 1A shows the summary statistics of GC overnight repo rates.

[Insert Table 1A about here.]

All rates are expressed in percentage points per annum. Mean and standard deviations of ON and TN rates are fairly close together, differing only by a few basis points (bps), and display cross-sectional differences. For example, the average German GC ON rate is less than 1 basis point smaller than the average TN rate, while the spread between the mean GC ON and TN rates for Italian repos is more than five times larger than the German spread for the same time period. In general, spreads between TN and ON rates are positive over time and across all countries, suggesting the presence of a *forward premium* in repo rates.

[8]Prior empirical research provides evidence on the fragility of U.S. bilateral repos (Gorton and Metrick, 2012) and triparty repos (Krishnamurthy, Nagel, and Orlov, 2014; Copeland, Martin, and Walker, 2014) and Euro bilateral repos (Mancini, Ranaldo, and Wrampelmeyer, 2016). A resilient part of the U.S. triparty repo market is the GCF segment based on a CCP and an anonymous electronic order book (Agueci et al., 2014).

[9]Analogously, "spot-next" (SN) trades are overnight transactions settled two business days later.

Panel B of Table 1A reports the descriptive statistics of overnight special rates, showing that the differences in means and standard deviations are much larger than for GC rates. For example, the average premium between French ON and TN special rates is almost 10 bps, while for Spain the difference is more than 25 bps – and thus comparable to the bond term premiums found in long-maturity forward rates (e.g., Fama, 1984b; Fama and Bliss, 1987). With regard to the different time periods, the reduction of the spreads between 2010 and 2015 is even more pronounced for specials than for GC rates, revealing fairly large cross-sectional differences. Taking into account the different starting dates of GC repos in our sample, the observed differences in the forward premiums in Table 1A serve as a *prima facie* indicator that the test results of the EH may vary across time, countries, and repo type.

Table 1B provides an overview of the traded volume across collateral securities. With a total volume of EUR 196 and 128 trillion, respectively, German and Italian repos are the most traded in the sample, whereas the total trading volume in the GCX index slightly exceeds EUR 14 trillion.

[Table 1B about here.]

Table 1B shows that specials constitute a market share of more than 76%, and that more than 95% of all trading is conducted in overnight repos (ON, TN, SN).[10] While GC repos are traded predominantly ON and TN, specials are traded mostly TN and SN. Given the cumulative trading volume of more than EUR 600 trillion in one-day forward and spot rates, our analysis of the overnight forward premium thus covers by far the most traded contract type in the repo market and ensures a consistent analytical framework by using identical tenors (Longstaff, 1990).

2. The Repo Overnight Forward Premium

In this section, we address the question whether the forward premium can be explained by time-varying risk. In this framework, the natural source of risk is funding liquidity risk. For country c and date t, our

[10] Other repo terms include maturities from one week to 12 months.

baseline regression takes the form:

$$y_{c,t} = \gamma_c + \gamma_t + \beta X_{c,t} + \theta R_t + \varepsilon_{c,t}, \tag{1}$$

where $y_{c,t}$ is either the forward premium $s_{c,t} = f_{c,t} - i_{c,t}$, measured as the spread between the TN ($f_{c,t}$) and ON ($i_{c,t}$) repo rate, or the forward spread, $|s_{c,t}|$, depending on the specification. $X_{c,t}$ are country-specific repo determinants, R_t is a risk variable representing aggregate market risk (and thus independent of c), while γ_t and γ_c are time and repo fixed effects, respectively.

We replicate this regression for the forward premium and forward spread separately. The analysis of the forward premium allows us to understand in which direction funding liquidity risk materializes, i.e., whether the spot or forward rate is most affected. By contrast, the analysis of the forward spread provides us with information on the general misalignment between forward and spot rates during times of (funding) risk. The latter is particularly relevant for our tests of the expectations hypothesis, which generally focus only on testing whether the forward *spread* is constant or time-varying.

We analyze the forward premium in short-term rates using overnight order flows and repo specialness as repo-specific determinants, and the Libor-OIS spread representing aggregate money market risk. The repo ON order flow is the difference between borrower- and lender-initiated ON repo volumes, denoted by *ONDemand*, and the TN order flow is the net borrowing volume of TN repos, denoted by *TNDemand*. In this framework, these two variables represent the microstructural measures of net funding demand, thus capturing the price impact of trading immediacy (Demsetz, 1968) on the forward premium. When analyzing the forward spread, we take their absolute values, which then represent *order imbalance*. The presumption in this specification is that contemporaneous trade influences repo rates, but not the other way round, which reflects (Granger-Sims) causality running from trades to price revisions as in, e.g., Hasbrouck (1991). Repo specialness is the repo market counterpart of bonds' liquidity premiums (e.g., Duffie, 1996), which is computed by the spread between a country's volume-weighted average overnight

GC and special repo rates.[11] Higher liquidity premiums are often associated with investors' flight-to-safety during crisis times, and thus we expect repo specialness to be correlated with higher forward spreads. The Libor-OIS spread is a well-accepted measure of money market funding stress, computed by the difference between the 3-month Euribor and overnight index swap (OIS) rates.[12] Given this set of variables, the following testing hypotheses arise:

(1) *Higher ON borrowing net demand leads to a lower overnight forward premium.*

(2) *Higher TN borrowing net demand leads to a higher overnight forward premium.*

(3) *Higher specialness leads to a higher overnight forward spread.*

(4) *Money market funding stress leads to a higher forward spread.*

Table 2 reports the regression results separately for GC repos in Panel A and special repos in Panel B.

[Insert Table 2 about here.]

The results for GC repos broadly support our hypotheses. Specifically, higher ON borrowing demand decreases the forward premium (column 1), and higher TN borrowing demand increases the forward premium (column 2). This finding suggests that funding demand pushes the respective repo rates up, thereby affecting the overnight forward premium. Column (4) of Panel A shows that aggregate funding risk, as measured by the Libor-OIS spread, is also associated with a higher forward premium, indicating that money market participants expect an increase in funding costs during times of high market risks. Panel A of Table 2 also reports the regression results with the forward spread as the dependent variable. Unlike for TN repos, ON order imbalance and the Libor-OIS spread show a significant positive coefficient, while repo specialness is somewhat less strongly correlated with the forward spread.

The results for special repos are presented in Panel B of Table 2. Three main findings emerge compared to GC repos: First, repo order flows are not significant anymore. Second, specialness becomes significant

[11] Both averages are constructed using all available spot (ON), tomorrow-next (TN), and spot-next (SN) repos.

[12] For robustness, we also use other risk proxies instead of the Libor-OIS spread, including the TED spread, measured by the difference between the 3-month Euribor and the 3-month French T-Bill, the Vstoxx 50 implied volatility index, which is the Euro counterpart of the S&P 500 VIX, CDS spreads as well as the European bank sector CDS spreads. All these variables deliver consistent results and details are available upon request.

implying that larger specialness leads to a larger forward premium. Third, the Libor-OIS spread is still significant, thus suggesting hypothesis 4 holds strongly for both special repos as well as GC repos. The first two results, i.e., insignificant repo order flows and significant specialness, are consistent with the nature of special repos, which are mainly driven by the net demand for the collateral assets rather than cash.

Next, we repeat our previous analysis including the variables that have been shown to be significantly correlated with the forward premium and spread, i.e., ONDemand and Libor-OIS spread for GC repos, and the latter together with specialness for special repos. This analysis allows us to examine whether these variables, in particular the Libor-OIS spread, remain significant in a multivariate setting and when controlling for several seasonal effects.

To do this, we refine Equation 1 by dropping the day fixed effects, and account for four calendar issues originating from, e.g., the schedule of the ECB's monetary policy operations and financial stability regulation: First, we include day dummies in the regression representing the days surrounding the ECB's weekly main refinancing operation (MRO) on Wednesdays. In the Eurosystem, banks apply for new reserves on Tuesdays, which they receive from the ECB on Wednesdays as documented in Garcia-de-Andoain et al. (2016). Hence, Wednesday represents the cut-off day after which banks are endowed with new reserves from the ECB. Second, we include a dummy variable *EOMP*, which is equal to one for the last MRO week of each maintenance period and zero otherwise. The main idea is that the fulfilment of the MRO requirements might prompt liquidity hoarding and a more rigid demand for reserves. Third, we include a dummy variable *EOQ*, which is equal to one for the last five trading days of each quarter and zero otherwise. At quarter ends, the fulfilment of capital and liquidity requirements can create "window dressing", including a reduced supply of reserves or reverse repos (e.g., Munyan, 2017; BIS, 2017). Fourth, we include a dummy variable called *FRFA* that is equal to one after 15 October 2008, which represents the date on which the ECB switched from a variable-rate tender regime to a fixed-rate full allotment procedure. This new system may imply a structural reduction in liquidity needs, which could negatively impact the overnight forward premium.

[Insert Table 3 about here.]

Table 3 shows the regression results for GC repos in Panel A and for special repos in Panel B. The main finding from Table 3 is that the Libor-OIS spread remains statistically significant even after controlling for seasonal and calendar effects. Moreover, ON borrowing demand as well as ON order imbalance are also highly significant, while repo specialness loses some of its explanatory power in the multivariate setting. Table 3 also shows that calendar effects are mostly insignificant, with the only exceptions being Tuesdays for special repos (negative coefficient) and *EOQ* for the GC forward spread (positive coefficient).

Overall, our findings suggest that the Libor-OIS spread is the main funding risk factor for both GC and special repos, while the ON order imbalance (demand) is a strong predictor of the GC forward spread (premium). Given these strong results, in the following we analyze how the validity of the expectations hypothesis at the short end of the term structure depends on funding risk in short-term rates.

3. Theory and Methodology of the EH Tests

In this section, we summarize the theoretical relation of the unbiasedness hypothesis postulated by the EH, and describe the testing procedure of the VAR-GMM framework.

3.1. The Unbiasedness Hypothesis of the EH

Under rational expectations, the forward rate on a n-period repo loan equals the expected future n-period spot rate plus a constant risk premium, which is expressed by the EH as

$$f_t^n = \mathbb{E}_t(i_{t+h}^n) + c^n, \tag{2}$$

where f_t^n denotes the forward rate, i_{t+h}^n the spot rate at time $t+h$, and c^n is the risk premium. Intuitively, Equation (2) states that an investor in the repo market can borrow funds locking in today's forward rate, or wait and borrow at the future spot rate. As we look at overnight repos only, we drop subscript n and set $h = 1$, such that f_t becomes the TN repo rate and i_t is the ON repo rate. Under the EH, both repo rates should only differ by a constant risk premium (or be the same under the pure form of the EH, i.e., $c = 0$).

For every country, the spread-based test of the EH is written as

$$\Delta i_{t+1} = \alpha_1 + \beta_1 s_t + \varepsilon_{t+1}, \tag{3}$$

where ε_{t+1} is the rational expectations error term, $s_t = f_t - i_t$ is the forward premium, and the null hypothesis in Equation (3) is $\alpha_1 = 0$, $\beta_1 = 1$, stating that the forward premium is an unbiased predictor of the future spot spread, Δi_{t+1} (Froot, 1989).

3.2. Methodology

Since tests of Equation (3) in single line equations using ordinary least squares (OLS) have been shown to perform poorly in small samples producing biased coefficients (e.g., Schotman, 1997; Bekaert, Hodrick, and Marshall, 1997, 2001), we rely on a linear VAR testing framework developed by Bekaert and Hodrick (2001), in which we test a set of nonlinear restrictions derived from Equation (2) that make the VAR model consistent with the EH (e.g., Sarno, Thornton, and Valente, 2007; Della Corte, Sarno, and Thornton, 2008).[13] To that end, we constrain the coefficients of the VAR model such that the forward premium is the sole predictor of the future spot spread, estimate this constrained VAR system by the generalized methods of moments (GMM), and test the validity of these highly nonlinear restrictions with the Lagrange Multiplier (LM) and Distance Metric (DM) tests.[14]

[13]See Della Corte, Sarno, and Thornton (2008) for a discussion of the validity of the assumptions underlying a linear VAR model, in particular with respect to the literature on affine specifications (e.g., Duffie and Singleton, 1999; Dai and Singleton, 1999; Collin-Dufresne and Goldstein, 2002; Clarida et al., 2006).

[14]Bekaert and Hodrick (2001) find that the LM test has the most desirable properties in the presence of nonlinear restrictions, whereas the Wald test as well as the DM test perform much worse in small samples. Thus, while reporting LM and DM test statistics, we base our interpretations on the LM test results.

3.2.1 The VAR Framework

Consider Equation (3) with demeaned spot and forward spreads Δi_t and s_t, respectively. For each country separately, we set up a bivariate VAR system according to

$$\Delta i_t = a(L)\Delta i_{t-1} + b(L)s_{t-1} + u_{1,t}, \tag{4}$$

$$s_t = c(L)\Delta i_{t-1} + d(L)s_{t-1} + u_{2,t}, \tag{5}$$

with polynomials $a(L)$, $b(L)$, $c(L)$, and $d(L)$ of lag order p and error terms $u_{1,t}$ and $u_{2,t}$. This setting allows us to test the time variation of the risk premium without discriminating between the standard and pure form of the EH. Intuitively, Equation (4) determines the future spot spread, and Equation (5) generates the current forward premium. As thoroughly documented in the literature, the simultaneous estimation of the VAR equations improves efficiency by considering contemporaneous cross-correlations in the error terms (e.g., Mishkin, 1982; Pagan, 1984). Following Bekaert and Hodrick (2001), the lag length p is chosen by the Schwartz Criterion (BIC).

To derive the set of nonlinear restrictions, we translate Equations (4) and (5) into a first-order VAR companion form,

$$\begin{bmatrix} \Delta i_t \\ s_t \\ \Delta i_{t-1} \\ s_{t-1} \\ \vdots \\ \Delta i_{t-p+1} \\ s_{t-p+1} \end{bmatrix} = \begin{bmatrix} a_1 & b_1 & \dots & a_{p-1} & b_{p-1} & a_p & b_p \\ c_1 & d_1 & \dots & c_{p-1} & d_{p-1} & c_p & d_p \\ 1 & & & & & & \\ & 1 & & & & & \\ & & \ddots & & & & \\ & & & 1 & & & \\ & & & & 1 & & \end{bmatrix} \begin{bmatrix} \Delta i_{t-1} \\ s_{t-1} \\ \Delta i_{t-2} \\ s_{t-2} \\ \vdots \\ \Delta i_{t-p} \\ s_{t-p} \end{bmatrix} + \begin{bmatrix} u_{1,t} \\ u_{2,t} \\ \\ \\ \\ \\ \end{bmatrix}, \tag{6}$$

where blank elements are zeros. The companion VAR can be written in compact form as

$$Y_t = \Theta Y_{t-1} + \nu_t, \tag{7}$$

where Y_t is a 2p-elements vector of variables, Θ is a 2p square companion matrix, and $\nu_t = [u_t', 0, \dots, 0]'$

is an innovation vector orthogonal to the time t information set, with zero mean and covariance matrix Σ_ν. Based on the information in the VAR system at time t, the one-period forecast of the spot spread and forward premium is given by

$$E_t[Y_{t+1}] = \Theta Y_t. \tag{8}$$

Consistent with the EH in Equation (2), the vector of restrictions can thus be expressed as

$$e_1'\Theta = e_2', \tag{9}$$

where $e_1 = (1, 0, \ldots, 0)'$ and $e_2 = (0, 1, 0, \ldots, 0)'$ are 2p-dimensional indicator vectors. The left-hand side of Equation (9) is the expected future spot spread from Equation (8), and the right-hand side is the current forward premium. When estimated, the set of restrictions forces the coefficients in the VAR system to yield the theoretical relation postulated by the EH. In fact, the coefficient of the forward premium in Equation (4) compares directly with the OLS coefficient in Equation (3),

$$\beta_1 = \frac{e_1'\Theta\Psi e_2}{e_2'\Psi e_2}, \tag{10}$$

where Ψ is the unconditional variance of Y_t, computed from $vec(\Psi) = (I - \Theta \otimes \Theta')^{-1} vec(\Sigma_\nu)$. The numerator of the slope coefficient is the covariance between the forward premium and spot spread, and the denominator represents the variance of the forward premium. Stacking all relevant parameters from the companion matrix into vector $\theta = (a_1, \ldots, a_p, \ldots, d_1, \ldots, d_p)'$ and rewriting Equation (9) as

$$a(\theta) = e_1'\Theta - e_2', \tag{11}$$

we can define the null hypothesis of rational expectations and a constant risk premium as

$$H_0 : a(\theta) = 0. \tag{12}$$

Next, we estimate the VAR model based on the GMM method proposed by Bekaert and Hodrick (2001) under the null hypothesis that the EH holds, and test the significance of the cross-equation restrictions using the LM and DM tests.

3.2.2 The VAR Tests

To estimate the parameters, θ, subject to the nonlinear restrictions, we first establish the GMM criterion function by defining the moment conditions. From the VAR system, let $y_t \equiv [\Delta i_t, s_t]$ be the vector of data available at time t, u_t be the vector of orthogonal errors, and x_{t-1} be the vector of instruments available at time $t-1$, constructed by stacking lagged values of y_t (and a constant term). Define $z_t \equiv (y_t', x_{t-1}')'$, and let $g(z_t, \theta) \equiv u_t \otimes x_{t-1}$ be the vector-valued function of data and parameters to form the set of orthogonality conditions given by $\mathbb{E}_t[g(z_t, \theta)] \equiv 0$. For sample size T and corresponding sample moment conditions $g_T(\theta) \equiv T^{-1} \sum_{t=1}^{T} g(z_t, \theta)$, the parameters θ are estimated by maximizing the Lagrangian

$$\mathcal{L}(\theta, \gamma) = -\frac{1}{2} g_T(\theta)' \Omega_T^{-1} g_T(\theta) - a_T(\theta)'\gamma, \tag{13}$$

where the first term of Equation (13) is the GMM criterion function with positive semidefinite weighting matrix Ω_T^{-1} (Hansen, 1982), and the second term is the constraint, given by the sample restrictions $a_T(\theta)$ and the vector of Lagrange multipliers, γ.[15] When estimating the parameters, the Lagrange multipliers will be different from zero if the restrictions imposed the EH have a significant impact on the value of the objective function. The null hypothesis, that the Lagrange multipliers are jointly zero, can thus be tested using the LM statistic

$$T\overline{\gamma}'(A_T B_T^{-1} A_T')\overline{\gamma} \to \chi^2_{(2p)}, \tag{14}$$

[15] The Lagrangian is maximized indirectly through a recursive mechanism due to the nonlinearity of the constraints, extending the estimator proposed by Newey and McFadden (1994) (Bekaert and Hodrick, 2001). See the appendix for technical details of the constrained GMM maximization problem.

which follows a chi-square distribution with 2p degrees of freedom resulting from the number of EH restrictions. Finally, the DM statistic is

$$Tg_T(\overline{\theta})'\Omega_T^{-1}g_T(\overline{\theta}) \rightarrow \chi^2_{(2p)}, \tag{15}$$

where $\overline{\theta}$ denotes the constrained parameter estimates.

3.2.3 Small Sample Bias Correction

Tests of the EH are likely to suffer from finite sample bias estimation errors, as the sample distribution may differ significantly from the asymptotic distribution (e.g., Bekaert, Hodrick, and Marshall, 1997). In line with Longstaff (2000b) and Della Corte, Sarno, and Thornton (2008), we deal with small sample properties by simulating bias-corrected data sets of 70,000 observations via residual bootstrap from the original data series using homoskedastic and GARCH innovations, and use these simulated data sets for our analysis.[16]

4. Conditional Tests of the EH

In our empirical tests of the EH, we analyze the time variation of the risk premium by conditioning the EH tests on our main (funding) risk variables: First, we explore the time variation of aggregate funding risk as measured by the Libor-OIS spread. Second, we condition our tests on the ON order imbalance and repo specialness for GC and special repos, respectively. For robustness, we also base our tests on the calendar effects given by the ECB's main refinancing operations. For the interpretation of the test results, we rely on the LM test statistic, which has been shown to be superior to, e.g., the DM test (see Bekaert and Hodrick, 2001).[17]

[16] See the appendix for technical details on the data simulation process.

[17] Nevertheless, we also report the DM p-values for comparison.

4.1. Aggregate Funding Risk

We first condition our tests of the EH on the Libor-OIS spread, which proved highly significant in the regression analysis. The conditioning approach works as follows: For every country and repo, we first construct the respective samples according to the sorted Libor-OIS spread, i.e., from the highest to its lowest value. Then, we determine the samples' quartiles (i.e., the 25%-quantiles), which then serve as the time series for our conditional tests. Specifically, we bias-correct each quartile as described in Section 3.2.3 and test the EH for each subsample separately. If the time variation of the Libor-OIS spread matters for the validity of the EH, we expect the test results to show that the EH is violated more in the highest quartile and less in the lowest quartile. Table 4 reports the p-values of the EH tests, ordered from highest (1) to lowest (4).[18]

[Insert Table 4 about here.]

Panel A of Table 4 reports the p-values for GC repos. The results show that the p-values are lowest when funding risk is highest, and vice versa. The results for specials are reported in Panel B, and show that p-values are generally highest in the low-risk quartile, but not always lowest in the high-risk quartiles. However, the differences are miniscule, suggesting that across all countries and repos, the risk premium varies with aggregate funding risk, as represented by the Libor-OIS spread. While the EH general seems to have more support in the low-risk quartile, the EH cannot be rejected in any of the quartiles for the GC Pooling basket (GCP). Among all GC repos, the GCP basket is characterized by the highest degree of diversification and has the same collateral requirements, e.g., margins, as for refinancing operations with the ECB. By contrast, the GCX basket also includes collateral securities from countries such as, e.g., Italy and Spain, with more exposure to the European sovereign debt crisis in 2011/12 than countries in the GCP basket such as, e.g., Germany or Austria. In fact, from sorting the Libor-OIS spread, one observes that the highest quartile captures the time periods spanning from August 2007 to July 2009 and from August 2011 to July 2012, i.e., capturing the financial crisis in 2008 as well as the peak of the

[18]All results are reported for GARCH innovations.

European sovereign debt crisis at the end of 2011.

In the cross-section of GC repos, we find that the lowest p-values are reported for Spain, the GCX basket and Italy, thus supporting the close link between collateral and funding risk established in the theoretical literature (e.g., Brunnermeier and Pedersen, 2009). Moreover, the p-values across special repos are generally closer together, further suggesting that funding risk is more closely related to undiversified, idiosyncratic collateral risk.

4.2. Order Imbalance and Repo Specialness

The regression results in Tables 2 and 3 suggest a high correlation between the GC forward spread and ON order imbalance, and a (weaker) correlation of the special forward spread with repo specialness. Accordingly, we sort both variables as described in the previous section, such that the highest quartile of the ON order imbalance captures the largest absolute deviations between borrower- and lender-initiated trading volumes, and the lowest quartile is characterized by the smallest deviations or zero. Equivalently, repo specialness is sorted from its highest to lowest value, and we test the EH for each subsample separately. Table 5 reports the p-values of the conditional EH tests for GC ON order imbalance (Panel A) and repo specialness (Panel B).

[Insert Table 5 about here.]

The results in Panel A are straightforward. In times of high order imbalance, the EH is rejected, implying that the (lagged) forward premium seems to have no predictive power for the change in the ON repo rate. This means, the EH fails to hold when a larger mismatch between supply and demand of funding immediacy leads to a larger misalignment of its actual cost (ON rate) and expected cost (forward rate). It is important to emphasize at this point that we are testing one-day forward rates, and the misalignment between forward and spot rate leads to a statistical rejection of the EH already for the shortest possible forecast horizon. Conversely, the p-values in Table 5 show that the predictive ability of the forward premium is stronger when order flows in the repo market are more balanced, thus implying a better alignment of expectations.

Panel B provides results for special repos and the time variation of repo specialness. The p-values reported in Table 5 suggest that repo specialness cannot thoroughly account for the time variation in the forward premium as already indicated by the results in Table 3. This finding confirms the general notion that special repo rates are much harder to predict than GC rates given their exposure to idiosyncratic collateral risks.

4.3. MRO Calendar Effects

Finally, we run EH tests conditional on weekdays to see whether the time variation of the risk premium is affected by deterministic patterns stemming from the weekly MRO schedule. While the results in Table 3 suggest that day-of-the-week effects cannot explain the variation in the daily forward premium (i.e., only the Tuesday dummy is slightly significant for special repos), we report the findings as a robustness check to verify that the test results of the EH are highly consistent with our results from the regression analysis. To test these patterns, we sort the data according to weekdays, such that the reported weekday always refers to the ON rate, and the TN rate to the day before. Table 6 reports the p-values for GC repos in Panel A, and for specials in Panel B.

[Insert Table 6 about here.]

As expected, the test results indicate that no clear pattern emerges from the reported p-values. Except for Italy, Table 6 shows that p-values are never highest on Wednesdays, indicating that the positive liquidity shock on Wednesdays may actually lower the ON spot rate, thereby increasing the forward premium. In fact, these findings further support our previous results that the forward premium is largely affected by demand pressure and funding risk as opposed to following specific weekday patterns. If anything, the results show that liquidity provision by the central bank can actually distort short-term expectations, as the additional funds which banks receive on Wednesdays are reallocated across money market participants through the repo market. For example, banks with a liquidity surplus offer their excess funds in the repo market for a lower rate, which can lead to a misalignment of forward and spot rates to the same extent that deficit banks bid more aggressively in order to obtain funding.

5. Conclusion

Despite its long history and central importance in economics and finance, the EH has found very little empirical support so far. In this paper, we relate the rejection of the EH to funding risk in the forward premium of very short-term rates. To do this, we analyze a unique and comprehensive data set of European repurchase agreements (repos) that are ideal for highlighting the role of time-varying risk premiums. In fact, some important characteristics such as collateralization, anonymous CCP-based trading, and a close connection with central bank liquidity essentially narrow down the sources of risk to funding risk.

We perform various panel regressions and find clear evidence in support of funding risk in the overnight forward premium. We identify aggregate funding risk and demand for funding immediacy as the main variables affecting the forward premium in general collateral (GC) repos. These are measured by the Libor-OIS spread and order flow, respectively. Together with "specialness", aggregate funding risk is also the main determinant for the forward premium in special repo rates. We perform conditional analyses of the unbiasedness hypothesis by testing the EH based on the sorted funding risk variables and find clear results in support of the EH when funding risk is in its lowest quartiles.

Another original contribution in this paper is the cross-sectional analysis, in which we compare repo contracts with different collateral securities. Our results clearly show that the violation of the EH is likely to arise for repos bearing collateral risk, that is, collateral securities more affected by sovereign risk (e.g., Italian and Spanish government bonds) or idiosyncratic risk (i.e., "specials").

Several policy implications can be drawn from this study. Overall, we show that it is possible to make a neater distinction between expectations and risk premiums, at least for very short-term maturities. This should improve the analysis and decision making of important aspects of the social welfare system that needs accurate interpretation of agents' expectations and risk premiums, including investment, regulatory, and monetary policies.

References

Acharya, V., Bisin, A., 2014. Counterparty risk externality: Centralized versus over-the-counter markets. Journal of Economic Theory 149, 153–182.

Agueci, P., Alkan, L., Copeland, A., Davis, I., Martin, A., Pingitore, K., Prugar, C., Rivas, T., 2014. A primer on the gcp repo service. https://www.newyorkfed.org/research/staff_reports/sr671.html, Staff Report 671, Federal Reserve Bank of New York.

Bekaert, G., Hodrick, R., 2001. Expectations hypotheses tests. Journal of Finance 56, 1357–1394.

Bekaert, G., Hodrick, R., Marshall, D., 1997. On biases in tests of the expectations hypothesis of the term structure of interest rates. Journal of Financial Economics 44, 309–348.

Bekaert, G., Hodrick, R., Marshall, D., 2001. Peso problem explanations for term structure anomalies. Journal of Monetary Economics 48, 241–270.

BIS, 2017. Repo market functioning. https://www.bis.org/publ/cgfs59.htm, Bank for International Settlements.

Boissel, C., Darrien, F., Ors, E., Thesmar, D., 2017. Systemic risk in clearing houses: Evidence from the european repo market. Journal of Financial Economics 125, 511–536.

Brunnermeier, M. K., Pedersen, L. H., 2009. Market liquidity and funding liquidity. The Review of Financial Studies 22, 2201–2238.

Buraschi, A., Menini, D., 2002. Liquidity risk and specialness. Journal of Financial Economics 64, 243–284.

Campbell, J., Shiller, R., 1991. Yield spreads and interest rate movements: A bird's eye view. Review of Economic Studies 58, 495–514.

Clarida, R., Sarno, L., Taylor, M., Valente, G., 2006. The role of asymmetries and regime shifts in the term structure of interest rates. Journal of Business 79, 1193–1224.

Collin-Dufresne, P., Goldstein, R., 2002. Do bonds span the fixed income markets? theory and evidence for unspanned stochastic volatility. Journal of Finance 57, 1685–1730.

Copeland, A., Davis, I., LeSueur, E., Martin, A., 2012. Mapping and sizing the u.s. repo market. June, Federal Reserve Bank of New York Liberty Street Economics Blog, Federal Reserve Bank of New York.

Copeland, A., Martin, A., Walker, M., 2014. Repo runs: Evidence from the tri-party repo market. Journal of Finance 69, 2343–2380.

Dai, Q., Singleton, K., 1999. Specification analysis of affine term structure models. Journal of Finance 55, 1943–1978.

Della Corte, P., Sarno, L., Thornton, D., 2008. The expectation hypothesis of the term structure of very short-term rates : Statistical tests and economic value. Journal of Financial Economics 89, 158–174.

Demsetz, H., 1968. The cost of transacting. Quarterly Journal of Economics 82, 33–53.

Duffie, D., 1996. Special repo rates. Journal of Finance 51, 493–526.

Duffie, D., Dworczak, P., Zhu, H., 2017. Benchmarks in search markets. Journal of Finance 72, 1983–2044.

Duffie, D., Krishnamurthy, A., 2016. Passthrough efficiency in the fed's new monetary policy setting. Journal article, Stanford University.

Duffie, D., Singleton, K., 1999. Modeling term structures of defaultable bonds. Review of Financial Studies 12, 687–720.

Duffie, D., Zhu, H., 2011. Does a central clearing counterparty reduce counterparty risk? Review of Asset Pricing Studies 1, 74–95.

ECB, 2014. Euro money market survey. `https://www.ecb.europa.eu/stats/money/mmss/html/index.en.html`, European Central Bank.

Fama, E., 1984a. The information in the term structure. Journal of Financial Economics 13, 509–528.

Fama, E., 1984b. Term premiums in bond returns. Journal of Financial Economics 13, 529–546.

Fama, E., Bliss, R., 1987. The information in long-maturity forward rates. American Economic Review 77, 680–692.

Financial Stability Board, 2012. Securities Lending and Repos: Market Overview and Financial Stability Issues. Interim Report of the FSB Workstream on Securities Lending and Repos.

Fisher, I., 1896. Appreciation and interests. Publications of the American Economic Association 11, 21–29.

Frankel, J., Froot, K., 1987. Using standard survey data to test standard propositions regarding exchange rate expectations. American Economic Review 77, 133–153.

Froot, K., 1989. New hope for the expectations hypothesis of the term structure of interest rates. Journal of Finance 44, 283–305.

Garcia-de-Andoain, C., Heider, F., Hoerova, M., Manganelli, S., 2016. Lending-of-last-resort is as lending-of-last-resort does: Central bank liquidity provision and interbank market functioning in the euro area. Journal of Financial Intermediation 28, 32–47.

Gorton, G., Metrick, A., 2012. Securitized banking and the run on repo. Journal of Financial Economics 104, 425–451.

Gorton, G., Ordonez, G., 2014. Collateral crises. American Economic Review 104, 343–378.

Hansen, L., 1982. Large sample properties of generalized method of moments estimators. Econometrica 50, 1029–1054.

Hasbrouck, J., 1991. Measuring the information content of stock trades. Journal of Finance 46, 179–207.

Hicks, J., 1946. Value and Capital. Oxford University Press, Oxford.

Holmstrom, B., 2015. Understanding the role of debt in the financial system. January, Bank for International Settlements.

Jordan, B., Jordan, S., 1997. Special repo rates: An empirical analysis. Journal of Finance 52, 2051–2072.

Keynes, J. M., 1936. The General Theory of Employment, Interest, and Money. Brace, New York: Harcourt.

Krishnamurthy, A., Nagel, S., Orlov, D., 2014. Sizing up repo. Journal of Finance 69, 2381–2417.

Longstaff, F., 1990. Time varying term premia and traditional hypotheses about the term structure. Journal of Finance 45, 1307–1314.

Longstaff, F., 2000a. Arbitrage and the expectations hypothesis. Journal of Finance 55, 989–994.

Longstaff, F., 2000b. The term structure of very short term rates: New evidence for the expectations hypothesis. Journal of Financial Economics 58, 397–415.

Mancini, L., Ranaldo, A., Wrampelmeyer, J., 2016. The euro repo interbank market. Review of Financial Studies 29, 1747–1779.

Martin, A., Skeie, D., von Thadden, E.-L., 2014. Repo runs. Review of Financial Studies 27, 957–989.

MEFF, 2014. Monthly statistics. `http://www.meff.es/aspx/MeffREPO/EstadisticasMensuales.aspx?id=ing.`, MEFF Repo.

Melino, A., 2001. Estimation of a rational expectations model of the term structure. Journal of Empirical Finance 8, 639–668.

Mishkin, F., 1982. Does anticipated monetary policy matter? an econometric investigation. Journal Political Economy 90, 22–51.

Munyan, B., 2017. Regulatory arbitrage in repo markets. June.

Newey, W., McFadden, D., 1994. Large sample estimation and hypothesis testing. Handbook of Econometrics 4, Amsterdam.

Pagan, A., 1984. Econometric issues in the analysis of regressions with generated regressors. International Economic Review 25, 221–247.

Roll, R., 1970. The behavior of interest rates: An application of the efficient market model to US treasury bills. Basic Books, New York.

Sarno, L., Thornton, D., Valente, G., 2007. The empirical failure of the expectations hypothesis of the term structure of bond yields. Journal of Financial and Quantitative Analysis 42, 81–100.

Schotman, P., 1997. Small sample properties of the regression test of the expectations model of the term structure. Economics Letters 57, 129–134.

Stambaugh, R., 1988. The information in forward rates: Implications for models of the term structure. Journal of Financial Economics 21, 41–70.

Appendix: Econometric Procedures

GMM Iterative Procedure

The constrained GMM maximization problem is solved via an iterative procedure. Optimizing the Lagrangian in Equation (13), the first-order condition is given by

$$\begin{bmatrix} 0 \\ 0 \end{bmatrix} = \begin{bmatrix} -G_T'\Omega_T^{-1}\sqrt{T}g_T(\overline{\theta}) - A_T'\sqrt{T}\overline{\gamma} \\ -\sqrt{T}a_T(\overline{\theta}) \end{bmatrix}, \tag{A.1}$$

where $A_T \equiv \nabla_\theta \alpha_T(\theta)$ and $G_T \equiv \nabla_\theta g_T(\theta)$. While the first-order conditions are nonlinear in the parameters, Bekaert and Hodrick (2001) derive an approximate asymptotic solution using the law of large numbers and a Taylor's series expansion of $g_T(\theta)$ and $a_T(\theta)$ around the true parameter value θ_0. Note that

$$\sqrt{T}g_T(\theta_0) \to \mathbb{N}(0, \Omega), \tag{A.2}$$

$$\sqrt{T}g_T(\overline{\theta}) \approx \sqrt{T}g_T(\theta_0) + G_T\sqrt{T}(\overline{\theta} - \theta_0), \tag{A.3}$$

and

$$\sqrt{T}a_T(\overline{\theta}) \approx \sqrt{T}a_T(\theta_0) + A_T\sqrt{T}(\overline{\theta} - \theta_0). \tag{A.4}$$

Under the null hypothesis, $a_T = 0$, and substituting Equations (A.3) and (A.4) into Equation (A.1), we have

$$\begin{bmatrix} 0 \\ 0 \end{bmatrix} = \begin{bmatrix} -G_T'\Omega_T^{-1}\sqrt{T}g_T(\theta_0) \\ 0 \end{bmatrix} - \begin{bmatrix} B_T & A_T' \\ A_T & 0 \end{bmatrix} \begin{bmatrix} \sqrt{T}(\overline{\theta} - \theta_0) \\ \sqrt{T}\overline{\gamma} \end{bmatrix}. \tag{A.5}$$

The formula for a partitioned inverse implies that

$$\begin{bmatrix} B_T & A_T' \\ A_T & 0 \end{bmatrix}^{-1} = \begin{bmatrix} B_T^{-1/2}M_T B_T^{-1/2} & B_T^{-1}A_T'(A_T B_T^{-1}A_T')^{-1} \\ (A_T B_T^{-1}A_T')^{-1}A_T B_T^{-1} & -(A_T B_T^{-1}A_T')^{-1} \end{bmatrix}, \tag{A.6}$$

where $M_T \equiv I - B_T^{-1/2} A_T' (A_T B_T^{-1} A_T')^{-1} A_T B_T^{-1/2}$ is an idempotent matrix, and $B_T \equiv G_T' \Omega_T^{-1} G_T$. Thus, the asymptotic distribution of the constrained estimator and Lagrange multiplier becomes $\sqrt{T}(\overline{\theta} - \theta_0) \rightarrow \mathbb{N}(0, B_T^{-1/2} M_T B_T^{-1/2})$ and $\sqrt{T}(\overline{\gamma}) \rightarrow \mathbb{N}(0, (A_T B_T^{-1} A_T')^{-1})$, respectively. Since direct maximization of the Lagrangian in Equation (A.1) is considered as computationally difficult (e.g., Melino, 2001), Bekaert and Hodrick (2001) propose an iterative scheme, extending the approach in Newey and McFadden (1994). Starting with an initial unconstrained estimate $\tilde{\theta}$, we derive $g_T(\overline{\theta}) = g_T(\tilde{\theta}) + G_T(\overline{\theta} - \tilde{\theta})$ and $a_T(\overline{\theta}) = a_T(\tilde{\theta}) + A_T(\overline{\theta} - \tilde{\theta})$, substitute into the first-order condition, and solve

$$\overline{\theta} \approx \tilde{\theta} - B_T^{-1/2} M_T B_T^{-1/2} G_T' \Omega_T^{-1} g_T(\tilde{\theta}) - B_T^{-1} A_T' (A_T B_T^{-1} A_T')^{-1} a_T(\tilde{\theta}), \tag{A.7}$$

$$\overline{\gamma} \approx -(A_T B_T^{-1} A_T')^{-1} A_T B_T^{-1} G_T' \Omega_T^{-1} g_T(\tilde{\theta}) + (A_T B_T^{-1} A_T')^{-1} a_T(\tilde{\theta}). \tag{A.8}$$

To obtain the constrained parameters $\overline{\theta}$, we iterate on Equations (A.7) and (A.8), substituting the first constrained estimate for the initial consistent unconstrained estimate to derive a second constrained estimate and so forth. The iterative process stops when the constrained estimate satisfies the constraints, that is, when $a_T(\overline{\theta}) = 0$.

Small Sample Bias Correction

Let $Z_t = [i_t, s_t]'$ be the set of our initial data, where $s_t = f_t - i_t$ is the spread between the overnight forward rate f_t ("tomorrow-next") and the overnight spot rate i_t, and assume VAR(p) dynamics analogous to Equations (4) and (5) in the text.

For the first data generating process (DGP), we estimate an unconstrained VAR and use the parameter estimates to generate 100,000 artificial data sets containing T observations, using an i.i.d. bootstrap of the residuals. We reestimate the VAR for each replication, compute the average of the parameter estimates of all artificial data sets, and determine bias as the difference between the parameter estimates of the initial data and the average of the estimates of the artificial data sets. Next, we correct the initial parameter estimates by adding the bias, simulate 70,000 observations (plus 1,000 starting values that are discarded to avoid any dependence on the initial values), and add each simulated i_t to each simulated spread s_t. As a result, we obtain a series of 70,000 spot and forward overnight repo rates, which we use for the iterative procedure.

In the second DGP, we reparameterize the residuals from the first DGP, $\varepsilon_t = F\eta_t$, to capture the effects of temporal heteroskedasticity, where η_t is a vector of idiosyncratic innovations and F is a 2×2 factor loadings matrix. In line with Bekaert and Hodrick (2001) as well as Longstaff (2000b) and Della Corte, Sarno, and Thornton (2008), we use a Factor-GARCH(1,1) model augmented with the square root of the (absolute) overnight rate to accommodate for shifts in the short rate, $h_{j,t} = \omega_j \sqrt{|i_{t-1}|} + \beta_j h_{j,t-1} + \alpha_j \eta^2_{j,t-1}$, with $j \in \{1, 2\}$. We use the absolute value of the short rate to account for negative repo rates towards the end of the sample. Then, analogous to the i.i.d. bootstrap, we construct 100,000 artificial data sets with T observations, reestimate each replication and bias-correct the unconstrained parameter estimates. Finally, we estimate the GARCH parameters via quasi-maximum likelihood, and simulate a second bias-corrected data set of 70,000 (plus 1,000 starting values that are discarded) observations of i_t and f_t as described above.

Table 1A

Descriptive Statistics for Daily European Overnight Repo Rates

This table presents summary statistics of daily repo rates of European government collateral securities from 2006 to 2016. Panel A presents repo rates for general collateral (GC) repos and Panel B for special (SC) repos. The forward premium is denoted by s and equals the (average) spread between TN and ON repo rates. All statistics are measured in percentage points per annum.

Panel A: GC Repo Rates

	DE	FR	BE	NL	ES	IT	GCP	GCX
GC ON Repo Rates								
Mean	0.8930	0.7829	0.7587	0.4818	0.0797	0.1883	1.0126	0.1537
Std Dev	1.4992	1.4035	1.3856	1.1989	0.3970	0.4317	1.5288	0.4411
Min	−2.0000	−1.0667	−1.0000	−1.0357	−1.9375	−0.4155	−0.4800	−0.4142
Max	4.5250	4.6730	4.4750	4.4000	2.6500	1.8654	5.1497	2.9000
GC TN Repo Rates								
Mean	0.9021	0.7946	0.7745	0.4944	0.0909	0.2091	1.0274	0.1687
Std Dev	1.5046	1.4060	1.3929	1.2035	0.3917	0.4440	1.5332	0.4496
Min	−1.0737	−1.1979	−0.7000	−1.0000	−1.6700	−0.4241	−0.5100	−0.5000
Max	4.4750	4.6643	4.4800	4.5000	2.7000	2.0482	4.9667	2.9500
s (bps)	0.9040	1.1703	1.5794	1.2593	1.1266	2.0837	1.4807	1.4921
$s_{2010-15}$ (bps)	0.4277	1.0180	1.1810	0.9744	1.1008	2.0837	1.1909	1.4178
Obs	2,423	2,464	2,133	1,619	1,242	1,792	2,625	1,631
Start	2006	2006	2006	2008	2008	2010	2010	2006

Panel B: Special Repo Rates

	DE	FR	BE	NL	ES	IT
SC ON Repo Rates						
Mean	0.7019	0.8737	0.6142	0.3229	0.1340	−0.0886
Std Dev	1.4934	1.5744	1.4287	1.2256	1.1953	0.3553
Min	−2.7321	−1.8726	−2.6500	−2.0000	−2.8400	−2.9190
Max	4.2500	4.5268	4.3500	4.4250	4.3500	1.2125
SC TN Repo Rates						
Mean	0.8319	0.9722	0.7354	0.4516	0.3700	0.0644
Std Dev	1.5300	1.5809	1.4551	1.2313	1.1311	0.3544
Min	−2.9910	−1.7613	−1.1450	−1.2438	−1.1475	−0.6839
Max	4.3088	4.5592	4.3330	4.3057	4.2868	1.4561
s (bps)	13.0009	9.8843	12.1221	12.8934	23.6163	15.2899
$s_{2010-15}$ (bps)	10.0760	8.5791	10.1301	12.1595	25.2395	15.2899
Obs	2,695	2,814	2,267	1,878	2,165	1,786
Start	2006	2006	2006	2006	2006	2010

Table 1B

Descriptive Statistics for Daily European Repo Trading Volumes

This table reports descriptive statistics of daily trading activity in European government general collateral (GC) and special repos from 2006 to 2016. Trading volumes (in EUR trillions) and transactions refer to the sum of all repos traded on BrokerTec, Eurex Repo, and MTS Repo. Maturity shares report the percentage of total volume traded overnight (ON, TN, SN) and longer terms (other). Repo shares measure the relative trading volume between GC and special repos. Countries are listed in columns and GCP and GCPx refer to two pooling baskets of GC securities as described in the text.

	DE	FR	BE	NL	ES	IT	GCP	GCX	All
Total Volume (tn)	196	91	30	29	33	128	34	14	601
Transactions ('000)	6,349	3,852	1,517	1,411	1,880	5,512	98	53	23,699
Maturity Shares (%)									
ON	1.02	4.55	4.17	1.92	2.53	4.03	22.95	19.71	4.17
TN	14.80	24.27	22.17	18.44	18.83	23.63	31.60	36.45	20.61
SN	80.32	68.17	71.91	78.30	73.74	69.58	24.44	28.25	70.52
Other	3.87	3.02	1.75	1.34	4.91	2.76	21.01	15.59	4.69
Repo Shares (%)									
GC	10.70	13.92	15.01	10.42	11.45	33.13	100	100	23.52
SP	89.30	86.08	84.99	89.58	88.55	66.87	0	0	76.48
GC Maturity Shares (%)									
ON	8.04	25.53	25.33	16.20	18.03	11.30	22.95	19.71	16.33
TN	76.53	67.92	70.21	79.79	56.16	40.86	31.60	36.45	49.46
SN	7.09	5.24	2.52	2.34	14.21	42.53	24.44	28.25	23.95
Other	8.35	1.30	1.94	1.67	11.60	5.31	21.01	15.59	10.27
Special Maturity Shares (%)									
ON	0.18	1.15	0.43	0.26	0.52	0.42			0.44
TN	7.40	17.21	13.69	11.30	14.00	15.09			11.74
SN	89.09	78.34	84.17	87.14	81.43	82.98			84.85
Other	3.33	3.29	1.72	1.30	4.04	1.51			2.97

Table 2
Daily Repo Forward Premium

Reported are panel regression coefficients for the daily forward premium and the daily forward spread. The forward premium is the difference between the TN and ON repo rate, and the forward spread is computed by their absolute difference. LIBOR denotes the 3-month Libor-OIS spread (EUR). Specialness is the daily spread between countries' volume-weighted GC and SC rates, and ONDemand and TNDemand, respectively, denote overnight and tomorrow-next net borrowing volumes. In the forward spread analysis, ONDemand and TNDemand are computed as the absolute order imbalance. Countries included are Belgium, France, Germany, Italy, Netherlands, and Spain, as well as Eurex' GC Pooling and GC Pooling Extended indices for the GC panel. Standard errors are clustered at country- and day-level (shown in parentheses). The stars ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively.

	Panel A: GC Repo Rates							
	Forward Premium: $s_{i,t}$				Forward Spread: $\lvert s_{i,t}\rvert$			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ONDemand	-0.1909^{***}				0.0689^{***}			
	(0.0207)				(0.0166)			
TNDemand		0.0960^{**}				0.0251		
		(0.0294)				(0.0279)		
Specialness			-0.0283				0.0314^{*}	
			(0.0254)				(0.0140)	
LIBOR				0.0237^{***}				0.0514^{***}
				(0.0063)				(0.0045)
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Day FE	Yes	Yes	Yes	No	Yes	Yes	Yes	No
Adj. R^2 (%)	52.76	51.46	55.61	1.80	60.08	59.99	61.62	9.54
# Obs.	15,825	15,825	11,451	15,929	15,825	15,825	11,451	15,929

	Panel B: Special Repo Rates							
	Forward Premium: $s_{i,t}$				Forward Spread: $\lvert s_{i,t}\rvert$			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ONDemand	-0.4456				-0.0518			
	(0.3974)				(0.2398)			
TNDemand		-0.7234				0.7121		
		(0.5787)				(0.6760)		
Specialness			0.5377^{**}				0.5951^{**}	
			(0.1582)				(0.1644)	
LIBOR				0.1223^{***}				0.1316^{***}
				(0.0199)				(0.0153)
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Day FE	Yes	Yes	Yes	No	Yes	Yes	Yes	No
Adj. R^2 (%)	2.93	2.89	3.48	2.65	3.59	3.61	4.57	3.51
# Obs.	13,525	13,525	12,941	13,552	13,525	13,525	12,941	13,552

Table 3
Seasonal and Calendar Effects

Weekday dummies include all weekdays but Wednesdays. EOMP is equal to one for the last week of the ECB's maintenance period and zero otherwise. EOQ is equal to one for the last five trading days of each quarter and zero otherwise. FRFA is equal to one after 15 October 2008 and zero before. ONDemand denotes the net borrowing demand in (1)-(4), and the absolute order imbalance in (5)-(8). Standard errors are clustered at country- and day-level (shown in parentheses). The stars ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively. The star ($\star$) denotes that at least one dummy variable has statistical significance at the 5% or 1% level.

Panel A: GC Repo Rates

	Forward Premium: $s_{i,t}$				Forward Spread: $\lvert s_{i,t} \rvert$			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ONDemand	-0.3688^{***}	-0.3713^{***}	-0.3686^{***}	-0.3718^{***}	0.1195^{**}	0.1209^{**}	0.1147^{**}	0.1234^{**}
	(0.0386)	(0.0387)	(0.0385)	(0.0393)	(0.0359)	(0.0358)	(0.0350)	(0.0381)
LIBOR	0.0237^{***}	0.0237^{***}	0.0237^{***}	0.0231^{***}	0.0516^{***}	0.0516^{***}	0.0513^{***}	0.0518^{***}
	(0.0059)	(0.0059)	(0.0059)	(0.0061)	(0.0044)	(0.0045)	(0.0044)	(0.0044)
Weekdays	Yes	No	No	No	Yes	No	No	No
EOMP	No	Yes	No	No	No	Yes	No	No
EOQ*	No	No	Yes	No	No	No	Yes	No
FRFA	No	No	No	Yes	No	No	No	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adj. R^2 (%)	7.34	7.24	7.81	7.31	9.90	9.88	12.77	9.87
# Obs.	15,929	15,929	15,929	15,929	15,929	15,929	15,929	15,929

Panel B: Special Repo Rates

	Forward Premium: $s_{i,t}$				Forward Spread: $\lvert s_{i,t} \rvert$			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Specialness	0.3431	0.3394	0.3385	0.3574^{*}	0.4238^{*}	0.4195^{*}	0.4146^{*}	0.4417^{*}
	(0.1750)	(0.1740)	(0.1798)	(0.1715)	(0.1826)	(0.1821)	(0.1873)	(0.1792)
LIBOR	0.1018^{**}	0.1015^{**}	0.1023^{**}	0.0975^{**}	0.1055^{***}	0.1053^{***}	0.1063^{***}	0.1002^{***}
	(0.0266)	(0.0264)	(0.0266)	(0.0267)	(0.0196)	(0.0195)	(0.0195)	(0.0187)
Weekdays*	Yes	No	No	No	Yes	No	No	No
EOMP	No	Yes	No	No	No	Yes	No	No
EOQ	No	No	Yes	No	No	No	Yes	No
FRFA	No	No	No	Yes	No	No	No	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adj. R^2 (%)	4.04	4.04	3.99	4.20	5.58	5.54	5.51	5.84
# Obs.	12,994	12,994	12,994	12,994	12,994	12,994	12,994	12,994

Table 4
Libor-OIS

This table shows the results of the Lagrange Multiplier (LM) and Distance Metrics (DM) tests of the EH under the null hypothesis that the EH holds. The J-Test is the Hansen (1982) test for overidentifying restrictions in the GMM estimation. All values reported are p-values and calculated as described in the text. Panel A reports results for GC repo rates, and Panel B for special repos. Results are shown for generalized autoregressive conditional heteroskedasticity (GARCH) innovations. Country baskets include Germany (DE), France (FR), Belgium (BE), Netherlands (NL), Spain (ES), and Italy (IT), as well as two GC pooling baskets (GCP and GCX). Numbers (1) to (4) refer to quartiles sorted according to the Libor-OIS spread in descending order, i.e., (1) refers to the highest 25% values of the Libor-OIS spread, and (4) to the lowest.

Panel A: GC Repo Rates									
	DE					FR			
	(1)	(2)	(3)	(4)		(1)	(2)	(3)	(4)
LM	0.0295	0.0578	0.0611	0.1933	LM	0.0022	0.0688	0.0782	0.2661
DM	0.0011	0.0001	0.0284	0.1123	DM	0.0002	0.0022	0.0226	0.0119
J-Test	0.3281	0.2015	0.6081	0.8220	J-Test	0.2657	0.2705	0.4758	0.6938
	BE					NL			
	(1)	(2)	(3)	(4)		(1)	(2)	(3)	(4)
LM	0.0095	0.0079	0.1478	0.2560	LM	0.0381	0.0430	0.1795	0.1747
DM	0.0006	0.0011	0.0022	0.0369	DM	0.0001	0.0013	0.0605	0.0278
J-Test	0.3873	0.4712	0.4212	0.5803	J-Test	0.2412	0.3513	0.8296	0.9485
	ES					IT			
	(1)	(2)	(3)	(4)		(1)	(2)	(3)	(4)
LM	0.0121	0.0112	0.0756	0.0756	LM	0.0019	0.0486	0.0259	0.1591
DM	0.0000	0.0002	0.0167	0.0004	DM	0.0000	0.0004	0.0023	0.0384
J-Test	0.1518	0.1441	0.5989	0.4502	J-Test	0.1257	0.4660	0.4319	0.7529
	GCP					GCX			
	(1)	(2)	(3)	(4)		(1)	(2)	(3)	(4)
LM	0.1093	0.2183	0.1969	0.5596	LM	0.0014	0.0532	0.0938	0.1021
DM	0.0219	0.0008	0.0274	0.1645	DM	0.0001	0.0000	0.0001	0.0022
J-Test	0.6502	0.2899	0.9007	0.8905	J-Test	0.2739	0.2168	0.2871	0.5710
Panel B: Special Repo Rates									
	DE					FR			
	(1)	(2)	(3)	(4)		(1)	(2)	(3)	(4)
LM	0.0024	0.0291	0.0386	0.0563	LM	0.0006	0.0296	0.0802	0.0495
DM	0.0002	0.0214	0.0002	0.0000	DM	0.0000	0.0083	0.0201	0.0139
J-Test	0.1714	0.9326	0.1525	0.2277	J-Test	0.2127	0.2950	0.9286	0.5655
	BE					NL			
	(1)	(2)	(3)	(4)		(1)	(2)	(3)	(4)
LM	0.0140	0.0796	0.1381	0.1336	LM	0.0771	0.0873	0.0481	0.1072
DM	0.0018	0.0127	0.0037	0.0002	DM	0.0000	0.0003	0.0032	0.0036
J-Test	0.3944	0.3658	0.7619	0.2604	J-Test	0.1003	0.1820	0.3206	0.7578
	ES					IT			
	(1)	(2)	(3)	(4)		(1)	(2)	(3)	(4)
LM	0.0026	0.0021	0.0009	0.0428	LM	0.0053	0.0023	0.0309	0.0373
DM	0.0013	0.0015	0.0005	0.0118	DM	0.0001	0.0019	0.0004	0.0003
J-Test	0.2095	0.2259	0.4899	0.3523	J-Test	0.3403	0.2544	0.3406	0.4450

Table 5
GC ON Order Imbalance and SC Specialness

This table reports results of the EH tests conditional on the GC ON order imbalance in Panel A, and "specialness" for special (SC) repos in Panel B. All values reported are p-values and calculated as described in the text. Results are shown for GARCH innovations. Countries included are as described in Table 4. Numbers (1) to (4) refer to quartiles sorted according to ON order imbalance/specialness in descending order, i.e., (1) refers to the highest 25%, and (4) to the lowest.

Panel A: GC Repo Rates - ON Order Imbalance									
	DE					FR			
	(1)	(2)	(3)	(4)		(1)	(2)	(3)	(4)
LM	0.0195	0.0392	0.0962	0.1606	LM	0.0262	0.0438	0.0722	0.1300
DM	0.0044	0.0008	0.0323	0.0308	DM	0.0011	0.0052	0.0010	0.0024
J-Test	0.3666	0.1638	0.7222	0.5412	J-Test	0.4635	0.8018	0.1816	0.2849
	BE					NL			
	(1)	(2)	(3)	(4)		(1)	(2)	(3)	(4)
LM	0.0131	0.0343	0.1611	0.2507	LM	0.0878	0.0635	0.0474	0.0849
DM	0.0004	0.0037	0.0027	0.0615	DM	0.0074	0.0027	0.0000	0.0156
J-Test	0.3471	0.3438	0.7212	0.9595	J-Test	0.7470	0.4546	0.2101	0.5870
	ES					IT			
	(1)	(2)	(3)	(4)		(1)	(2)	(3)	(4)
LM	0.0172	0.0444	0.0800	0.0805	LM	0.0002	0.0654	0.0972	0.1987
DM	0.0002	0.0001	0.0209	0.0001	DM	0.0000	0.0001	0.0010	0.0250
J-Test	0.3940	0.3229	0.6414	0.3069	J-Test	0.1106	0.2861	0.4581	0.8920
	GCP					GCX			
	(1)	(2)	(3)	(4)		(1)	(2)	(3)	(4)
LM	0.0246	0.0373	0.1049	0.2080	LM	0.0295	0.0667	0.0732	0.1896
DM	0.0010	0.0001	0.0308	0.0034	DM	0.0059	0.0028	0.0010	0.0125
J-Test	0.1822	0.2190	0.7136	0.4887	J-Test	0.8161	0.4585	0.3115	0.5457
Panel B: Special Repo Rates - Specialness									
	DE					FR			
	(1)	(2)	(3)	(4)		(1)	(2)	(3)	(4)
LM	0.0063	0.0334	0.0444	0.0021	LM	0.0310	0.0016	0.0054	0.0041
DM	0.0003	0.0022	0.0123	0.0008	DM	0.0017	0.0001	0.0023	0.0019
J-Test	0.4220	0.2712	0.6990	0.1672	J-Test	0.2392	0.1764	0.2798	0.3991
	BE					NL			
	(1)	(2)	(3)	(4)		(1)	(2)	(3)	(4)
LM	0.0290	0.1086	0.0029	0.0460	LM	0.0490	0.0731	0.0446	0.0013
DM	0.0022	0.0002	0.0001	0.0096	DM	0.0041	0.0193	0.0022	0.0008
J-Test	0.2737	0.3527	0.2054	0.4975	J-Test	0.5195	0.4437	0.2709	0.2909
	ES					IT			
	(1)	(2)	(3)	(4)		(1)	(2)	(3)	(4)
LM	0.0002	0.0310	0.0010	0.1014	LM	0.0042	0.0066	0.0037	0.0667
DM	0.0001	0.0001	0.0001	0.0052	DM	0.0000	0.0000	0.0030	0.0191
J-Test	0.2461	0.3068	0.1524	0.8039	J-Test	0.1055	0.1759	0.4686	0.9249

Table 6
Calendar Effects - MRO

This table reports the p-values of the EH tests conditional on weekdays. All values reported are calculated as described in the text. Panel A reports results for GC repo rates, and Panel B for special repos. Results are shown for GARCH innovations. Country baskets include Germany (DE), France (FR), Belgium (BE), Netherlands (NL), Spain (ES), and Italy (IT), as well as two GC pooling baskets (GCP and GCX). Weekdays are ordered from Monday (1) to Friday (5).

Panel A: GC Repo Rates

	DE						FR				
	(1)	(2)	(3)	(4)	(5)		(1)	(2)	(3)	(4)	(5)
LM	0.0560	0.0972	0.0612	0.4133	0.1077	LM	0.0015	0.0107	0.0551	0.3349	0.0653
DM	0.0001	0.0402	0.0221	0.0825	0.0064	DM	0.0009	0.0002	0.0483	0.0415	0.0005
J-Test	0.4800	0.8693	0.6520	0.8782	0.4279	J-Test	0.3040	0.2702	0.7928	0.7666	0.3654
	BE						NL				
	(1)	(2)	(3)	(4)	(5)		(1)	(2)	(3)	(4)	(5)
LM	0.1774	0.0460	0.0600	0.0211	0.0513	LM	0.0195	0.0128	0.0275	0.0214	0.0402
DM	0.1051	0.0046	0.0108	0.0020	0.0026	DM	0.0001	0.0005	0.0206	0.0015	0.0058
J-Test	0.8089	0.5388	0.5193	0.2597	0.2930	J-Test	0.3341	0.5037	0.6384	0.2258	0.4116
	ES						IT				
	(1)	(2)	(3)	(4)	(5)		(1)	(2)	(3)	(4)	(5)
LM	0.0262	0.0128	0.0054	0.0621	0.0010	LM	0.0156	0.0123	0.0537	0.0201	0.0239
DM	0.0120	0.0017	0.0006	0.0006	0.0008	DM	0.0001	0.0002	0.0010	0.0001	0.0006
J-Test	0.3554	0.3868	0.2568	0.3956	0.1840	J-Test	0.2277	0.1737	0.4506	0.2300	0.3930
	GCP						GCX				
	(1)	(2)	(3)	(4)	(5)		(1)	(2)	(3)	(4)	(5)
LM	0.0103	0.0324	0.0082	0.0373	0.0992	LM	0.0271	0.0326	0.0103	0.0568	0.0233
DM	0.0014	0.0006	0.0014	0.0018	0.0492	DM	0.0134	0.0005	0.0002	0.0105	0.0011
J-Test	0.3563	0.2569	0.2231	0.3921	0.8924	J-Test	0.7127	0.4967	0.1594	0.6736	0.3333

Panel B: Special Repo Rates

	DE						FR				
	(1)	(2)	(3)	(4)	(5)		(1)	(2)	(3)	(4)	(5)
LM	0.0409	0.0529	0.0018	0.0481	0.0590	LM	0.0054	0.0013	0.0200	0.0024	0.0721
DM	0.0001	0.0042	0.0002	0.0001	0.0003	DM	0.0001	0.0001	0.0006	0.0006	0.0001
J-Test	0.3153	0.2046	0.2445	0.2905	0.1753	J-Test	0.2612	0.3334	0.5193	0.2535	0.2255
	BE						NL				
	(1)	(2)	(3)	(4)	(5)		(1)	(2)	(3)	(4)	(5)
LM	0.0562	0.0221	0.0112	0.0030	0.0029	LM	0.0715	0.0338	0.0004	0.0915	0.0070
DM	0.0013	0.0000	0.0034	0.0007	0.0001	DM	0.0103	0.0061	0.0002	0.0005	0.0024
J-Test	0.3477	0.2155	0.7513	0.1556	0.3364	J-Test	0.8741	0.8214	0.2761	0.4922	0.7088
	ES						IT				
	(1)	(2)	(3)	(4)	(5)		(1)	(2)	(3)	(4)	(5)
LM	0.0197	0.0034	0.0029	0.0052	0.0056	LM	0.0150	0.0133	0.0271	0.0065	0.0026
DM	0.0038	0.0021	0.0005	0.0033	0.0004	DM	0.0004	0.0109	0.0063	0.0002	0.0014
J-Test	0.3473	0.4176	0.2276	0.4835	0.2120	J-Test	0.4683	0.5205	0.8253	0.2662	0.3572