DOI: 10.28934/ea.22.55.2.pp1-19 First Online: October 21, 2022

ORIGINAL SCIENTIFIC PAPER

Repo Rates as Reference Interest Rates: Testing the Expectations Hypothesis of the Term Structure of Interest Rates

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ABSTRACT

The subject of this paper is the consideration of the role of the repo market and the quality of repo rates in the formation of reference interest rates that would be used to assess the value of financial instruments and derivatives. Unsecured money markets carry a certain level of risk; thus, the question arises whether the existing reference interest rates should be replaced by repo rates or other interest rates on secured loans. Through operations on the short-term money market, Central Banks try to influence interest rates with long maturities. One of the most well-known theories that considers the question of the relationship between short-term and long-term interest rates is the expectations hypothesis. In this paper, the expectations hypothesis is tested on the example of daily data of overnight interest rates related to secured interbank loans. Two samples were used, and term premiums were estimated for both short-term (up to one year using LIBOR interest rates) and long-term maturities (from two to ten years using ICE swap interest rates). The hypothesis is tested using two traditional econometric tests. The first test examines the relationship between the long-term change in the overnight rate on secured loans and term premiums for different maturities. The second test examines the relationship between the short-term change in long-term rates from the unsecured market and term premiums. By applying both tests together, it should be determined how well the overnight interest rates on secured interbank loans predict long-term interest rates on unsecured loans. The tests were also applied to the overnight interest rates of interbank loans that are not secured in order to get a better comparative picture. The results show that collateralized interest rates are good indicators of benchmark interest rates and, in some cases, even more accurate predictors of long-term interest rates

Keywords: *reference interest rates, repo rates, expectations hypothesis, IBOR transition, collateralization*

JEL Classification: G12, G17, G20

INTRODUCTION

Repo markets provide financial institutions with the necessary cash, so they play an essential role in managing short-term cash fluctuations. In addition to the necessary cash, the repo markets provide access to securities, enabling the efficient functioning of secondary markets. The regulatory definition of high-quality liquid assets (HQLA), as part of the liquidity coverage ratio (see Basel Committee on Banking Supervision, 2001), recognizes the importance of the

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repo market for the liquidity of the secondary securities market. Defining high-quality liquid assets includes the existence of an active repo market. Repo, which has HQLA as collateral, serves to mitigate credit and liquidity risks, so interest rates on such loans are suitable for the role of reference rates.

There are two main segments in the repo market, bilateral and tri-party repo. The bilateral repo market consists of investors and collateral owners who exchange money and securities directly without a clearing bank. Bilateral repo transactions may allow general collateral or impose restrictions on eligible collateral (special repo transactions).

In addition to investors and collateral owners, the tri-party repo market includes the participation of clearing banks that enable settlements. Clearing banks act as intermediaries, administrative processing details between the two parties in a repo transaction. Tri-party repo is used to finance general collateral (so-called general repo transactions), where investors accept any collateral in securities. Here, the centralized settlement mechanism minimizes operational risk.

The issue of benchmarking became more urgent after the British regulator announced that banks would no longer be required to implement LIBOR after 2021. Moreover, the monetary policy caused declining market liquidity has undermined previously reliable unsecured benchmarks, such as EONIA, the overnight rate. Consequently, reference interest rate administrators have been looking for virtually risk-free interest rates that would serve as a replacement for existing reference interest rates. The repo rates emerged as the first logical solution. As liquidity has migrated from unsecured money markets in recent decades, the question arises whether the investor should use repo rates instead of IBOR reference rates. Some markets have already done that. Reference rate administrators have chosen the Secured Overnight Financing Rate (SOFR) for the USD, Swiss Average Overnight Rate (SARON) for the CHF, the Canadian Overnight Repo Rate Average (CORRA) for the CAD, the Overnight Repurchase Rate (THOR) for THB, etc.

However, one of the main disadvantages of repo rates is the significant variations in their amount depending on collateral quality. Such variations suggest that market microstructure issues could have played a more significant role in explaining repo rate movements (Hull and White, 2013). One attempt to circumvent these problems is the MTS / NEX Markets family of repo rates (RFR), in which the statistical filter shortens the upper and lower quartiles of daily repo rates. [1]

Another objection to using repo rates in constructing yield curves is that there is no way to determine the complete maturity structure of repo contracts. There are not enough maturity repo transactions in all repo indices to extend the yield curve to more maturities. The reliance on market swaps could mitigate the unavailability of repo transactions in extrapolating time rates. Consultations initiated by ISDA (see ISDA, 2020) related to the transition to RFR rates suggest continuous compounding of overnight rates throughout the observed period.

Still, repo market plays a critical role in the transmission of monetary policy and the overall functioning of the financial system. In the Euro area, repo market is the largest segment of money market. The Euro repo market has grown significantly in the last couple of decades. Realized repo transactions in 5 most active countries of the Euro area (UK, France, Germany, Italy and Spain) reached 234.5 billion euros in 2018.[2] In US, 2.5 trillion US dollars are financed using repos on average daily in 2021.[3] Large volumes on repo market have an impact on financial stability, and therefore this market should not be neglected when discussing the scope of money market interest rates that should be considered as reference interest rates.

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[1] Source: https://www.icmagroup.org.
[2] Source: https://sdw.ecb.europa.eu.
[3] Source: https://www.sifma.org.

The main research question of the paper addresses the suitability of collateralized interest rates as reference interest rates. In particular, it tests the eligibility of these rates with traditional tests of the expectations hypothesis, such as those proposed by Campbell and Shiller (1991). Answering the aforementioned research question is important from the standpoint of asset pricing, since adequate reference rates, in addition to carrying minimal risk, should be solid predictors of future interest rates, both short-term and long-term.

LITERATURE REVIEW

Numerous authors have dealt with the issue of repo rates and the role of the repo market. The earliest works relate to special repo rates and the effects of the special repo market. One of the best-known in this field is Duffie (1996), which discusses the theoretical factors that lead to special repo rates lower than most interest rates on loans with similar maturities and risk profiles. Jordan and Jordan (1997) deal with a similar issue, empirically confirming the previous hypothesis. Fisher (2002) explains the close relationship between the price premiums of securities and special repo rates on the same securities. Buraschi and Menini (2002) deal with the link between liquidity risk and repo rates. They quantify the amount of average liquidity premium contained in the difference between general and special repo rates, which they claim is variable over time. Vayanos and Weill (2008) show that liquidity and the fact that some of the securities are special are two components of the price premiums of securities and derive a theoretical model that includes the absence of arbitrage.

Recent works are more focused on the general repo market. Bartolini, Hilton, Sundaresan, and Tonetti (2011) discuss general repo markets and collateralization associated with these markets. Gorton and Metrick (2012) investigate the link between the 2007-2008 financial crisis and the repo market, showing that changes in the LIBOR -OIS spread highly correlate with repo rates. Bottazzi, Luque and Páscoa (2012) examine how securities markets and repo markets coexist within the general economic equilibrium. Huh and Infante (2017) point to the importance of the role of repo transactions in brokerage in the securities market. The components of the difference between repo rates and rates on unsecured loans are empirically analyzed by Nyborg and Rösler (2019), using data on general repo rates on overnight transactions.

There are some recent papers focused on the role of repo market in general economic environment and its behaviour during debt crisis. Armenter and Lester (2017) provide a model that includes key features of the federal funds market and instruments introduced by the Federal Reserve. They use this model to study the effects of overnight reverse repurchase agreements on federal funds rate and other factors in the economic environment. Boissel, Derrien, Ors and Thesmar (2017) analyze a segment of the repo market during the Eurozone sovereign debt crisis. They show that during the crisis of 2011, repo rates strongly respond to movements in sovereign risk, in particular for GIIPS countries, indicating significant CCP stress. D'Amico, Fan and Kitsul (2018) quantify the scarcity value of Treasury collateral. They estimate the impact of security-specific demand and supply factors on the repo rates of U.S. Treasury securities and find an economically and statistically significant scarcity premium. Arrata, Nguyen, Rahmouni-Rousseau and Vari (2020) test the interactions between the PSPP and repo rates using empirical data. Their results show a negative correlation between bond purchases and associated repo rates.

However, repo markets and collateralization do not mean the total absence of credit risk. The parties in repo transactions may still fail to fulfill their obligations. The presence of credit risk leads to the need for careful selection of contractual parties to perform repo transactions as efficiently as possible. Government bonds are the most commonly used collateral in the repo market. The risk with these bonds is minimal (especially credit risk) as governments meet their obligations. Although there is no risk-free financial instrument, by minimizing the impact of the credit risk of counterparties, then adequate collateral management, and implementing operational efficiency, repo can significantly reduce credit and liquidity risk. In addition, most repo transactions are overnight. That is why it is less risky than interest rates on long-term loans. However, an overnight rate not secured by collateral, regardless of the rate in question, carries a risk precisely because of the non-coverage by collateral. Some authors, such as Longstaff (2000), argue that an overnight rate is a better indicator of a risk-free rate due to borrowing. He tests the validity of the expectations hypothesis on the example of short-term USD repo rates. Corte, Sarno, and Thornton (2008) further expand the test, which they also apply to the example of short-term USD repo rates. However, these papers do not test how reasonable repo rates are in estimating the forward-term structure of interest rates from the unsecured market (for example, LIBOR and swap markets), which would allow repo rates to play the role of reference interest rates.

EXPECTATIONS HYPOTHESIS OF THE TERM STRUCTURE OF INTEREST RATES

The expectation hypothesis assumes that the yield on a long-term bond is equal to the average expected yield on a short-term bond over the life of the long bond plus some constant risk premium. Most tests examine the ability of implicit interest rates to predict future yields. Test results generally indicate that forward yields are biased predictors of future interest rates (see Fama, 1984; Campbell and Shiller, 1991; and Bekaert, Hodrick, and Marshall, 1997).

Campbell and Shiller (1991) proposed the most famous tests of the expectation hypothesis, also used in this paper. These tests focus on predicting the difference in yields between long-term and short-term bonds. According to the hypothesis, predicting this difference should reflect the weighted average change in yields on short-term bonds over the life of the long-term bond and changes in yields on long-term bonds over the life of the short-term bond.

The equation represents the relationship between the long-term and the expected short-term rate

$$\bar{r}_t^n = \frac{1}{k}\sum_{i=0}^{k-1} E_t(\bar{r}_{t+mi}^m) + c_{n,m} \qquad (1)$$

in which $n = km$ denotes the maturity of the long-term rate, which is equal to the product of the maturity of the short-term rate (m) and its time-frequency (k).

Assuming rational expectations, the expression also applies

$$\bar{r}_{t+mi}^m = E_t(\bar{r}_{t+mi}^m) + \upsilon_{t+mi} \qquad i = 0, \dots, k-1 \qquad (2)$$

where the υ_{t+mi} process is a white noise process, i.e., an error term of the $\bar{r}_{t+mi}^m$.

Substitution (2) in (1) gives

$$\bar{r}_t^n = \frac{1}{k}\sum_{i=0}^{k-1} \bar{r}_{t+mi}^m - \frac{1}{k}\sum_{i=0}^{k-1} \upsilon_{t+mi} + c_{n,m}. \qquad (3)$$

In order to ensure stationarity, a short-term rate is deducted from both sides, which gives

$$\frac{1}{k}\sum_{i=0}^{k-1} \bar{r}_{t+mi}^m - \bar{r}_t^m = \alpha_1 + \beta_1(\bar{r}_t^n - \bar{r}_t^m) + \omega(t+n-m). \qquad (1)$$

Equation (4) represents the first test of the expectations hypothesis. The null hypothesis is that the slope coefficient β_1 is equal to one. Error $\omega(t+n-m)$ must be orthogonal to the constant and the difference between the long-term and short-term rate. The ordinary least squares method is suitable for estimating the unknown parameters. In contrast, the standard errors are calculated by the general method of moments due to Hansen (1982), since overlapping observations cause serial correlation.

The equation (1) is equivalent to

$$(n-m)E_t(\bar{r}_{t+m}^{n-m}) = n\bar{r}_t^n + m\bar{r}_t^m + nc_{n,m}. \quad (5)$$

By subtracting (n-m)$\bar{r}_t^n$ from both sides, it is clear that

$$E_t(\bar{r}_{t+m}^{n-m}) - \bar{r}_t^n = \frac{m}{n-m}(\bar{r}_t^n - \bar{r}_t^m) + \frac{n}{n-m}c_{n,m}. \quad (6)$$

It is obtained by applying relation (2) to equation (6) and introducing parameterization

$$\bar{r}_{t+m}^{n-m} - \bar{r}_t^n = \alpha_2 + \beta_2 \frac{m}{n-m}(\bar{r}_t^n - \bar{r}_t^m) + \vartheta(t+m). \quad (7)$$

Regression (7) represents the second test of the expectations hypothesis. The OLS specification uses the orthogonality of the error $\vartheta(t+m)$ according to the constant and the adjusted difference between the long-term and short-term rate at the moment t. The null hypothesis is that the slope coefficient is β_2 equal to one.

Equations (4) and (7), viewed together, fully reflect the expectations hypothesis. Equation (4) represents the relationship between term premiums and long-term changes in short-term interest rates. In contrast, equation (7) represents the relationship between term premiums and short-term changes in long-term interest rates. If one is valid for each n and m, then the other is valid for each n and m. However, for specific values n and m, one may be valid, while the other may not necessarily be valid (see Cambpell and Shiller, 1991).

EMPIRICAL RESULTS

This chapter will present the test results of the hypothesis given by equations (4) and (7). The idea is to test the extent to which overnight interest rates secured by collateral are good predictors of interest rates with longer maturities, which are collateral-free. Two alternative samples are analyzed, a shorter one (the so-called subsample) covering the period from 3.4.2018 until 7.10.2021, and longer, which covers the period from 2.1.2001 until 7.10.2021. The emphasis is put on the shorter sample to compare better results between new interest rates published from 2018 (e.g. SOFR) and those for which data historically reached far. At the same time, the period after 2018 eliminates the period of the financial crisis in 2008. On the other hand, the tests of the expectations hypothesis show bias in smaller samples (see Bekaert, Hodrick, and Marshall, 2001), so a larger sample was analyzed to test the stability of estimates. Table (1) provides an overview of summary indicators for both samples.

Table 1. Descriptive statistics of daily interest rate series

	Subsample					Whole Sample				
Interest Rates	**Subsample Size**	**Mean**	**SD**	**Min**	**Max**	**Sample Size**	**Mean**	**SD**	**Min**	**Max**
effr	1284	1.15	0.99	0.04	2.45	7584	1.44	1.64	0.04	6.67
sofr	1284	1.16	1.03	0.01	5.25	1284	1.16	1.03	0.01	5.25
libonusd	1281	1.15	0.99	0.05	2.40	7581	1.49	1.66	0.05	6.87
eonia	1284	-0.42	0.05	-0.50	-0.25	1375	-0.42	0.05	-0.50	-0.25
ester	738	-0.55	0.01	-0.58	-0.51	738	-0.55	0.01	-0.58	-0.51
liboneur	1281	-0.53	0.06	-0.60	-0.44	7581	1.15	1.69	-0.60	5.77
repoeur	1277	0.10	0.07	-0.03	0.38	1368	0.10	0.07	-0.03	0.38
sonia	1284	0.39	0.31	0.04	0.71	7584	2.02	2.08	0.04	6.93
libongbp	1284	0.38	0.30	0.03	0.70	7584	2.06	2.10	0.03	7.00
repogbp	88	0.48	0.01	0.45	0.49	6388	2.31	2.10	-0.25	6.74
saron	1284	-0.72	0.02	-0.79	-0.63	7583	0.23	1.01	-1.69	3.72

	Subsample					Whole Sample				
Interest Rates	Subsample Size	Mean	SD	Min	Max	Sample Size	Mean	SD	Min	Max
libonchf	1284	-0.79	0.01	-0.89	-0.75	7584	0.29	1.12	-1.16	4.58
tona	1284	-0.04	0.02	-0.08	-0.01	7582	0.07	0.15	-0.08	0.71
libonjpy	1284	-0.09	0.02	-0.21	-0.03	7584	0.09	0.19	-0.21	1.58
repojpy						1825	0.21	0.19	0.07	0.76

Source: Author's calculations. No data for the JPY denominated repo rates due to data unavailability.

Data and calculation methodologies

The LIBOR and ICE swap interest rates data come from the Refinitive (Thompson Reuters). The data are publicly available for other series of interest rates used in the paper. Interest rate data for five major global currencies are analyzed: the US dollar (USD), the Euro (EUR), the British pound (GBP), the Swiss franc (CHF) and the Japanese yen (JPY). Table 2 provides an overview of the interest rates used in this paper.

The term premium is the difference between interest rates with a maturity of more than one day (LIBOR and swap) and overnight interest rates, whether they relate to transactions covered or not covered by collateral. For each series of overnight interest rates, an analysis was performed on the same yield curves constructed from LIBOR (for shorter maturities) and swap (for longer maturities).

SOFR and SARON represent secured interest rates for USD and CHF. SOFR, which the Federal Reserve Bank of New York announced in April 2018 as an almost risk-free rate, is the average of transactions weighted for overnight repo rates on securities in the US repo market, and it replaces the LIBOR dollar. SARON is an overnight repo rate for the Swiss franc, developed by the Swiss National Bank (SNB) and the Swiss Stock Exchange as a risk-free rate that changes the Swiss franc LIBOR.

For the British pound, the Euro and the Japanese yen, repo rates are used as indicators of collateralized rates. These are overnight GILT repo rates with general collateral for GBP. The Bank of England publicly reported these data until 2.6.2018. The observation period for GILT repo rates is 4.1.2000 to 29.6.2018.

Table 2. An Overview of Analyzed Interest Rates

Interest rate	Currency	Tenor (s) *	Collateral coverage
Effective Federal Funds Rate (EFFR)	USD	on	no
Secured Overnight Financing Rate (SOFR)	USD	on	yes
Euro short-term rate (ESTER)	EUR	on	no
European Overnight Index Average (EONIA)	EUR	on	no
Overnight repo rate for EUR	EUR	on	yes
Sterling Overnight Index Average (SONIA)	GBP	on	no
Overnight repo rate for GBP	GBP	on	yes
Swiss Average Overnight Rate (SARON)	CHF	on	yes
Tokyo Overnight Average Rate (TONA)	JPY	on	no
Overnight repo rate for JPY	JPY	on	yes
London Interbank Offered Rate (LIBOR)	all 5 currencies	on, 1w, 1m, 2m, 3m, 6m, 12m	no
ICE swap rate	all 5 currencies	2y, 3y, 4y, 5y, 6y, 7y, 8y, 9y, 10y	no

Source: Author's calculations. on – overnight; w – week; m – month; y – year.

The Tokyo Repo Rate / Overnight transaction (% (T + 1)) is used for JPY. Data are published by the Bank of Japan and are available for the period from 30.10.2007 to 26.10.2012. Due to daily data unavailability, the Euro data for repo rate are approximated. The data on the daily level of the EONIA index are modified with the difference between the monthly data for the EONIA index and monthly bank repo transaction rates for the Euro area. Data on banking rates are published by the European Central Bank and are publicly available. The observation period is 31.12.2018 to 4.1.2021.

The data are observed at a daily frequency. All the rates are continuously compounded zero-coupon rates, calculated using the formula

$$\bar{r}_t^n = ln\left|\frac{1}{1+f\, r_t^n}\right|\frac{1}{f} \tag{8}$$

where f represents day count convention. The assumption is that every month has 30 days and the year 360. For the number of days shorter than 30, the exact number of days is used for the given period. Interpolated values have replaced missing data (non-working days, for example). Swap rates are also zero-coupon interest rates, calculated using the bootstrap method with a semi-annual frequency.

Hypothesis testing results

Tables 3 and 4 show the results of regression tests of equations (4) and (7) using the data described in the previous chapter. The tables show slope estimates and their standard errors that include Newey-West corrections (Newey and West, 1987).

Estimates show a slight increase in interest rates on US dollar-denominated loans in the subsample. The results for the remaining four currencies indicate the absence of a correlation between the level of estimates and the term structure of interest rates. A negative sign appears in the repo rate for the British pound and SARON interest rates. At the significance level of 5%, the coefficients for interest rates SOFR, EFFR, LIBORONUSD, repo rate for EUR, LIBORONCHF, TONA and LIBORONJPY deviate statistically significantly from zero.

On the whole sample, the estimates differ from those on the subsample. Similar to the results in the subsample, estimates of the slope of interest rates on US dollar-denominated loans grow up to 12 months. The estimates remain relatively unchanged for the remaining maturities, varying around one. A similar pattern is not observed for other currencies. The statistical significance of the coefficients changed at the interest rates for the Japanese yen, whose coefficients are not significantly different from zero on the whole sample. Most estimates are statistically significantly different from zero in the long-run part of the curve.

In both observed samples, the collateralized rates SOFR and repo EUR have an advantage over non-collateralized rates. Their estimates are relatively closer to unity and with a similar level of precision as estimates for non-collateralized interest rates. Repo GBP has much less favourable results than SONIA and LIBOR ON rates on the subsample. However, such results are prone to a small sample bias (for the GBP repo, only 88 observations were available). On the whole sample, the results for the GBP repo are more favourable and closer to the results of non-collateralized rates. This similarity of the results is especially noticeable in the short-term part of the curve. The results favour a collateralized rate for the Japanese yen on the short-term part of the curve. In this part of the curve, repo slopes are closer to one than the slopes for TONA and LIBOR ON rates.

The only currency where the results speak in favour of the superiority of non-collateralized rates is the CHF. The estimates for SARON deviate far from the ratings for the LIBOR ON rate, which are closer to unity. Similar conclusions are reached in analyzing the results for both observed samples.

Table 3. The results of equation (4) testing

	Subsample														
Period	sofr	effr	libonusd	repoeur	ester	eonia	liboneur	repogbp	sonia	libongbp	saron	libonchf	repojpy	tona	libonjpy
	0.5*	0.15	0.16	0.05*	0.01	0.1*	0.07	0.28*	0.45*	0.59*	0.01	0.19*		0.04*	0.27*
1W	(0.17)	(0.09)	(0.11)	(0.01)	(0.01)	(0.04)	(0.05)	(0.1)	(0.22)	(0.25)	(0.01)	(0.03)		(0.01)	(0.03)
	0.5*	0.28	0.27	0.21*	-0.01	0.06	0.06	-0.01	0.55	0.50	0.00	0.21*		0.12*	0.25*
1M	(0.21)	(0.16)	(0.17)	(0.05)	(0.01)	(0.05)	(0.05)	(0.1)	(0.3)	(0.28)	(0.07)	(0.04)		(0.05)	(0.04)
	0.48*	0.31*	0.29	0.41*	-0.01	0.06	0.06	-0.03	0.34	0.29	-0.03	0.1*		0.17*	0.28*
2M	(0.19)	(0.14)	(0.15)	(0.08)	(0.01)	(0.06)	(0.06)	(0.02)	(0.21)	(0.18)	(0.06)	(0.04)		(0.06)	(0.05)
	0.48*	0.35*	0.34*	0.43*	-0.01	0.04	0.05	-0.01	0.24	0.19	-0.1*	0.01		0.11*	0.28*
3M	(0.14)	(0.11)	(0.12)	(0.08)	(0.01)	(0.05)	(0.05)	(0.01)	(0.13)	(0.11)	(0.04)	(0.03)		(0.04)	(0.07)
	0.7*	0.6*	0.59*	0.38*	-0.02*	0.04	0.04	-0.01	0.28	0.21	-0.11*	-0.04		0.07*	0.18*
6M	(0.12)	(0.14)	(0.15)	(0.1)	(0.01)	(0.05)	(0.06)	(0.01)	(0.15)	(0.13)	(0.05)	(0.04)		(0.03)	(0.07)
	1.11*	1.02*	0.98*	0.33*	-0.03*	-0.01	-0.01	-0.01	0.38	0.29	-0.11	-0.08*		0.12*	0.18*
12M	(0.19)	(0.26)	(0.27)	(0.08)	(0.00)	(0.05)	(0.06)	(0.01)	(0.26)	(0.23)	(0.06)	(0.02)		(0.05)	(0.04)
	Sample														
Period	sofr	effr	libonusd	repoeur	ester	eonia	liboneur	repogbp	sonia	libongbp	saron	libonchf	repojpy	tona	libonjpy
	0.5*	0.03	0.33*	0.05*	0.01	0.09*	0.38*	0.57*	0.55*	0.83*	0.05	0.4*	0.33*	0.01	0.23*
1W	(0.17)	(0.03)	(0.12)	(0.01)	(0.01)	(0.04)	(0.04)	(0.06)	(0.05)	(0.04)	(0.03)	(0.1)	(0.02)	(0.01)	(0.08)
	0.5*	0.03	0.20	0.22*	-0.01	0.06	0.2*	0.4*	0.44*	0.64*	0.05	0.6*	0.2*	-0.01	0.09
1M	(0.21)	(0.07)	(0.16)	(0.04)	(0.01)	(0.05)	(0.08)	(0.13)	(0.13)	(0.1)	(0.06)	(0.2)	(0.04)	(0.02)	(0.09)
	0.48*	0.03	0.21	0.41*	-0.01	0.06	0.08	0.21	0.27	0.44*	0.01	0.46*	0.15*	-0.02	0.06
2M	(0.19)	(0.1)	(0.15)	(0.07)	(0.01)	(0.06)	(0.13)	(0.18)	(0.19)	(0.16)	(0.09)	(0.22)	(0.04)	(0.03)	(0.09)
	0.48*	0.08	0.25	0.43*	-0.01	0.04*	0.00	0.09	0.15	0.29	-0.02	0.39*	0.12*	-0.02	0.05
3M	(0.14)	(0.14)	(0.16)	(0.08)	(0.01)	(0.01)	(0.15)	(0.2)	(0.22)	(0.2)	(0.11)	(0.16)	(0.04)	(0.04)	(0.08)
	0.7*	0.26	0.42*	0.38*	-0.02*	0.04*	-0.03	-0.03	0.04	0.16	-0.03	0.39*	0.07	-0.03	0.02
6M	(0.12)	(0.22)	(0.2)	(0.1)	(0.01)	(0.01)	(0.21)	(0.3)	(0.3)	(0.28)	(0.19)	(0.18)	(0.04)	(0.05)	(0.07)
	1.11*	0.65*	0.77*	0.34*		-0.01	-0.01	0.05	0.09	0.16	0.01	0.38	0.02	-0.04	-0.02
12M	(0.19)	(0.32)	(0.27)	(0.09)		(0.01)	(0.28)	(0.28)	(0.28)	(0.25)	(0.31)	(0.36)	(0.03)	(0.07)	(0.07)
		1.34*	1.32*	0.26*		-0.05*	-0.07	0.15*	0.49*	0.43	0.07	0.36	-0.03	0.04	0.12
2Y		(0.22)	(0.23)	(0.04)		(0.01)	(0.04)	(0.07)	(0.24)	(0.22)	(0.25)	(0.25)	(0.02)	(0.17)	(0.2)
		1.18*	1.17*	0.15*		-0.06*	-0.13*	-0.04	0.25	0.20	-0.12	-0.11	-0.07*	-0.02	0.00
3Y		(0.12)	(0.13)	(0.02)		(0.00)	(0.05)	(0.05)	(0.19)	(0.18)	(0.12)	(0.14)	(0.02)	(0.08)	(0.1)
		1.16*	1.16*	0.1*		-0.06*	-0.15*	-0.06*	0.24	0.19	-0.10	-0.10	-0.06*	-0.02	-0.02
4Y		(0.08)	(0.08)	(0.01)		(0.00)	(0.06)	(0.01)	(0.14)	(0.13)	(0.08)	(0.09)	(0.01)	(0.05)	(0.06)
		1.15*	1.15*	0.07*		-0.06*	-0.17*	-0.07*	0.26*	0.22*	-0.07	-0.08	-0.05*	-0.02	-0.02
5Y		(0.07)	(0.07)	(0.01)		(0.00)	(0.05)	(0.01)	(0.09)	(0.09)	(0.05)	(0.06)	(0.01)	(0.03)	(0.04)
		1.06*	1.06*	0.06*		-0.06*	-0.19*	-0.08*	0.22*	0.18*	-0.06*	-0.06	-0.05*	-0.01	-0.01
6Y		(0.05)	(0.05)	(0.00)		(0.00)	(0.05)	(0.01)	(0.08)	(0.08)	(0.03)	(0.04)	(0.01)	(0.02)	(0.03)

*Source: author's calculations of OLS estimates for slope coefficients (Newey-West standard errors with n-m-1 lag in parentheses). * statistical significance at 5%*

The slope estimates for equation (7) in both samples are pessimistic in many cases, which are results similar to those published by Campbell and Shiller (1991). They show that estimates have a negative, therefore erroneous, sign for different subsamples that they analyze at different periods and sample sizes. The exceptions to this "rule" are the interest rates for USD and GBP for the shorter sample, where the ratings are positive. Also, for a larger sample, the slopes of the long-run part of the curve have a positive sign, but they deviate from the unit. For most interest rates, as n increases, the slope estimates with positive signs also increase, while for the negative ones, the estimates decrease as n increases, all moving away from unity.

Slope estimates are wildly inaccurate in many cases, with reasonably high Newey West standard errors. The statistical significance of the estimated slopes (at a significance level of 5%) on the shorter sample exists for the US dollar for maturities greater than 12 months, the repo rate denominated in the British pound for maturities over six years, and the TONA interest rate for maturities up to 3 months. The situation is slightly better for all currencies except EUR in the sample, especially for shorter maturities (up to 12 months), where many coefficients deviate statistically significantly from zero.

When comparing results between collateralized and non-collateralized rates, there is no significant difference in the results. Similar behaviour in terms of signs, the statistical significance of coefficients and deviations of estimates from the unit exist with collateralized interest rates. Due to the unavailability of data for $\bar{r}_{t+m}^{n-m}$ which are non-observable data, the regression-based equation (7) is approximated by $\bar{r}_{t+m}^{n}$. Bekaert, Hodrick, and Marshall (2001) note that this change in variables leads to an upward bias in predicting the slope coefficient.

Values greater than one are expected under the null hypothesis, even asymptotically. However, since the exact approximation is used for all series, they are all exposed to the same bias, so it is possible to compare their estimated values.

Table 4. The results of equation (7) testing

	Subsample														
Period	sofr	effr	libonusd	repoeur	ester	eonia	liboneur	repogbp	sonia	libongbp	saron	libonchf	repojpy	tona	libonjpy
	0.00	0.00	0.00	-0.01	-0.18	-0.09	-0.07	-0.33	0.52	0.77	-0.21*	-0.06		-0.2*	-0.05
1W	(0.03)	(0.09)	(0.11)	(0.01)	(0.11)	(0.07)	(0.08)	(0.17)	(0.45)	(0.59)	(0.07)	(0.11)		(0.05)	(0.13)
	0.11	0.13	0.12	-0.02	-0.23	-0.20	-0.17	-1.54	0.74	0.78	-0.72	-0.17		-0.62*	0.04
1M	(0.14)	(0.2)	(0.22)	(0.03)	(0.22)	(0.19)	(0.18)	(1.52)	(0.66)	(0.67)	(0.44)	(0.37)		(0.24)	(0.31)
	0.14	0.16	0.15	0.07	-0.22	-0.22	-0.18	-1.33	0.46	0.46	-0.90	-0.23		-0.73*	0.23
2M	(0.26)	(0.31)	(0.33)	(0.07)	(0.24)	(0.23)	(0.21)	(1.76)	(0.51)	(0.5)	(0.67)	(0.52)		(0.32)	(0.36)
	0.17	0.18	0.18	0.10	-0.23	-0.26	-0.22	-1.35	0.04	0.04	-0.95	-0.15		-0.59*	-0.09
3M	(0.33)	(0.36)	(0.38)	(0.13)	(0.33)	(0.31)	(0.3)	(1.63)	(0.37)	(0.37)	(0.61)	(0.43)		(0.21)	(0.43)
	0.77	0.82	0.86	0.30	-0.26	-0.26	-0.21	-3.21	0.07	0.06	-1.24	-0.35		-0.61	-0.29
6M	(0.42)	(0.44)	(0.47)	(0.25)	(0.47)	(0.44)	(0.45)	(3.76)	(0.45)	(0.44)	(0.93)	(0.84)		(0.36)	(0.72)
	1.73*	1.86*	1.93*	0.32	-0.46	-0.38	-0.38	-8.35	0.02	-0.02	-2.47	-1.05		-1.00	-0.93
12M	(0.76)	(0.78)	(0.81)	(0.52)	(0.95)	(0.81)	(0.84)	(8.57)	(0.73)	(0.71)	(2.03)	(1.88)		(0.83)	(1.42)
	2.28*	1.90	1.96*	-0.33	-3.34	-1.16	-1.33	-24.31	1.12	1.03	-3.88	-4.96		-3.21	-5.50
2Y	(1.03)	(0.98)	(1)	(0.86)	(3.15)	(1.39)	(1.5)	(20.34)	(1.23)	(1.27)	(2.55)	(2.9)		(2.87)	(4.42)
	3.29*	2.91*	3*	-1.16	-6.27	-2.07	-2.28	-46.72	1.60	1.48	-4.36	-4.81		-5.13	-7.35
3Y	(1.5)	(1.47)	(1.51)	(1.39)	(4.92)	(1.89)	(1.99)	(36.3)	(1.87)	(1.94)	(2.68)	(2.86)		(4.23)	(5.4)
	4.33*	4.06*	4.24*	-2.15	-9.73	-3.08	-3.28	-83.56	1.90	1.72	-5.45	-5.74		-7.17	-9.29
4Y	(1.65)	(1.58)	(1.62)	(1.96)	(7.49)	(2.45)	(2.55)	(54.37)	(2.41)	(2.5)	(3.14)	(3.27)		(5.42)	(6.39)
	5.44*	5.22*	5.43*	-3.11	-13.15	-4.02	-4.23	-142.47	2.11	1.88	-6.73	-6.95		-9.23	-11.39
5Y	(2.03)	(1.97)	(2.01)	(2.48)	(9.99)	(2.97)	(3.07)	(73.69)	(2.96)	(3.07)	(3.73)	(3.83)		(6.38)	(7.18)
	4.52*	5.18*	5.36*	-3.92	-14.97	-4.76	-4.96	-208.21*	2.32	2.05	-7.74	-7.93		-11.03	-13.03
6Y	(1.97)	(2.1)	(2.15)	(2.86)	(11.82)	(3.34)	(3.44)	(94.21)	(3.45)	(3.57)	(4.31)	(4.4)		(7.29)	(7.98)
	5.31*	6.09*	6.28*	-4.58	-16.13	-5.39	-5.59	-279.81*	2.53	2.23	-8.72	-8.88		-12.90	-14.72
7Y	(2.31)	(2.46)	(2.52)	(3.22)	(13.39)	(3.69)	(3.8)	(117.53)	(4)	(4.14)	(4.9)	(4.98)		(8.12)	(8.72)
	6.65*	7.62*	7.8*	-5.22	-17.16	-5.99	-6.19	-339.32*	2.78	2.43	-9.56	-9.70		-14.10	-15.76
8Y	(2.49)	(2.64)	(2.71)	(3.54)	(14.8)	(4.02)	(4.12)	(141.41)	(4.57)	(4.73)	(5.47)	(5.54)		(8.73)	(9.24)
	7.27*	8.33*	8.52*	-5.80	-17.95	-6.54	-6.74	-388.46*	2.97	2.56	-10.34	-10.46		-15.16	-16.68
9Y	(2.84)	(3)	(3.08)	(3.84)	(16.04)	(4.32)	(4.42)	(165.04)	(5.15)	(5.33)	(6.02)	(6.08)		(9.45)	(9.91)
	7.87*	9.03*	9.21*	-6.19	-19.01	-6.86	-7.06	-434.35*	3.20	2.74	-11.03	-11.15		-15.84	-17.21
10Y	(3.17)	(3.36)	(3.45)	(3.89)	(17)	(4.35)	(4.47)	(185.47)	(5.74)	(5.94)	(6.53)	(6.59)		(9.95)	(10.36)
	Sample														
Period	sofr	effr	libonusd	repoeur	ester	eonia	liboneur	repogbp	sonia	libongbp	saron	libonchf	repojpy	tona	libonjpy
	0.00	-0.18*	-0.25*	-0.01	-0.18	-0.08	0.04	0.4*	0.4*	0.91*	-0.10	0.00	-0.03	-0.18*	0.01
1W	(0.03)	(0.05)	(0.09)	(0.01)	(0.11)	(0.07)	(0.04)	(0.1)	(0.07)	(0.07)	(0.06)	(0.13)	(0.02)	(0.06)	(0.16)
	0.11	-0.38*	-0.67*	-0.02	-0.23	-0.19	-0.22*	-0.09	-0.14	0.02	-0.27*	-0.44*	-0.09*	-0.17*	-0.21*
1M	(0.14)	(0.12)	(0.14)	(0.03)	(0.22)	(0.19)	(0.06)	(0.16)	(0.13)	(0.11)	(0.08)	(0.14)	(0.02)	(0.05)	(0.1)
	0.14	-0.42*	-0.71*	0.07	-0.22	-0.22	-0.35*	-0.38	-0.4*	-0.26	-0.41*	-0.68*	-0.1*	-0.13*	-0.19*
2M	(0.26)	(0.18)	(0.19)	(0.06)	(0.24)	(0.23)	(0.07)	(0.23)	(0.19)	(0.16)	(0.15)	(0.24)	(0.03)	(0.05)	(0.07)
	0.17	-0.39	-0.64*	0.11	-0.23	-0.26	-0.37*	-0.55*	-0.58*	-0.45*	-0.49*	-0.73*	-0.1*	-0.11*	-0.18*
3M	(0.33)	(0.23)	(0.22)	(0.12)	(0.33)	(0.31)	(0.07)	(0.27)	(0.22)	(0.19)	(0.17)	(0.24)	(0.03)	(0.05)	(0.06)
	0.77	-0.10	-0.29	0.29	-0.26	-0.26	-0.38*	-0.85*	-0.89*	-0.7*	-0.77*	-0.99*	-0.17*	-0.11	-0.19*
6M	(0.42)	(0.27)	(0.3)	(0.23)	(0.47)	(0.44)	(0.11)	(0.43)	(0.35)	(0.3)	(0.32)	(0.42)	(0.04)	(0.06)	(0.06)
	1.73*	0.34	0.14	0.31	-0.46	-0.38	-0.38	-0.80	-0.96*	-0.63	-1.1*	-1.03	-0.24*	-0.11	-0.14*
12M	(0.76)	(0.39)	(0.46)	(0.49)	(0.95)	(0.81)	(0.21)	(0.52)	(0.45)	(0.35)	(0.49)	(0.57)	(0.06)	(0.09)	(0.07)
	2.28*	2.71*	2.69*	-0.29	-3.34	-0.99	-2.23	-3.40	-0.53	-0.57	-1.23*	-1.61*	-0.87	-0.29	-0.06
2Y	(1.03)	(0.79)	(0.82)	(0.79)	(3.15)	(1.29)	(1.44)	(2.04)	(0.95)	(1.03)	(0.52)	(0.63)	(0.49)	(0.57)	(0.69)
	3.29*	2.82*	2.75*	-0.85	-6.27	-1.54	-2.61	-5.93*	-1.80	-1.95	-0.86	-1.03*	-1.28	-0.55	-0.48
3Y	(1.5)	(1.11)	(1.14)	(1.23)	(4.92)	(1.67)	(1.72)	(2.78)	(1.45)	(1.54)	(0.44)	(0.48)	(0.82)	(0.75)	(0.83)
	4.33*	2.68*	2.61*	-1.45	-9.73	-2.09	-3.16	-7.71*	-2.85	-3.07	-0.78	-0.89	-1.62	-0.83	-0.81
4Y	(1.65)	(1.26)	(1.29)	(1.71)	(7.49)	(2.11)	(2.02)	(3.53)	(1.9)	(2)	(0.45)	(0.47)	(1.12)	(0.9)	(0.96)
	5.44*	2.51	2.40	-2.03	-13.15	-2.63	-3.96	-9.96*	-3.95	-4.24	-0.79	-0.88	-1.97	-1.08	-1.09
5Y	(2.03)	(1.53)	(1.57)	(2.16)	(9.99)	(2.57)	(2.41)	(4.37)	(2.33)	(2.45)	(0.5)	(0.51)	(1.36)	(1.01)	(1.06)
	4.52*	1.97	1.83	-2.50	-14.97	-3.03	-4.64	-12.06*	-4.84	-5.17	-0.83	-0.90	-2.26	-1.31	-1.33
6Y	(1.97)	(1.7)	(1.74)	(2.5)	(11.82)	(2.9)	(2.73)	(5.18)	(2.71)	(2.84)	(0.55)	(0.56)	(1.53)	(1.1)	(1.14)
	5.31*	1.82	1.66	-2.93	-16.13	-3.43	-5.36	-14.29*	-5.71	-6.09	-0.86	-0.92	-2.45	-1.52	-1.56
7Y	(2.31)	(1.93)	(1.97)	(2.82)	(13.39)	(3.23)	(3.05)	(6.02)	(3.08)	(3.22)	(0.59)	(0.6)	(1.65)	(1.18)	(1.21)
	6.65*	1.91	1.73	-3.38	-17.16	-3.85	-6.11	-16.71*	-6.57	-7.00	-0.92	-0.98	-2.53	-1.62	-1.64
8Y	(2.49)	(2.07)	(2.12)	(3.12)	(14.8)	(3.54)	(3.38)	(6.92)	(3.46)	(3.61)	(0.67)	(0.68)	(1.72)	(1.22)	(1.24)
	7.27*	1.75	1.56	-3.83	-17.95	-4.27	-6.83	-19.29*	-7.46	-7.95*	-0.99	-1.05	-2.55	-1.67	-1.69
9Y	(2.84)	(2.28)	(2.33)	(3.41)	(16.04)	(3.84)	(3.69)	(7.85)	(3.84)	(4.01)	(0.75)	(0.76)	(1.76)	(1.25)	(1.27)
	7.87*	1.58	1.37	-4.22	-19.01	-4.64	-7.55	-21.87*	-8.31*	-8.85*	-1.07	-1.12	-2.60	-1.67	-1.69
10Y	(3.17)	(2.49)	(2.54)	(3.56)	(17)	(3.99)	(3.95)	(8.78)	(4.21)	(4.39)	(0.83)	(0.84)	(1.81)	(1.28)	(1.29)

*Source: author's calculations of OLS estimates for slope coefficients (Newey-West standard errors with zero lags in parentheses). * statistical significance at 5%*

The regressions (4) and (7) indicate that the expectations hypothesis may be valid for the US dollar, where the hypothesis for SOFR holds a higher probability relative to EFFR and LIBOR ON rates. Table 5 gives the results of hypothesis testing $\beta_1 = 1$ and $\beta_2 = 1$. Only the results for which the null hypothesis cannot be rejected at the significance level of 5% are presented. In the first test ($\beta_1 = 1$), the hypothesis cannot be rejected at relatively longer maturities for the USD interest rates (EFFR, SOFR and LIBOR ON). Estimates of coefficients for maturities of 12 months do not deviate significantly from the unit in both samples. On the whole sample, other maturities for which the coefficients do not deviate significantly from the unit are 2, 3 and 6 years. On the whole sample, the collateralized interest rate (SOFR) recorded better results in higher p values than the non-collateralized interest rates (EFFR and LIBOR ON).

As for the second hypothesis $\beta_2 = 1$, it cannot be rejected for shorter maturities, namely USD 6M, GBP 1W and GBP 1M. The slope estimates of these pairs do not deviate significantly from the unit on the subsample. The exception is LIBOR ON for the one-week term premium, where the slope estimates do not deviate significantly from the unit on both observed samples. For the US dollar, the collateralized rate SOFR has similar results as non-collateralized rates, while for the British pound, non-collateralized rates have better results at these maturities.

Table 5. Slope constraint tests in equations (4) and (7)

beta1=1	**n**	**F(1.n)**	**p**
effr 12M	1279	0.00	0.95
effr 12M	7579	1.19	0.28
effr 2Y	2620	2.40	0.12
effr 3Y	2620	2.22	0.14
effr 6Y	2620	1.84	0.18
sofr 12M	1279	0.35	0.56
sofr 2Y	1279	0.01	0.92
sofr 3Y	1279	1.00	0.32
libonusd 12M	1279	0.00	0.95
libonusd 12M	7579	0.74	0.39
libonusd 2Y	2620	1.87	0.17
libonusd 3Y	2620	1.73	0.19
libonusd 6Y	2620	1.76	0.18
beta2=1	**n**	**F(1.n)**	**p**
effr 6M	1278	0.16	0.69
sofr 6M	1278	0.30	0.59
libonusd 6M	1278	0.09	0.76
sonia 1W	1281	1.13	0.29
sonia 1M	1281	0.15	0.70
libongbp 1W	1281	0.16	0.69
libongbp 1W	7581	1.66	0.20
libongbp 1M	1281	0.11	0.74

Source: author's calculations (only the results for which H_0 is not rejected).

CONCLUSION

This paper analyses the eligibility of repo rates in forming reference interest rates by checking the validity of the expectation hypothesis. Reference interest rates should be indicators of risk-free interest rates, and the expectations hypothesis is one of the essential theories of the term structure of interest rate on risk-free loans.

Other contributions from the literature have not given the repo rates as risk-free rates much attention so far. The main reason is the presence of considerable variability in their amount, which is a consequence of different collateral quality structures. In addition, there is no way to determine the entire maturity of the structure of repurchase agreements, which constitutes a serious potential obstacle for future research. Therefore, most authors use some of the interest rates on unsecured loans that do not face the above problems.

The paper applies the traditional tests of the expectation hypothesis proposed by Campbell and Shiller (1991). The hypothesis on daily data for 15 overnight interest rates is tested, in which five of them are covered with the general collateral. Five currencies were considered: USD, EUR, GBP, CHF and JPY. The term structure from LIBOR and ICE swap interest rates for all five currencies is constructed. The analysis was conducted on shorter and longer samples to compare different interest rates better. Some of the overnight interest rates for which the hypothesis was tested are relatively new (e.g. SOFR and ESTER), so there is limited data availability.

Based on the results of testing the expectations hypothesis, the conclusion is that overnight interest rates covered by collateral are equally good predictors of term premiums as their unsecured rivals. In some cases, they have proven to be even more precise indicators (for example, SOFR regressed to the swap rate in equation (7)). When we add to that the fact that collateral contributes to lower credit risk, it can be concluded that there is no reason not to apply repo rates as an official benchmark for risk-free interest rates. Relatively low credit risk is a significant advantage of repo rates worth considering and far outweighs the disadvantages of repo rates, which are mainly methodological. Quantifying this advantage could be a topic for future research in the area of repo rates and collateralization.

ACKNOWLEDGEMENTS

I wish to thank Milos Bozovic, Branislav Boricic, Dejan Soskic, Irena Jankovic and two referees for their comments on the previous version of this paper.

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Article history:	Received: July 4, 2022
	Revised: September 30, 2022
	Accepted: October 3, 2022