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OVERNIGHT INDEXED SWAP MARKET-BASED MEASURES OF MONETARY POLICY EXPECTATIONS

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Abstract

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JEL Codes: E43, E44, E52, G1.

Key Words: Federal Funds Futures; Overnight Indexed Swaps; Monetary Policy Expectations.

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1 Introduction

Researchers, policymakers and financial market participants closely monitor the evolution of expectations about the future path of monetary policy. This has been particularly apparent in recent years, as central banks have considered raising policy rates from their effective lower bound (ELB) (Lao and Mirza, 2015). Because of the keen interest in monetary policy expectations, empirical measures of investors' expectations of future short-term interest rates are highly sought-after. Within the academic literature, such measures have formed an important part of the empirical toolkit for monetary economists, informing numerous methodological contributions (e.g. Gürkaynak, Sack, and Swanson, 2005a,b; Gertler and Karadi, 2015; Cesa-Bianchi, Thwaites, and Vicondoa, 2016).

Broadly speaking, empirical measures of investors' expectations of future short-term interest rates can be categorised into three groups:[1] (i) financial market-based, where interest rate expectations are extracted from raw financial market data, such as futures and swaps; (ii) model-based, where interest rate expectations are estimated within models that use financial market data as an input, such as dynamic term structure models;[2] and (iii) survey-based, for instance from surveys of professional forecasters.

Financial market-based measures are the primary focus of this paper. To date, the principal measures amongst these are federal funds futures (FFFs) rates. In a widely cited paper, Gürkaynak, Sack, and Swanson (2007) compare the empirical success of a number of US financial market-based measures — including FFFs and eurodollar futures — as predictors of the future monetary policy stance. They conclude that, out to a 6-month horizon, FFFs dominate all other financial market instruments in forecasting monetary policy and, at longer horizons, the predictive power of many instruments is similar. However, Gürkaynak et al. (2007) do not compare FFFs to overnight indexed swap (OIS) rates.

FFFs have played an important role in forging an empirical toolkit for monetary economists, enabling the study of monetary policy and its effects. However, FFFs are US-only financial instruments and very few similar instruments are traded elsewhere. Therefore, the majority of questions to which this empirical toolkit has been applied have focused almost exclusively on the US. For example, work by Kuttner (2001) and Gürkaynak et al. (2005a) has assessed the effect of US monetary policy shocks on investors' interest rate expectations, as measured by FFFs rates. Similarly, FFFs have been used to analyse the effects of US 'unconventional' monetary policies, such as large-scale asset purchases and forward guidance, on financial markets (Swanson, 2016).[3]

Financial market-based measures of interest rate expectations offer certain advantages over model and survey-based measures for these applications. Most importantly, financial market

[1]These three categories are not mutually exclusive. See Lloyd (2017a) for a proposal that incorporates both financial market and model-based measures to estimate investors' interest rate expectations at horizons up to 10 years, and Kim and Orphanides (2012) for a proposal that combines model and survey-based measures.

[2]See Lloyd (2017a) and the references within.

[3]Notwithstanding this, model-based estimates of investors' interest rate expectations have been widely used to assess the transmission channels of unconventional monetary policies (e.g. Gagnon, Raskin, Remache, and Sack, 2011; Lloyd, 2017b).

data is available at intraday frequencies. In comparison, model-based measures are most-widely available at monthly or daily frequencies, while survey-based measures are (at best) available at monthly frequencies. The availability of intraday data has been critical in the aforementioned literature, permitting the identification of exogenous shocks to monetary policy uninfluenced by other economic news. Moreover, financial market-based instruments circumvent potentially contentious modelling assumptions applied to model-based measures, and the limitations of sampling from a population of individuals to create survey measures of interest rate expectations.

Most recently, a burgeoning literature, motivated by Stock and Watson (2012) and Mertens and Ravn (2013), has combined high-frequency identification techniques with structural vector autoregression methods to estimate the macroeconomic effects of monetary policy shocks. Gertler and Karadi (2015) use surprise movements in FFFs rates during 30-minute windows around monetary policy announcements from Gürkaynak et al. (2005a) as exogenous instruments to structurally identify monetary policy shocks. With this literature in its infancy, the application of financial market-based measures of interest rate expectations in academic research is set to grow. Moreover, with the growth of a parallel literature assessing the international transmission of monetary policy (Rey, 2016), there is a need to find financial market measures of interest rate expectations that are available outside the US and are globally comparable.

In this paper, I propose and test the use of OIS rates for this purpose. Since their inception in the early 2000s, OIS contracts have grown in popularity within financial markets. An OIS contract is an over-the-counter traded derivative in which two counterparties exchange fixed and floating interest rate payments. The floating interest rate on OIS contracts is the overnight interbank rate, which provides a measure of the *de facto* monetary policy stance.[4]

OIS contracts have numerous features that make them excellent candidate measures of investors' interest rate expectations. First, there is no exchange of principal, minimising counterparty risk. Second, OIS contracts do not involve any initial cash flow, minimising liquidity risk. Third, because many OIS contracts are collateralised, credit risk is also minimised (Tabb and Grundfest, 2013). Finally, unlike many LIBOR-based instruments, OIS contracts have increased in popularity following the 2007-2008 financial crisis (Cheng, Dorji, and Lantz, 2010).

Within the US, OIS rates offer potential advantages over FFFs rates too. First, OIS rates are now available at maturities in excess of 3 years. Cheng et al. (2010) state that OIS contracts tend to be liquid out to at least the 3-year horizon. FFFs are traded at up to a 3-year horizon, but remain largely illiquid at maturities in excess of 1 year. Second, the horizon of OIS contracts on a given day aligns with the horizon of government bond yields, whereas the horizon of FFFs contracts is a specific calendar month in the future, changing only at the beginning of a new calendar month. This permits easier comparison across financial instruments than FFFs.[5]

These promising features of OIS contracts have been recognised in papers assessing the efficacy of recent 'unconventional' monetary policies and their effect on expectations of future short-term interest rates (e.g. Christensen and Rudebusch, 2012; Woodford, 2012; Lloyd, 2017b).

[4] For example, the floating reference rate on US OIS contracts is the effective federal funds rate.

[5] Lloyd (2017a) proposes a method for estimating interest rate expectations out to a 10-year horizon that combines OIS rates and zero-coupon government bond yields.

Yet, despite the growing use of OIS rates as measures of interest rate expectations, no study has formally assessed the empirical success of OIS rates for this purpose.

In this paper, I address two questions. First, how accurate are implied interest rate expectations from US OIS rates, and how do they compare to those from FFFs? This offers a useful benchmark for comparison, as the behaviour of FFFs rates has been widely studied (e.g. Gürkaynak et al., 2007; Piazzesi and Swanson, 2008; Hamilton, 2009). Second, how accurate are implied interest rate expectations from OIS rates in other countries — specifically the UK, Eurozone and Japan? This is important for the global application of OIS rates as a financial market-based measure of monetary policy expectations.

To compare US OIS rates and FFFs, I build on the methodology of Piazzesi and Swanson (2008) and calculate *ex post* excess returns on these instruments. In order to perform this comparison accurately, I design a method to ensure that the horizons of OIS and FFFs contracts are identical. I create 'portfolios' of FFFs contracts and compare them to US OIS rates on the penultimate business day of each month. Plots of the unconditional *ex post* excess returns on OIS contracts and comparable-maturity portfolios of FFFs strongly indicate that OIS and FFFs rates contain similar information pertaining to investors' expectations of future short-term interest rates. I find that 1 to 11-month OIS contracts provide measures of investors' interest rate expectations that are as good as those from comparable-horizon FFFs contracts.

I then assess the global comparability of OIS rates. I first calculate the average *ex post* excess returns on US contracts using daily data to attain a benchmark against which to compare global OIS rates. The average *ex post* returns on US OIS contracts are comparable at monthly and daily frequencies, indicating that the OIS-FFF comparison is not blurred by calendar effects. Between 2002 and 2016, 1 to 24-month US OIS contracts, on average, provide accurate measures of investors' expectations of future short-term interest rates. I then calculate the average *ex post* excess returns on UK, Eurozone and Japanese OIS contracts at the same daily frequency. I find that, on average, 1 to 24-month OIS contracts in these jurisdictions also provide accurate measures of investors' expectations of future short-term interest rates.

These results have important implications for the future fashioning of an empirical toolkit for monetary economists. OIS rates have a useful role to play as a globally comparable market-based measure of interest rate expectations in empirical and policy research on positive and normative economic questions from a global, non-US-centric, perspective.

The remainder of this paper is structured as follows. Section 2 describes FFFs and OIS contracts. Section 3 presents the empirical comparison of FFFs and OIS. The global comparison of OIS contracts is in section 4. Section 5 concludes.

2 Financial Market Instruments

2.1 Federal Funds Futures (FFFs)

FFFs contracts were introduced by the Chicago Board of Trade (CBOT) in 1988 and are unique to US financial markets. They have a variety of maturities extending to the first 35 calendar months into the future. The contracts pay out at maturity based on the average effective federal funds rate realised in the calendar month specified in the contract. For example, the first FFF settles based on the average effective federal funds rate for the calendar month in which the contract was purchased. The second FFF settles based on the average effective federal funds rate in the calendar month subsequent to purchase, and so on.

Let $p^{FFF}_{t,t+n}$ denote the price of the FFFs contract purchased on a given day during month t that settles based on the average daily effective federal funds rate (an annualised rate) during month $t+n$ (the 'delivery month') $\overline{ffr}_{t+n}$, for $n = 0, 1, ..., 35$.[6] The contract matures at the end of the calendar month $t+n$, with settlement occurring on the subsequent day. The contract settles at "100 minus the arithmetic average of the daily effective federal funds rate during the delivery month".[7] The price quote is equal to 100 minus the expectation of the average daily effective federal funds rate in the delivery month. As such, the n-month FFFs rate, $i^{FFF}_{t,t+n} = 100 - p^{FFF}_{t,t+n}$, represents market participants' expectations of the average effective federal funds rate in the delivery month. Thus, for the buyer of the contract, the *ex post* realised (annualised) excess return equals:[8]

$$rx^{FFF}_{t,t+n} = i^{FFF}_{t,t+n} - \overline{ffr}_{t+n} \tag{1}$$

where $\overline{ffr}_{t+n}$ is the *ex post* realised average daily effective federal funds rate for month $t+n$.[9]

Under the expectations hypothesis, the FFF rate $i^{FFF}_{t,t+n}$ must equal the *ex ante* expectation of the average daily effective federal funds rate $\overline{ffr}_{t+n}$ for the contract month $t+n$:

$$i^{FFF}_{t,t+n} = \mathbb{E}_t \left[\overline{ffr}_{t+n}\right] \tag{2}$$

Thus, if the *ex post* realised excess return in (1) has zero mean, the *ex ante* forecasting error under the expectations hypothesis also has zero mean, and the n-month FFF can be said to provide an accurate measure of expected future short-term interest rates.

2.2 Overnight Indexed Swaps (OIS)

An OIS is an over-the-counter traded interest rate derivative with two participating agents who agree to exchange fixed and floating interest payments over a *notional* principal for the life of the contract. The floating leg of the contract is constructed by calculating the accrued interest payments from a strategy of investing the notional principal in an overnight reference rate and

[6] That is, $n = 1$ refers to the one-month ahead contract (`FF2` on financial market platforms); $n = 2$ the two-month ahead contract (`FF3`), and so on.

[7] See CME Rulebook, Chapter 22, 22101: `www.cmegroup.com/rulebook/CBOT/V/22/22.pdf`.

[8] Piazzesi and Swanson (2008) remark that (1) treats FFFs contracts as forward contracts, abstracting from the fact that futures contracts are 'marked to market'. Nevertheless, they demonstrate that the empirical difference between the precise definition of the *ex post* realised excess return on FFFs contracts, which accounts for marking to market, and (1) is small and does not influence their results for FFFs contracts. As in the main body of Piazzesi and Swanson (2008), I therefore use (1) to define *ex post* realised excess returns for simplicity.

[9] The *ex post* realised average effective federal funds rate for month $t+n$ is formally calculated as the arithmetic mean of the daily effective federal funds rate for the contract month, where the rate on non-business days is defined to be the rate that prevailed on the preceding business day.

repeating this on an overnight basis for the duration of the contract, investing principal plus interest each time. The reference rate for US OIS contracts is the effective federal funds rate, while for UK, Eurozone and Japanese contracts the reference rates are SONIA, EONIA and TONAR, respectively. The 'OIS rate' represents the rate on the fixed leg of the contract. For a vanilla OIS contract with a maturity of one year or less, money is only exchanged at the conclusion of the contract. Upon settlement, only the net cash flow is exchanged between the parties.[10] That is, if the accrued fixed interest rate payment exceeds the floating interest payment, the agent who took on the former payments must pay the other at settlement. Importantly, there is no exchange of principal at any time for OIS contracts of all maturities.

Due to the features of the contracts, OIS rates are closely linked to investors' expectations of future overnight interest rates over the horizon of the contract. Specifically, liquidity premia on OIS contracts should be small because there is no initial cash flow and, as an OIS contract is in zero net supply, it is unclear which party would demand a liquidity premium. Counterparty risk is small because there is no exchange of principal. Moreover, because many OIS trades are collateralised, credit risk is also minimised (Tabb and Grundfest, 2013, pp. 244-245). Finally, unlike many LIBOR-based instruments, OIS contracts have increased in popularity amongst investors following the 2007-2008 financial crisis (Cheng et al., 2010).

Let $i^{OIS}_{t,t+n}$ denote the annualised n-month OIS rate in month t, the swap's fixed interest rate. $i^{FLT}_{t,t+n}$ is the annualised *ex post* realised (net) return from the floating leg of the same contract.

The floating leg of the contract $i^{FLT}_{t,t+n}$ is calculated by considering a strategy in which an investor borrows the swap's notional principal x, invests in the overnight reference rate and repeats the transaction on an overnight basis, investing principal plus interest each time. Let the contract trade day be denoted t_{1-s}, where s denotes the 'spot lag' of the contract in days.[11] Suppose the n-month (N-day) contract matures on the day t_N in month $t+n$.[12] The floating leg of the contract is calculated based on the realised overnight reference rate on days t_1 to t_N.[13] Thus, the contract settlement period is given by the days $t_1, t_2, ..., t_N$. The floating overnight reference rate for the OIS contract on day t_i is denoted flt_i, for $i = 1, ...N$. Following market convention, the expression for the floating leg of an n-month (N-day) OIS contract, purchased on day t_{1-s}, in month t is:

$$i^{FLT}_{t,t+n} = \left(\left[\prod_{j=1}^{N} (1 + \gamma_j flt_j) \right] - 1 \right) \times \frac{360}{N} \tag{3}$$

where γ_j is the accrual factor of the form $\gamma_j = D_j/360$, where D_j is the day count between

[10]For contracts with maturity in excess of one year, the net cash flow exchange occurs at the end of every year.

[11]In the US market, OIS payment calculations begin with a two-day spot lag ($s = 2$) from the trade date, so the trade day is labelled t_{-1}. The same spot lag is included in Eurozone and Japanese OIS contracts. However, the spot lag on UK contracts is zero days, so the trade day is t_1.

[12]That is, the contract matures on day t_N, $(s-1)+N$ days after the trade date t_{1-s}.

[13]The floating leg is calculated using the actual month lengths, not normalised month lengths.

business days t_j and t_{j+1}.[14] To compare this floating leg to the fixed leg $i^{OIS}_{t,t+n}$, which is reported on an annualised basis, $i^{FLT}_{t,t+n}$ is a multiple of $360/N$ in (3).[15]

From the perspective of an agent who swaps fixed interest payments for the floating rate over the notional principal x, $\left(i^{OIS}_{t,t+n} - i^{FLT}_{t,t+n}\right) \times x$ represents the payoff of a zero-cost portfolio.[16] Thus, the *ex post* realised (annualised) excess return on the n-month OIS contract purchased during month t is:

$$rx^{OIS}_{t,t+n} = i^{OIS}_{t,t+n} - i^{FLT}_{t,t+n} \tag{4}$$

Under the expectations hypothesis, the fixed leg of the OIS contract must equal the *ex ante* expectation of the floating leg:

$$i^{OIS}_{t,t+n} = \mathbb{E}_t \left[i^{FLT}_{t,t+n}\right] \tag{5}$$

Thus, if the *ex post* realised excess return in (4) has zero mean, the *ex ante* forecasting error under the expectations hypothesis also has zero mean, and the n-month OIS contract can be said to provide an accurate measure of expected future short-term interest rates.

3 A Comparison of US OIS and FFFs Rates

3.1 Comparing OIS and FFFs Rates

(1) and (4) provide definitions for the *ex post* realised excess returns on FFFs and OIS contracts respectively. However, a direct comparison of excess returns of the two instruments on any given day is prevented by two distinct complications which motivate my empirical strategy.

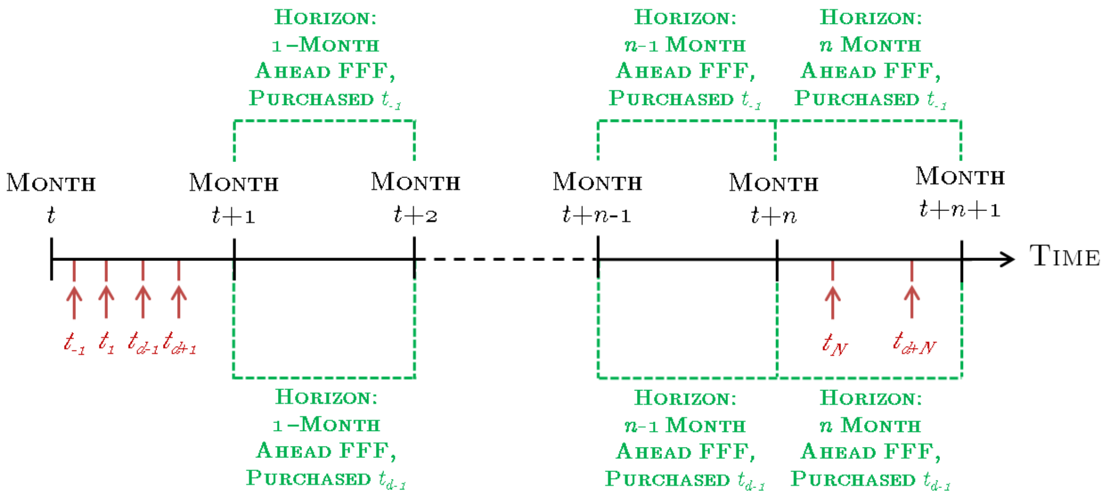
First, an n-month ahead FFF contract traded in the calendar month t has the same settlement date, regardless of the day in the month it is traded. In contrast, the n-month (N-day) OIS contract has a settlement horizon spanning the n-months (N-days) subsequent to the trade date (once the spot lag has been accounted for). This difference is depicted in figures 1 and 2. Figure 1 illustrates that an n-month ahead FFF contract traded on day t_{-1} in month t pertains to the same time horizon as an n-month ahead FFF contract traded on a different day t_{d-1} in the same calendar month t. Figure 2 demonstrates that an n-month US OIS contract, with N days to maturity and a two-day spot lag, traded on day t_{-1} settles based on the geometric average of the daily effective federal funds rate from day t_1 (accounting for the spot lag) to t_N (the maturity date), while the n-month contract traded on a different day t_{d-1} in the same month t settles based on the geometric average of the daily effective federal funds rate from day t_{d+1} to t_{d+N}.

[14] For example, on a week with no public holidays, the day count D_j will be set to 1 on Monday to Thursday, 3 on Friday, and 0 on Saturday and Sunday. That is, the floating overnight reference rate on a non-business day is defined as the rate that prevailed on the preceding business day. For US and Eurozone contracts, the day count is divided by 360, while for UK and Japanese contracts it is divided by 365, as per market convention.

[15] This accords with US and Eurozone market quoting conventions. Specifically, the fixed and floating legs of US OIS contracts are quoted according to the *Actual 360* convention. The UK and Japanese market quoting convention is *Actual 365*, so the floating rate is a multiple of $365/N$ instead (OpenGamma, 2013, p. 6).

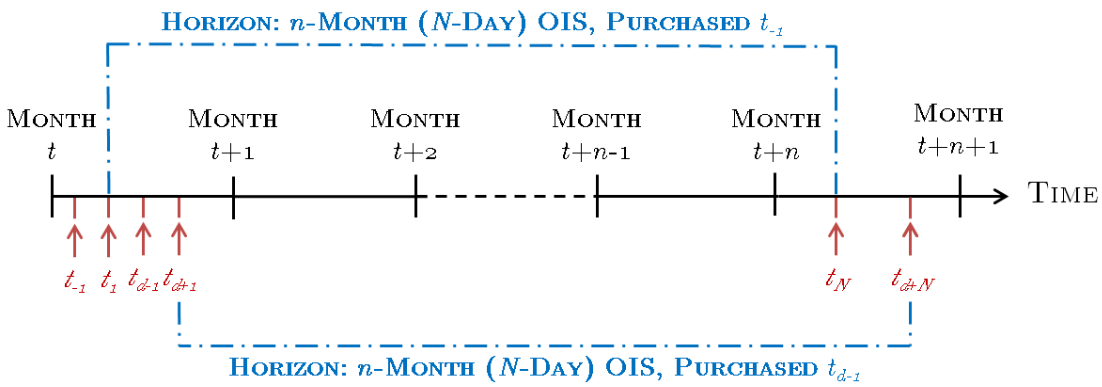
[16] Formally, this portfolio involves borrowing x at the floating overnight index rate at day t_1 and rolling over the borrowing to day t_N, while investing the x borrowed on day t_1 in the fixed interest rate $i^{OIS}_{t,t+n}$ to day t_N.

Figure 1: The Horizon of Federal Funds Futures Contracts Traded on Different Days, t_{-1} and t_{d-1}, in the Month t



Note: This figure depicts the horizons of federal funds futures (FFFs) contracts traded on different days, t_{-1} and t_{d-1}, in the calendar month t. An n-month ahead FFF contract purchased on day t_{-1} in month t pertains to the same time horizon as an n-month ahead FFF contract purchased on a different day t_{d-1} in the same calendar month t.

Figure 2: The Horizon of Overnight Indexed Swap Contracts Traded on Different Days, t_{-1} and t_{d-1}, in the Month t



Note: The figure depicts the horizons of US overnight indexed swap (OIS) contracts traded on different days, t_{-1} and t_{d-1}, in the calendar month t. The horizon of an n-month OIS contract purchased on day t_{-1} in month t spans from day t_1 (accounting for a two business day spot lag according to US market convention) to day t_N in month $t+n$. In contrast, the horizon of an n-month OIS contract purchased on a different day t_{d-1} of the same calendar month t spans from day t_{d+1} to day t_{d+N} in month $t+n$.

Second, the horizon of an n-month FFF contract purchased on any day t_{-1} in month t pertains to a specific calendar month in the future $t+n$, while the horizon of an n-month OIS contract purchased on the same day t_{-1} of month t spans the n months (N days) subsequent to the date t_1 (accounting for the two business day spot lag for US contracts). Figures 1 and 2 illustrate this. In figure 2, the n-month OIS contract traded on day t_{-1} of month t has a horizon spanning from day t_1 (accounting for the spot lag) in month t to day t_N in month $t+n$. In contrast, the n-month ahead FFF contract traded on the same day t_{-1} in month t has a horizon corresponding to the calendar month $t+n$ only (see figure 1).

To address these complications and attain comparable measures of *ex post* realised excess returns on FFFs and OIS contracts, I perform two data transformations.

First, I construct hypothetical n-month 'portfolios' of FFFs contracts that are traded in month t with horizons that begin on the first day of month $t+1$ and conclude on the final day of month $t+n$. To construct the interest rate on the n-month FFFs-portfolio $i^{FFF,port}_{t,t+n}$, I take the arithmetic average of the 1, 2, ..., n-month ahead FFFs rates on a given day in month t:

$$i^{FFF,port}_{t,t+n} = \frac{1}{N}\sum_{j=1}^{n} N_j i^{FFF}_{t,t+j} \tag{6}$$

where N_j denotes the number of days in month $t+j$ and $N \equiv \sum_{j=1}^{n} N_j$ is the total number of days in months $t+1, ..., t+n$.

This hypothetical n-month contract settles based on the arithmetic average of the daily effective federal funds rate from the first day of month $t+1$ to the final day of month $t+n$, denoted $\overline{ffr}^{port}_{t+n} = \frac{1}{N}\sum_{j=1}^{n} N_j \overline{ffr}_{t+j}$.[17] Thus, the *ex post* realised excess return on the hypothetical n-month portfolio of FFFs contracts, relative to the contract's settlement, is defined as:[18]

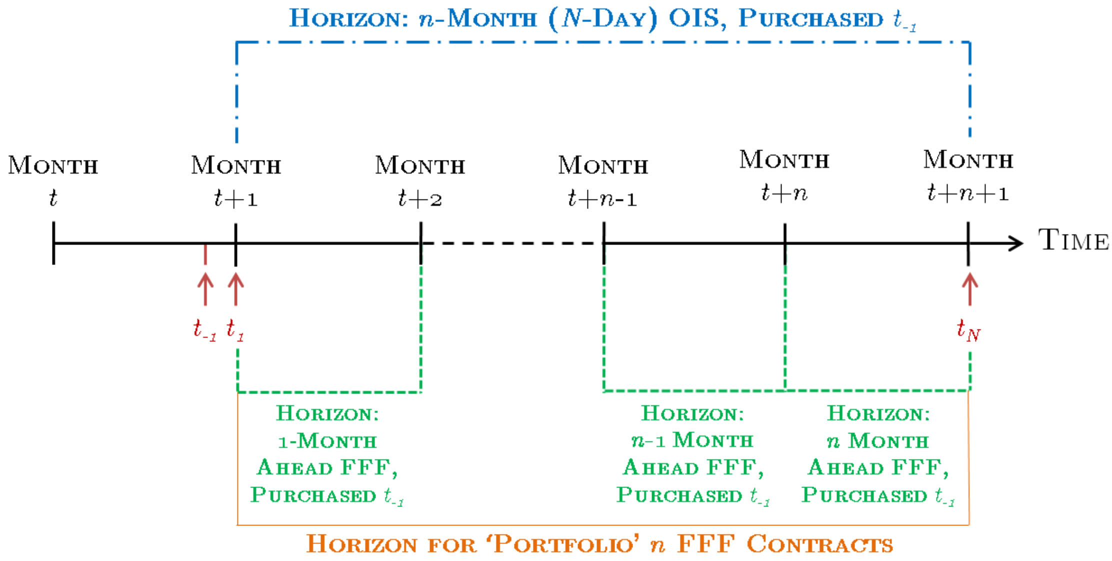
$$rx^{FFF,port}_{t,t+n} = i^{FFF,port}_{t,t+n} - \overline{ffr}^{port}_{t+n} \tag{7}$$

Second, the horizon of an n-month US OIS contract will only match the horizon of an n-month portfolio of FFFs contracts on the penultimate business day of a given month because of the two-day spot lag in US OIS contracts. Figure 3 demonstrates this. Here, day t_{-1} is the penultimate business day of month t. The horizon of the n-month OIS contract traded on this day begins on day t_1, the first day of the month $t+1$, because of the spot lag in the contract.

[17] The *ex post* realised average effective federal funds rate from the beginning of month $t+1$ to the end of month $t+n$ is formally calculated as the arithmetic mean of the daily effective federal funds rate for the period, where the rate on non-business days is defined to be the rate that prevailed on the preceding business day. I use the arithmetic average in accordance with FFFs market convention.

[18] With the exception of the 1-month horizon, the timing of receipts from an n-month OIS contract differs from an n-month portfolio of FFFs. Unlike an OIS contract, the portfolio of FFFs does not provide a single payoff at the end of its n-month horizon, but one at the end of each month as each FFF contract matures. This is mitigated by focusing on the *ex post* realised excess returns on the portfolios, assuming that FFFs receipts prior to month $t+n$ can earn a compounded return equal to the effective federal funds rate until the portfolio matures. For example, at the end of month $t+1$, the investor earns an excess return from the 1-month FFFs contract in the portfolio $rx^{FFF}_{t,t+1}$, which could earn compounded interest at the effective federal funds rate from the first day of month $t+2$ to maturity at $t+n$. Because (7) defines an *ex post* excess return, the interest earned on $rx^{FFF}_{t,t+1}$ and the interest foregone exactly cancel, so do not feature on the right-hand side of (7).

Figure 3: The Horizon of Federal Funds Futures, Overnight Indexed Swap Contracts and Portfolios of Federal Funds Futures Traded on the Penultimate Business Day t_{-1} in Month t



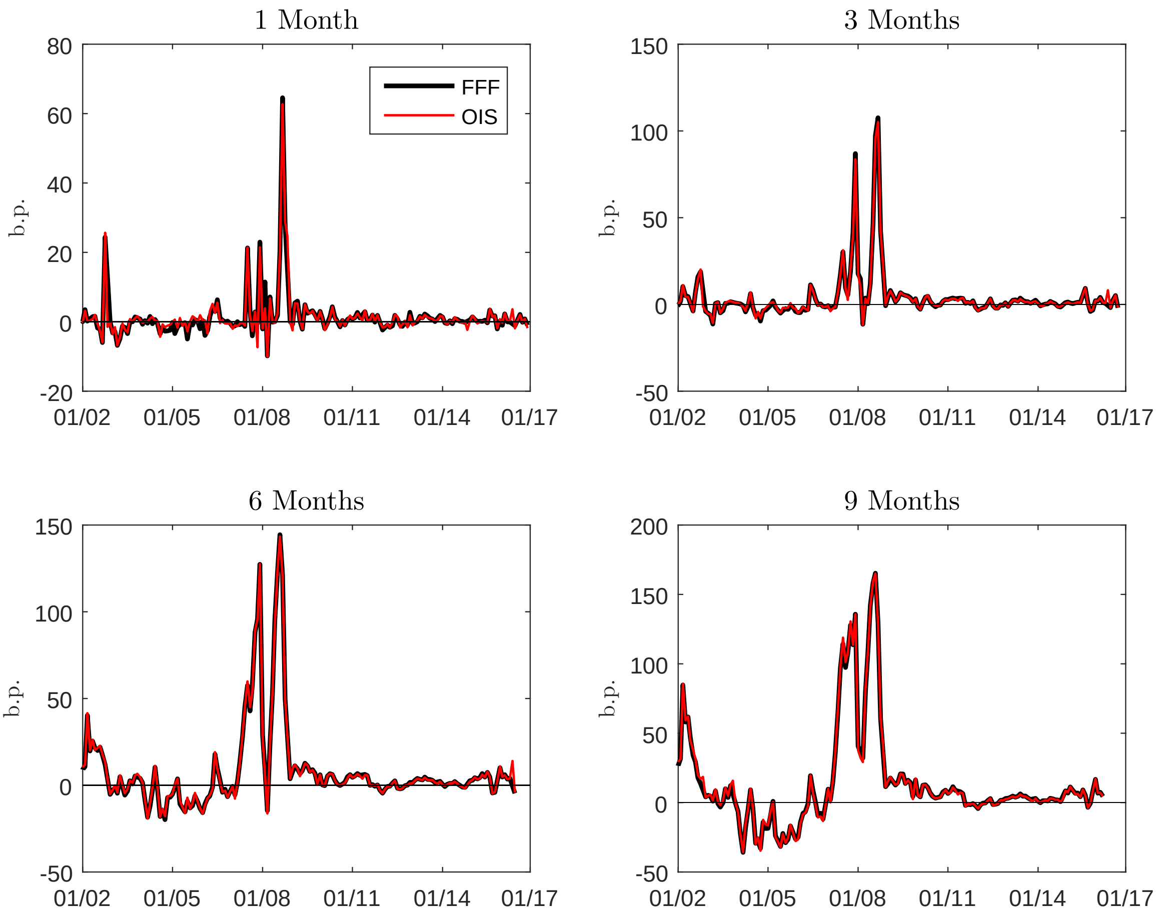
Note: The figure depicts the horizons of an n-month ahead federal funds futures (FFFs) contract, an n-month overnight indexed swap (OIS) contract, and a hypothetical n-month portfolio of FFFs contracts — defined in equation (6) — traded on the penultimate business day t_{-1} in the calendar month t. The horizon of an n-month OIS contract purchased on the penultimate business day t_{-1} of month t spans from day t_1, the first day of month $t+1$, to day t_N, the final day in month $t+n$. The horizon of the hypothetical n-month portfolio of FFFs contracts purchased on the same day t_{-1} of the same calendar month t spans the same period.

It concludes on day t_N, the final day of month $t+n$. The horizon of the hypothetical n-month portfolio of FFFs contracts, defined in (6), spans the same period. Because of this, I compare the *ex post* realised excess returns on n-month OIS contracts and n-month portfolios of FFFs contracts for the month t on the penultimate business day of that month, using the definitions in (4) and (7) respectively.[19] This yields a monthly time series of *ex post* realised excess returns for OIS and FFFs contracts that are comparable in horizon and formed on the same date.

Figure 4 plots the time series of unconditional *ex post* excess returns on 1, 3, 6 and 9-month OIS contracts and portfolios of FFFs contracts on the penultimate business day of each month. These plots preview some of the conclusions from the formal empirical analysis. Notably, at all tenors, unconditional *ex post* excess returns on OIS contracts and portfolios of FFFs contracts are strikingly similar for the majority of the 2002-2016 period. The plots strongly suggest that these OIS and FFFs rates contain similar information about financial market participants' expectations of future short-term interest rates. Although the excess returns fluctuate around zero for most of the period, the plots exhibit notable spikes during the 2007-2008 period, indicative of money market turmoil that influenced overnight interbank rates and *ex ante* unexpected monetary policy loosening in response to the 2007-2008 financial crisis. For this reason, I later

[19] Although the horizons of $i^{OIS}_{t,t+n}$ and $i^{FFF,port}_{t,t+n}$ traded on day t_{-1} match, these returns are not exactly comparable since the former is based on geometric compounding whereas the latter is not — as it is computed using an arithmetic average. This issue is mitigated by focusing on the *ex post* realised excess returns in (4) and (7), since they use the geometric and arithmetic average of the floating rate, respectively.

Figure 4: Unconditional *Ex Post* Excess Returns on US Overnight Indexed Swaps and Portfolios of Federal Funds Futures with Equivalent Horizon



Note: Time series plots of unconditional *ex post* excess returns for US OIS rates (solid red line) and portfolios of FFFs contracts (dashed black line) calculated using equations (4) and (7), respectively. The portfolios of FFFs contracts are constructed such that their horizon is equivalent to the horizon of corresponding-maturity OIS rates. The horizontal axis of each plot denotes the date of the *ex post* excess return and is labelled MM/YY. The data is plotted on penultimate business days of each month from January 2002 to December 2016.

conduct sensitivity analyses to account for the effects of the financial crisis and associated monetary policy loosening on estimated average *ex post* excess returns.

3.2 Regressions

To estimate the average *ex post* excess returns on US OIS contracts and comparable-horizon portfolios of FFFs contracts, I run the following regressions, for US OIS rates:

$$rx_{t,t+n}^{OIS} = \alpha_n^{OIS} + \varepsilon_{t+n}^{OIS} \tag{8}$$

and for the hypothetical portfolios of FFFs:

$$rx_{t,t+n}^{FFF,port} = \alpha_n^{FFF,port} + \varepsilon_{t+n}^{FFF,port} \tag{9}$$

for different monthly contract horizons $n = 1, 2, ..., 11$.[20]

All regressions are estimated using data observations on the penultimate business day of each calendar month. The sample runs from January 2002 to December 2016. The specific sample start date differs slightly across horizons due to the availability of US OIS rates at different tenors.[21] The selection of maturities is determined by FFFs rate data availability.[22]

Because contract horizons at adjacent time periods overlap, I compute standard errors using the heteroskedasticity and autocorrelation consistent procedure of Hodrick (1992), which generalises the Hansen and Hodrick (1980) method for overlapping contracts to the case of heteroskedasticity. Throughout the paper, I report t-statistics based on these standard errors. In regressions (8) and (9), α_n^{OIS} and $\alpha_n^{FFF,port}$ denote the average *ex post* excess return on OIS contracts and portfolios of FFFs respectively. If these are insignificantly different from zero, a contract is said to provide an accurate measure of expected future short-term interest rates. Because the reference rate on an OIS contract is a short-term money market rate, this empirical strategy formally analyses OIS rates as measures of short-term interest rate expectations, an indicator of the *de facto* monetary policy stance, rather than official policy rate settings.

Table 1 presents the baseline results from the estimation of (8) and (9) for the whole sample. Estimated average *ex post* realised excess returns are presented for the 1 to 11-month OIS and portfolios of FFFs contracts using observations on the penultimate business day of each month.

The primary result is that 1 to 11-month OIS contracts provide measures of investors' interest rate expectations that are as good as those from corresponding-maturity portfolios of FFFs contracts, corroborating with the information plotted in figure 4. In fact, for the 3 to 11-month tenors, the average *ex post* excess return on US OIS contracts is marginally smaller than that on the corresponding-maturity portfolio of FFFs contracts. For example, the average *ex post* excess return on the 8-month OIS contract is 11.43 basis points, 0.76 basis points lower than the average *ex post* excess return on the corresponding-maturity portfolio of FFFs contracts. Although the average *ex post* excess returns on 1 to 6-month OIS contracts are significant at the 10% level, at least, the same is true for 1 to 7-month portfolios of FFFs contracts. Moreover, in all cases, the average *ex post* excess returns are small — less than 9 basis points at the 6-month horizon — and subsequent analysis indicates that much of this can be explained by *ex ante* unexpected US monetary policy loosening in 2008.

A secondary result is that average excess returns on OIS contracts, as well as portfolios of FFFs contracts, are increasing with the maturity of the contracts. This is consistent with the view that longer-horizon OIS rates may contain some term premia (Michaud and Upper, 2008).

[20]In appendix B, I also provide estimates of excess returns on n-month ahead ('pure') FFFs contracts using the regression:

$$rx_{t,t+n}^{FFF} = \alpha_n^{FFF} + \varepsilon_{t+n}^{FFF}$$

to check that the data transformation used to construct hypothetical portfolios of FFFs contracts does not influence the results.

[21]See appendix A for a complete list of data sources and a detailed discussion of OIS rate availability.

[22]Although available prior to 2002, regular series for 12 to 36-month ahead FFFs rates are not available for the whole post-2002 period.

Table 1: Average *Ex Post* Excess Returns on US OIS Contracts and Portfolios of FFFs Contracts of Comparable Maturity

Panel A: US OIS Contracts						
Maturity in Months	**1**	**2**	**3**	**4**	**5**	**6**
$\widehat{\alpha}_n^{OIS}$	1.35***	2.52**	3.81**	5.22*	6.73*	8.45*
[t-statistic]	[2.72]	[2.19]	[1.98]	[1.92]	[1.86]	[1.81]
Maturity in Months	**7**[a]	**8**[a]	**9**	**10**[a]	**11**[a]	
$\widehat{\alpha}_n^{OIS}$	9.89	11.43	14.03	15.05	17.16	
[t-statistic]	[1.64]	[1.52]	[1.56]	[1.39]	[1.36]	
Panel B: Portfolios of FFFs Contracts						
Maturity in Months	**1**	**2**	**3**	**4**	**5**	**6**
$\widehat{\alpha}_n^{FFF,port}$	1.22***	2.44**	3.82*	5.30*	6.85*	8.52*
[t-statistic]	[2.39]	[2.01]	[1.91]	[1.88]	[1.83]	[1.76]
Maturity in Months	**7**	**8**	**9**	**10**	**11**	
$\widehat{\alpha}_n^{FFF,port}$	10.36*	12.19	14.16	17.06	19.05	
[t-statistic]	[1.68]	[1.60]	[1.53]	[1.51]	[1.43]	

Note: Panel A reports results from regression (8) and panel B reports results from regression (9) for contracts/portfolios with 1-11 month maturity. Sample: Monthly Frequency, January 2002 to December 2016, but for those indicated by [a] May 2002 to December 2016 (due to OIS rate availability). Hodrick (1992) t-statistics are reported in square brackets. An excess return is significantly different from zero at the 1%, 5% and 10% significance level when the absolute value of the t-statistic exceeds 2.33, 1.96, 1.645 respectively. These are denoted with asterisks ***, ** and * for the 1%, 5% and 10% significance levels respectively. All figures are reported in basis points to two decimal places.

Accounting for the 2008 US Monetary Policy Loosening During and after the 2007-2008 financial crisis, monetary policymakers lowered policy rates to their ELB. This was broadly unanticipated *ex ante* and, for this reason, may bias upwards the *ex post* excess returns presented in table 1. That is, the positive *ex post* excess returns in table 1 may actually reflect the unexpected policy loosening that occurred in response to the financial crisis and associated recession, rather than an excess return that reflects risk premia in OIS or FFFs contracts.

For this reason, I re-estimate (8) and (9) and include an additional dummy explanatory variable. This dummy is set to unity for periods in which the n-month OIS contract and portfolio of FFFs contracts measure expectations of future short-term interest rates during 2008, and zero otherwise. This choice aligns with the period in which US monetary policy was quickly loosened in response to the financial crisis and the associated recession.[23] For the 1-month contract, the dummy is set to unity from December 2007 to December 2008 (inclusive); for the 2-month contract, the dummy is set to unity from November 2007 to December 2008 (inclusive); and so on. Consequently, with the dummy variable included in the regression, α_n^{OIS} and $\alpha_n^{FFF,port}$ now represent the average *ex post* excess return on OIS and portfolios of FFFs outside the 2008 period, respectively. The coefficient on the dummy variable captures the average additional increase in *ex post* excess returns attributable to the unpredicted nature of the 2007-2008 financial crisis and associated monetary policy loosening during 2008.

The results from these extended regressions are reported in table 2. The estimates of α_n^{OIS}

[23]The federal funds rate target fell from 4.75% at the start of 2008 to 0-0.25% in December 2008.

and $\alpha_n^{FFF,port}$ are noticeably smaller than in table 1, typically at least half as small. The headline conclusion from table 1 is robust to the inclusion of a 2008 dummy. For 1 to 11-month OIS contracts, average *ex post* excess returns for the non-2008 period are quantitatively small, and the coefficients are statistically insignificant for the 5 to 11-month tenors. They are also quantitatively smaller than corresponding-maturity FFFs contracts. For example, the average *ex post* excess return for the 9-month OIS contract outside the 2008 period is 3.32 basis points, 10.71 basis points lower than its average *ex post* excess return for the whole 2002-2016 period and 0.94 basis points lower than the average *ex post* excess return on the comparable-maturity portfolio of FFFs contracts outside the 2008 period. Although the average *ex post* excess returns on OIS contracts for the non-2008 period are statistically significant at the 5% level for the 1 to 3-month tenors, and at the 10% level for the 4-month contract, their magnitude is small; the average *ex post* excess return on the 4-month OIS contract for the non-2008 period is just 1.54 basis points, 0.62 basis points lower than the comparable-maturity portfolio of FFFs. Thus, the usefulness of 1 to 11-month OIS rates as market-based measures of monetary policy expectations remains comparable to FFFs rates outside of the 2008 financial crisis period.

The coefficients on the 2008 dummy highlight the *ex ante* unpredicted nature of the financial crisis and associated policy loosening. For the OIS regressions in panel A of table 2, the coefficients on the 2008 dummy are positive and statistically significant, at the 5% level at least, for the 1 to 11-month OIS contracts. Moreover, the 2008 dummy coefficients are broadly increasing in the maturity of the OIS contracts, indicating that the extent to which the 2008 policy loosening was unanticipated increases at longer horizons. Interestingly, although the coefficients on the 2008 dummy for the FFFs regressions in panel B follow a similar qualitative pattern, the coefficients are statistically insignificant for 2 to 3-month portfolios of FFFs contracts. This implies that, at these maturities, FFFs rates did not include any statistically significant additional *ex post* excess returns during the 2008 period relative to the non-2008 period, indicating that the quality of these FFFs tenors as predictors of the future monetary policy stance did not significantly change during that period.

Overall, the results in tables 1 and 2 indicate that 1 to 11-month OIS rates provide measures of investors' interest rate expectations that are at least as good as those from comparable-horizon FFFs. This is important because FFFs have long been used to forecast future monetary policy, yet because OIS rates are available at longer maturities than FFFs and in a range of countries, OIS rates potentially offer a globally comparable financial market measure of monetary policy expectations.

Table 2: *Ex Post* Excess Returns on US OIS Contracts and Portfolios of FFFs Contracts After Controlling for a 2008 Dummy

Panel A: US OIS Contracts						
Maturity in Months	**1**	**2**	**3**	**4**	**5**	**6**
$\widehat{\alpha}_n^{OIS}$	0.50**	0.86**	1.14**	1.54*	1.91	2.22
[t-statistic]	[1.98]	[2.22]	[1.96]	[1.76]	[1.55]	[1.35]
2008 Dummy	12.76**	22.70**	33.70***	43.14***	52.72***	63.78***
[t-statistic]	[2.33]	[2.11]	[2.44]	[3.34]	[7.39]	[−7.54]
Maturity in Months	**7**[a]	**8**[a]	**9**	**10**[a]	**11**[a]	
$\widehat{\alpha}_n^{OIS}$	3.49	3.58	3.32	3.86	3.96	
[t-statistic]	[1.24]	[1.07]	[0.81]	[0.83]	[0.72]	
2008 Dummy	60.11***	69.37***	91.54***	88.47***	99.03***	
[t-statistic]	[−6.21]	[−7.13]	[−10.26]	[9.39]	[6.73]	
Panel B: Portfolios of FFFs Contracts						
Maturity in Months	**1**	**2**	**3**	**4**	**5**	**6**
$\widehat{\alpha}_n^{FFF,port}$	0.54*	1.18*	1.92*	2.16*	2.54	2.93
[t-statistic]	[1.82]	[1.79]	[1.70]	[1.64]	[1.43]	[1.32]
2008 Dummy	9.71*	16.56	22.92	35.20***	44.95***	54.56***
[t-statistic]	[1.77]	[1.44]	[1.53]	[2.43]	[4.82]	[−6.25]
Maturity in Months	**7**	**8**	**9**	**10**	**11**	
$\widehat{\alpha}_n^{FFF,port}$	3.49	3.98	4.26	7.43	9.84	
[t-statistic]	[1.24]	[1.14]	[1.00]	[1.11]	[1.07]	
2008 Dummy	63.01***	71.33***	81.16***	73.31***	65.26***	
[t-statistic]	[−5.00]	[−6.06]	[−12.03]	[4.25]	[2.93]	

Note: Panel A reports results from regression (8) and panel B reports results from regression (9) with an additional dummy variable set equal to one on dates when a contract's horizon spans the year 2008. Sample: Monthly Frequency, January 2002 to December 2016, but for those indicated by [a] May 2002 to December 2016 (due to OIS rate availability). Hodrick (1992) t-statistics are reported in square brackets. An excess return is significantly different from zero at the 1%, 5% and 10% significance level when the absolute value of the t-statistic exceeds 2.33, 1.96, 1.645 respectively. These are denoted with asterisks ***, ** and * for the 1%, 5% and 10% significance levels respectively. All figures are reported in basis points to two decimal places.

4 OIS Rates from a Global Perspective

Here, I assess whether OIS rates accurately measure monetary policy expectations globally.

4.1 US OIS Contracts

I calculate unconditional *ex post* excess returns on US OIS contracts at a daily frequency, between January 2002 and December 2016, for the following tenors: 1 to 12 months; 15, 18 and 21 months; 2, 3, 4 and 5 years.[24] I estimate (8) using this daily frequency data. Again, t-statistics use heteroskedasicity and autocorrelation robust Hodrick (1992) standard errors.

Panel A of table 3 presents the results from these regressions. Daily frequency average *ex post* excess returns on 1 to 11-month OIS contracts are similar to their excess returns at a monthly frequency reported in table 1, indicating that monthly frequency estimates from

[24]The choice of tenors is determined by data availability. See appendix A.

Table 3: Average *Ex Post* Excess Returns on US OIS Contracts at Daily Frequency

Panel A: US OIS Contracts					
Maturity in Months	**1**	**2**	**3**	**4**	**5**
$\widehat{\alpha}_n^{OIS}$	1.34*	2.54*	3.86*	5.32*	6.87*
[t-statistic]	[1.79]	[1.79]	[1.81]	[1.79]	[1.69]
Maturity in Months	**6**	**7**[a]	**8**[a]	**9**	**10**[a]
$\widehat{\alpha}_n^{OIS}$	8.54	9.93	11.54	14.09	15.20
[t-statistic]	[1.56]	[1.39]	[1.30]	[1.34]	[1.22]
Maturity in Months	**11**[a]	**12**	**15**	**18**	**21**
$\widehat{\alpha}_n^{OIS}$	17.24	20.98	27.61	35.59	44.25
[t-statistic]	[1.20]	[1.32]	[1.33]	[1.43]	[1.60]
Maturity in Months	**24**	**36**[b]	**48**[b]	**60**[b]	
$\widehat{\alpha}_n^{OIS}$	53.27*	86.86***	126.32***	173.60***	
[t-statistic]	[1.86]	[4.61]	[−5.37]	[−8.48]	
Panel B: US OIS Contracts with 2008 Dummy					
Maturity in Months	**1**	**2**	**3**	**4**	**5**
$\widehat{\alpha}_n^{OIS}$	0.41*	0.76*	1.14*	1.50	1.90
[t-statistic]	[1.75]	[1.80]	[1.75]	[1.61]	[1.40]
2008 Dummy	14.11	24.65**	34.79***	45.33***	54.76***
[t-statistic]	[1.58]	[2.00]	[3.08]	[−10.78]	[−5.04]
Maturity in Months	**6**	**7**[a]	**8**[a]	**9**[a]	**10**[a]
$\widehat{\alpha}_n^{OIS}$	2.22	1.88	1.86	3.28	2.41
[t-statistic]	[1.19]	[0.83]	[0.60]	[0.72]	[0.48]
2008 Dummy	65.20***	76.26***	86.01***	93.12***	101.68***
[t-statistic]	[−8.34]	[14.75]	[10.53]	[9.79]	[9.78]
Maturity in Months	**11**[a]	**12**	**15**	**18**	**21**
$\widehat{\alpha}_n^{OIS}$	2.93	5.73	8.34	12.11	16.02
[t-statistic]	[0.48]	[0.68]	[0.65]	[0.74]	[0.84]
2008 Dummy	108.41***	112.22***	123.26***	131.95***	141.13***
[t-statistic]	[10.56]	[13.46]	[−11.47]	[−7.16]	[−6.00]
Maturity in Months	**24**	**36**[b]	**48**[b]	**60**[b]	
$\widehat{\alpha}_n^{OIS}$	20.91	43.47**	84.49***	155.05***	
[t-statistic]	[1.07]	[2.01]	[3.57]	[21.59]	
2008 Dummy	145.15***	132.62***	93.14***	31.15	
[t-statistic]	[−4.77]	[−55.52]	[3.07]	[0.99]	

Note: Results from regression (8) for daily frequency OIS contracts. Sample: Daily Frequency, January 1, 2002 to December 31, 2016, but for those indicated by [a] May 7, 2002 to December 31, 2016 and [b] February 14, 2002 to December 31, 2016 (due to OIS rate availability). Hodrick (1992) t-statistics are reported in square brackets. An excess return is significantly different from zero at the 1%, 5% and 10% significance level when the absolute value of the t-statistic exceeds 2.33, 1.96, 1.645 respectively. These are denoted with asterisks ***, ** and * for the 1%, 5% and 10% significance levels respectively. All figures are reported in basis points to two decimal places. The 2008 dummy is set equal to unity on dates where the OIS contract horizon overlaps with the January 22, 2008 to December 16, 2008 US monetary policy loosening.

section 3 are not susceptible to calendar effects. For example, the average *ex post* excess return on the 9-month OIS contract calculated with daily frequency data is 14.09 basis points, while the corresponding figure calculated using observations on the penultimate business day of each month is just 0.06 basis points lower at 14.03 basis points. The average *ex post* excess returns on the 1 to 5-month OIS contracts are significant at the 10% level for the whole 2002-2016 sample, but remain quantitatively small — not exceeding 6.87 basis points.

The 12 to 21-month OIS contracts, for which section 3 did not present monthly frequency results, exhibit statistically insignificant *ex post* excess returns for the 2002-2016 sample period. As with the 1 to 11-month tenors, the estimated average *ex post* excess returns on the 12 to 21-month contracts are increasing in the contract horizon, but remain insignificantly different from zero. At the 2-year horizon, the average *ex post* excess return is 53.27 basis points — over double the excess return on the 1-year contract of 20.98 basis points — and is statistically significant at the 10% level. In subsequent sensitivity analysis, I conclude that this marginal significance is primarily driven by the money market turmoil and unanticipated loosening of monetary policy during 2007-2008, as opposed to risk premia within the contract.

At longer horizons — 3, 4 and 5 years — OIS contracts have statistically significant positive *ex post* excess returns at the 1% level, indicative of term premia in longer-horizon OIS rates that blur their use as market-based measures of monetary policy expectations.

Accounting for 2008 US Monetary Policy Loosening As a sensitivity test, I regress the daily frequency unconditional *ex post* excess returns of OIS contracts on a constant and a 2008 dummy. As in section 3, this dummy is defined to capture the unanticipated nature of US monetary policy loosening in the wake of the 2007-2008 financial crisis. This regression accounts for the possibility that the unanticipated 2008 monetary policy loosening biases estimates of average *ex post* excess returns on OIS contracts upwards. That is, the positive average *ex post* excess returns presented in panel A of table 3 may actually reflect the *ex ante* unexpected nature of monetary policy accommodation during 2008, rather than risk premia in OIS contracts that complicate their use as a market-based measure of monetary policy expectations. As before, I define a 2008 dummy for each OIS contract maturity, set equal to unity on dates where the horizon of an OIS contract overlaps with the 2008 US policy accommodation. I define the policy accommodation period as January 22, 2008 — the first date on which the US policy rate was lowered in 2008 — to December 16, 2008 — the date on which the federal funds rate target was lowered to 0-0.25%.[25] Here, the estimated α_n^{OIS} coefficient can be interpreted as the average *ex post* excess return on an n-month OIS contract in periods for which the contract's horizon did not overlap with the 2008 US monetary policy loosening. The coefficient on the 2008 dummy captures the additional increase in *ex post* excess returns during the 2008 period.

The results in panel B of table 3 further support the main conclusions of the paper. In particular, the average *ex post* excess returns outside the 2008 period on 4 to 24-month OIS

[25]That is, for the 1-month OIS contract the dummy is set to 1 on days between December 22, 2007 and December 16, 2008 (inclusive) and zero otherwise. For the 2-month OIS contract, the dummy is set to 1 on days between November 22, 2007 and December 16, 2008 (inclusive) and zero otherwise.

contracts are insignificantly different from zero, and are all substantially smaller than the estimated average *ex post* excess return for the whole 2002-2016 sample. For example, the average *ex post* excess return on the 8-month contract for the non-2008 period is 1.86 basis points, approximately 1/6th of the corresponding average for the whole 2002-2016 period. Although the average *ex post* excess returns on 1 to 3-month OIS contracts are significant at the 10% level, they are small — less than 1.14 basis points — indicating that OIS rates at these tenors do provide accurate measures of interest rate expectations.

The 2-year OIS contract exhibits an average *ex post* excess return of 20.91 basis points for the non-2008 period, a figure which is insignificantly different from zero. Thus, the (marginally) significant average figure for the whole 2002-2016 period appears to be a result of the unanticipated events of 2008, rather than risk premia in the contract. Aside the 2008 period, the 2-year OIS contract is able to successfully predict the future monetary policy stance.

At longer horizons — 3, 4 and 5 years — OIS contracts still exhibit significant term premia in the non-2008 period. However, the average *ex post* excess returns on these contracts for the non-2008 period are smaller than for the 2002-2016 period as a whole. For example, the non-2008 average *ex post* excess return for the 3-year contract is 43.47 basis points, which is approximately half the estimate for the whole 2002-2016 sample.

For the 2 to 48-month tenors, the 2008 dummy coefficients are all positive and significant, consistent with the claim that the 2008 monetary policy loosening was *ex ante* unexpected.

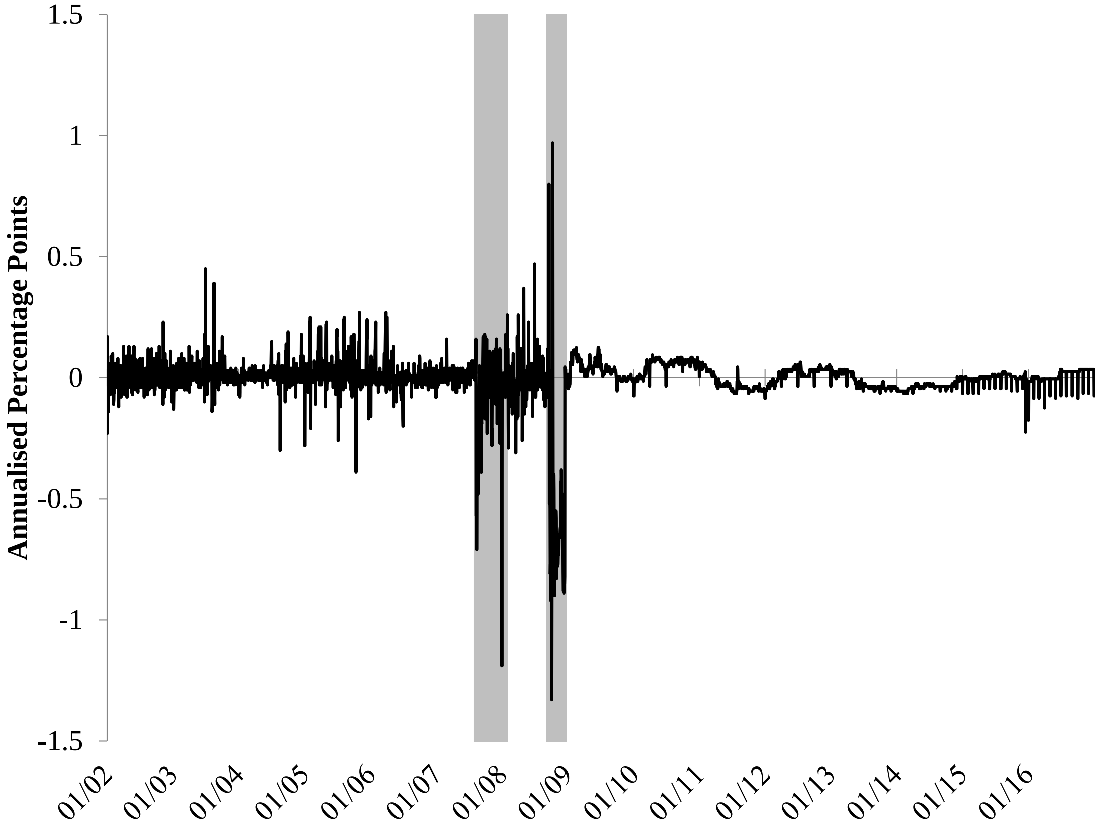
Accounting for 2007-2008 Money Market Turmoil Although the average *ex post* excess returns on 1 to 3-month OIS contracts in panel B of table 3 are small, they are significant at the 10% level. I conduct further sensitivity analysis by looking into the influence of 2007-2008 money market turmoil on estimated *ex post* excess returns. The money market turmoil of 2007-2008 had notable implications for US overnight interest rates. Taylor and Williams (2009) document that the effective federal funds rate, the OIS reference rate, jumped to unusually high levels compared with the Fed's target for the federal funds rate, the policy rate, on August 9, 2007.[26] On the following day, the Federal Reserve Bank of New York pumped liquidity into the market, leading to a marked fall in the effective federal funds rate relative to the federal funds target rate, as shown in figure 5.[27]

In general, the impact of differences between reference and policy rates will be expected to diminish at longer horizons, evidenced by the insignificant *ex post* excess returns on 4 to 24-month contracts reported in panel B of table 3. However, figure 5 illustrates that large differences between the effective federal funds rate and the federal funds target rate occurred during the 2007-2008 period, following money market turbulence that erupted on August 9, 2007 and, after some recovery in money market conditions during the first half of 2008, reignited after the failure of Lehman Brothers in September 2008. The turbulence led to a dramatic change in money market conditions.

[26]On August 9, 2007, the difference between the effective federal funds rate and the federal funds target rate rose from 2 to 16 basis points.

[27]On August 10, 2007 the effective federal funds rate was 57 basis points below the federal funds target rate.

Figure 5: Effective Federal Funds Rate Minus the Federal Funds Target Rate



Note: This figure depicts the difference between the effective federal funds rate and the federal funds target rate at a daily frequency from January 2002 to December 2016. From December 16, 2008, the difference is calculated by assuming that the federal funds target rate was halfway between its lower and upper bounds. The grey areas denote the periods of money market turbulence. The first begins on August 9, 2007 and ends on January 22, 2008, when the federal funds target rate was cut by 75 basis points. The second begins on September 15, 2008 — the day of Lehman Brothers' failure — and ends on December 16, 2008. *Data Source*: Federal Reserve.

The relationship between the effective federal funds rate and the federal funds rate target changed significantly during the period of initial money market turmoil, running from August 9, 2007 to January 21, 2008 — the day before the Federal Open Market Committee cut the federal funds target rate by 75 basis points.[28] The effective federal funds rate was significantly below its target following the failure of Lehman Brothers on September 15, 2008 until December 16, 2008 when the Fed cut its short-term policy rate to its ELB.[29]

Because the money market turmoil had a significant influence on the short-term interest rates of direct relevance to OIS rates, I carry out further sensitivity analysis to account for the

[28]The average difference between the effective federal funds rate and the federal funds target rate prior to the money market turmoil was 0 percent points. This figure is calculated using daily data from January 2, 2007 to August 8, 2007 (N = 219 observations), with a standard deviation of 0.03 percent points. The corresponding figure for the period of initial money market turmoil was −0.09 percent points. This figure is calculated using daily data from August 9, 2007 to January 21, 2008 (N = 166 observations), with standard deviation of 0.21 percent points. The corresponding t-statistic from a difference-in-mean hypothesis test is statistically significant.

[29]The average difference between the effective federal funds rate and the federal funds target rate from September 15, 2008 to December 15, 2008 was −0.59 percent points.

additional effect that this may have had on the *ex post* excess returns on OIS contracts. To do this, I estimate (8) with three dummy variables: (i) a dummy variable for the initial money market turmoil from August 9, 2007 to January 21, 2008; (ii) a dummy accounting for the unanticipated monetary policy loosening between January 22, 2008 and September 14, 2008; and (iii) a dummy to account for the money market turmoil and monetary policy loosening that occurred between September 15, 2008 and December 16, 2008. As for the 2008 dummy in panel B of table 3, the dummy variables are set to unity on dates when the horizon of an OIS contract overlaps with the stated period — not only on the day the *ex post* excess return is recorded. The results of these regressions are reported in table 4. The estimated α_n^{OIS} coefficient can be interpreted as the average *ex post* excess return on an n-month OIS contract in periods for which the contract's horizon did not overlap with the 2007-2008 US money market turbulence and monetary policy loosening.

The main conclusions of the paper are strengthened by the inclusion of an additional money market turmoil dummy. The average *ex post* excess returns on the 1 to 24-month US OIS contracts are insignificantly different from zero outside the 2007-2008 period. At longer horizons — 3, 4 and 5 years — OIS contracts still exhibit statistically significant *ex post* excess returns. Moreover, the coefficients on the dummy variables indicate that the post-Lehman money market turmoil and monetary policy loosening typically had the strongest upward influence on OIS *ex post* excess returns.

Overall, the above results support two of the main conclusions in this paper. First, 1 to 11-month OIS contracts provide measures of investors' interest rate expectations as good as comparable-horizon FFFs contracts. Second, 1 to 24-month OIS contracts accurately predict the future path of monetary policy on average; at longer horizons, OIS rates include statistically significant *ex post* excess returns that reflect premia for risks in OIS contracts.

4.2 UK OIS Contracts

To assess the global usefulness of OIS rates as financial market-based measures of monetary policy expectations, I apply the empirical specification developed for US OIS contracts to UK OIS contracts. I calculate unconditional *ex post* excess returns on UK OIS contracts, from January 2001 to December 2016, at a daily frequency. I use UK OIS rates of the following maturities: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 18 and 24 months.[30]

To calculate unconditional *ex post* excess returns on UK OIS contracts, I make two alterations to the equations laid out in section 2. First, because calculations of OIS floating leg payments occur with no spot lag ($s = 0$), I calculate the floating interest rate from the trade date to maturity. Second, because UK OIS rates are quoted according to the *Actual 365* convention, (3) is a multiple of $365/N$, not $360/N$. With daily frequency *ex post* excess returns on UK OIS contracts, I estimate average *ex post* excess returns using (8). Table 5 presents the results of this analysis.

Table 5 demonstrates that 2 to 18-month UK OIS contracts exhibit statistically insignificant

[30]The selection of maturities and sample length is, again, determined by data availability. See appendix A.

Table 4: Average *Ex Post* Excess Returns on US OIS Contracts at Daily Frequency with Controls for 2008 Monetary Policy Loosening and 2007-2008 Money Market Turmoil

Maturity in Months	**1**	**2**	**3**	**4**	**5**
$\widehat{\alpha}_n^{OIS}$	0.23	0.33	0.46	0.63	0.94
[t-statistic]	[0.88]	[0.85]	[0.87]	[0.77]	[0.75]
Initial Mon. Market Dummy	7.90	17.17***	24.18***	29.90***	34.04**
[t-statistic]	[1.59]	[3.04]	[3.07]	[2.39]	[2.17]
Mon. Pol. Loosening Dummy	0.18	3.56	7.86	13.27**	18.56***
[t-statistic]	[0.05]	[0.57]	[0.92]	[1.97]	[2.91]
Post-Lehman Dummy	35.95***	45.16***	51.46***	54.49***	55.02***
[t-statistic]	[3.49]	[−6.43]	[−4.42]	[−7.93]	[5.23]
Maturity in Months	**6**	**7**[a]	**8**[a]	**9**	**10**[a]
$\widehat{\alpha}_n^{OIS}$	1.42	1.28	1.67	3.34	2.58
[t-statistic]	[0.76]	[0.56]	[0.52]	[0.71]	[0.50]
Initial Mon. Market Dummy	34.10**	31.67*	25.77	18.41	14.85
[t-statistic]	[2.11]	[1.84]	[1.52]	[1.30]	[1.28]
Mon. Pol. Loosening Dummy	29.24**	42.40**	56.31***	65.17***	71.62***
[t-statistic]	[2.10]	[2.31]	[2.77]	[3.37]	[3.95]
Post-Lehman Dummy	49.66***	44.17***	38.10***	39.91***	45.16***
[t-statistic]	[3.97]	[3.35]	[2.71]	[3.54]	[14.65]
Maturity in Months	**11**[a]	**12**	**15**	**18**	**21**
$\widehat{\alpha}_n^{OIS}$	3.10	5.96	7.91	11.64	16.51
[t-statistic]	[0.49]	[0.70]	[0.61]	[0.72]	[0.95]
Initial Mon. Market Dummy	12.59	8.29	8.95	−0.74	−24.42
[t-statistic]	[1.33]	[1.37]	[−0.91]	[0.05]	[1.08]
Mon. Pol. Loosening Dummy	73.81***	75.83***	56.85***	48.59***	63.23***
[t-statistic]	[5.56]	[16.69]	[10.23]	[13.00]	[−6.35]
Post-Lehman Dummy	52.97***	58.62***	98.33***	125.43***	134.73***
[t-statistic]	[−4.17]	[−3.97]	[8.67]	[6.63]	[9.28]
Maturity in Months	**24**	**36**[b]	**48**[b]	**60**[b]	
$\widehat{\alpha}_n^{OIS}$	22.31	47.23***	90.77***	165.10***	
[t-statistic]	[1.44]	[3.10]	[4.95]	[25.57]	
Initial Mon. Market Dummy	−45.19*	−108.98***	−129.48***	−144.30***	
[t-statistic]	[1.70]	[6.24]	[−7.75]	[−8.15]	
Mon. Pol. Loosening Dummy	70.49***	27.00	−4.38	−33.59***	
[t-statistic]	[−8.18]	[−1.34]	[0.52]	[−3.89]	
Post-Lehman Dummy	145.22***	230.61***	231.30***	201.68***	
[t-statistic]	[11.17]	[11.76]	[14.18]	[32.61]	

Note: Results from regression (8) for daily frequency US OIS contracts. Sample: Daily Frequency, January 1, 2002 to December 31, 2016, but for those indicated by [a] May 7, 2002 to December 31, 2016 and [b] February 14, 2002 to December 31, 2016 (due to OIS rate availability). Hodrick (1992) t-statistics are reported in square brackets. An excess return is significantly different from zero at the 1%, 5% and 10% significance level when the absolute value of the t-statistic exceeds 2.33, 1.96, 1.645 respectively. These are denoted with asterisks ***, ** and * for the 1%, 5% and 10% significance levels respectively. All figures are reported in basis points to two decimal places. The 'Initial Mon. Market Dummy' is set equal to unity on dates where the OIS contract horizon overlaps with the August 9, 2007 to January 21, 2008 money market turmoil. The 'Mon. Pol. Loosening Dummy' is set equal to unity on dates where the OIS contract horizon overlaps with the January 22, 2008 to September 14, 2008 US monetary policy loosening. The 'Post-Lehman Dummy' is set equal to unity on dates where the OIS contract horizon overlaps with the September 15, 2008 to December 16, 2008 money market turmoil and monetary policy loosening following the failure of Lehman Brothers.

Table 5: Average *Ex Post* Excess Returns on UK OIS Contracts at Daily Frequency

Maturity in Months	**1**	**2**	**3**	**4**	**5**
$\widehat{\alpha}_n^{OIS}$	−2.72***	−1.61	−0.32	1.14	2.73
[t-statistic]	[−3.33]	[−0.99]	[−0.12]	[0.31]	[0.59]
Maturity in Months	**6**	**7**	**8**	**9**	**10**
$\widehat{\alpha}_n^{OIS}$	4.46	6.44	8.46	10.61	12.91
[t-statistic]	[0.78]	[0.93]	[1.02]	[1.09]	[1.16]
Maturity in Months	**11**	**12**	**18**	**24**	
$\widehat{\alpha}_n^{OIS}$	15.37	17.77	30.72	47.15*	
[t-statistic]	[1.22]	[1.27]	[1.48]	[1.77]	

Note: Results from regression (8) for UK OIS contracts. Sample: January 1, 2001 to December 31, 2016, Daily Frequency. Hodrick (1992) t-statistics are reported in square brackets. An excess return is significantly different from zero at the 1%, 5% and 10% significance level when the absolute value of the t-statistic exceeds 2.33, 1.96, 1.645 respectively. These are denoted with asterisks ***, ** and * for the 1%, 5% and 10% significance levels respectively. All figures are reported in basis points to two decimal places.

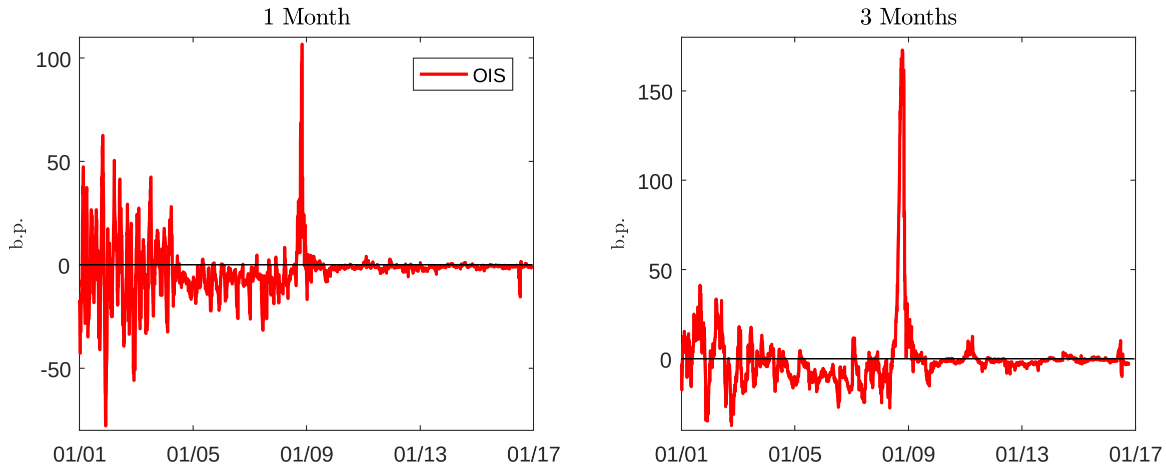
average *ex post* excess returns for the whole sample period. Although the average *ex post* excess return on the 1-month contract is significant at the 1% level, it is small in magnitude at −2.72 basis points. Thus, 1 to 18-month UK OIS rates appear to provide accurate measures of interest rate expectations on average. As in the US market, the average *ex post* excess return on the 2-year UK OIS contract, of 47.15 basis points, is statistically significant (at the 10% level) for the whole 2001-2016 period.

Accounting for UK Monetary Policy Loosening Figure 6 plots the time series of unconditional *ex post* excess returns on 1 and 3-month UK OIS contracts. There is a notable spike in both in late-2008, when UK monetary policy was being loosened in response to the financial crisis.[31] I investigate the significant *ex post* excess returns on 1-month and 2-year OIS contracts in table 5 by conducting sensitivity analysis to account for the possibility that the *ex ante* unanticipated UK monetary policy accommodation in response to the 2007-2008 financial crisis biases estimates of average *ex post* excess returns. I regress the unconditional *ex post* excess returns on UK OIS contracts on a constant and a monetary policy loosening dummy variable, set equal to unity on dates where the OIS contract horizon overlaps with the period spanning December 6, 2007 to March 5, 2009.[32] These dates are chosen, as following the onset of financial market turmoil in the summer 2007, the Bank of England cut Bank Rate from 5.75% to 0.5% between December 6, 2007 to March 5, 2009. I do not include a dummy variable to separately account for the potential effects of money market turmoil for two reasons. First, the relationship between SONIA and Bank Rate was not significantly different during the money

[31] The *ex post* excess returns in figure 6 are also highly volatile from 2001 to mid-2004, a consequence of UK money market operating procedures at the time. I study this in subsequent robustness analysis.

[32] That is, for the 1-month OIS contract, the dummy is set to 1 on days between November 6, 2007 and March 5, 2009 (inclusive) and zero otherwise.

Figure 6: Unconditional *Ex Post* Excess Returns on UK Overnight Indexed Swaps



Note: Time series of unconditional *ex post* excess returns for UK OIS rates calculated using equation (4). Sample: January 1, 2001 to December 31, 2016; daily frequency. The horizontal axis of each plot denotes the date of the *ex post* excess return and is labelled MM/YY.

market turmoil relative to the months prior to it.[33] Second, figure 6 shows that there is no notable spike in unconditional *ex post* excess returns on UK OIS contracts around initial money market turmoil in summer 2007, in contrast to the US excess returns in figure 4, indicating that UK money market conditions did not appreciably influence the variable of interest at this time.

Table 6 presents the regression results. The estimated α_n^{OIS} coefficient can be interpreted as the average *ex post* excess return on an n-month OIS contract in periods for which the contract's horizon did not overlap with UK monetary policy loosening. In comparison to table 5, the results in table 6 indicate that fewer OIS tenors have statistically insignificant *ex post* excess returns. The estimated α_n^{OIS} coefficients for the 1 to 3-month contracts are negative and statistically significant, like the 1-month contract coefficient in table 5. Although the estimates are quantitatively small — less than 3.25 basis points in absolute value — they indicate that these OIS tenors may not have provided the most accurate measures of UK interest rate expectations outside the 2007-2009 period. Moreover, while the estimated α_n^{OIS} coefficient for the 24-month contract is almost half its value in table 5, it remains significant at the 10% level.

Accounting for UK Money Market Reform One potential explanation for the significant *ex post* excess returns at the 1 to 3 and 24-month horizons in table 6 relates to differences between the OIS reference rate and the headline policy rate (Shareef, 2013). In the UK, open

[33] The average difference between SONIA and the UK Bank Rate prior to the money market turmoil was 0.053 percent points. This figure is calculated using daily data from January 2, 2007 to August 8, 2007, excluding a one-day spike on June 29 ($N = 152$ observations), with a standard deviation on 0.039 percent points. The corresponding figure for the initial period of money market turmoil was 0.075 percent points. This figure is calculated using daily data from August 9, 2007 to December 5, 2007 ($N = 84$ observations), with standard deviation of 0.126 percent points. The corresponding t-statistic from a difference-in-mean hypothesis test is -1.6, implying the difference is statistically insignificant. Nevertheless, when the regression is estimated with an additional money market turmoil dummy (set equal to unity when contracts mature between August 9, 2007 and December 5, 2007), $\widehat{\alpha}_n^{OIS}$ coefficients remain significant at the 1% level for 1 to 3-month contracts, while the 24-month coefficient is significant at 1% level. All other $\widehat{\alpha}_n^{OIS}$ coefficients remain statistically insignificant.

Table 6: Average *Ex Post* Excess Returns on UK OIS Contracts at Daily Frequency with Controls for UK Monetary Policy Loosening

Maturity in Months	**1**	**2**	**3**	**4**	**5**
$\widehat{\alpha}_n^{OIS}$	−3.24***	−2.94***	−2.55***	−2.15	−1.71
[t-statistic]	[−5.30]	[−3.61]	[−2.54]	[−1.64]	[−0.93]
Mon. Pol. Loosening Dummy	6.28	14.78	23.39	32.27	41.22
[t-statistic]	[0.95]	[1.06]	[1.15]	[1.34]	[1.62]
Maturity in Months	**6**	**7**	**8**	**9**	**10**
$\widehat{\alpha}_n^{OIS}$	−1.12	−0.34	0.51	1.52	2.65
[t-statistic]	[−0.44]	[−0.10]	[0.12]	[0.30]	[0.45]
Mon. Pol. Loosening Dummy	49.25*	56.51**	63.03***	68.47***	74.04***
[t-statistic]	[1.92]	[2.20]	[2.38]	[2.45]	[2.65]
Maturity in Months	**11**	**12**	**18**	**24**	
$\widehat{\alpha}_n^{OIS}$	3.91	5.35	13.15	25.26*	
[t-statistic]	[0.57]	[0.71]	[1.15]	[1.71]	
Mon. Pol. Loosening Dummy	79.27***	82.62***	92.30***	94.59***	
[t-statistic]	[3.02]	[3.31]	[−3.71]	[−2.37]	

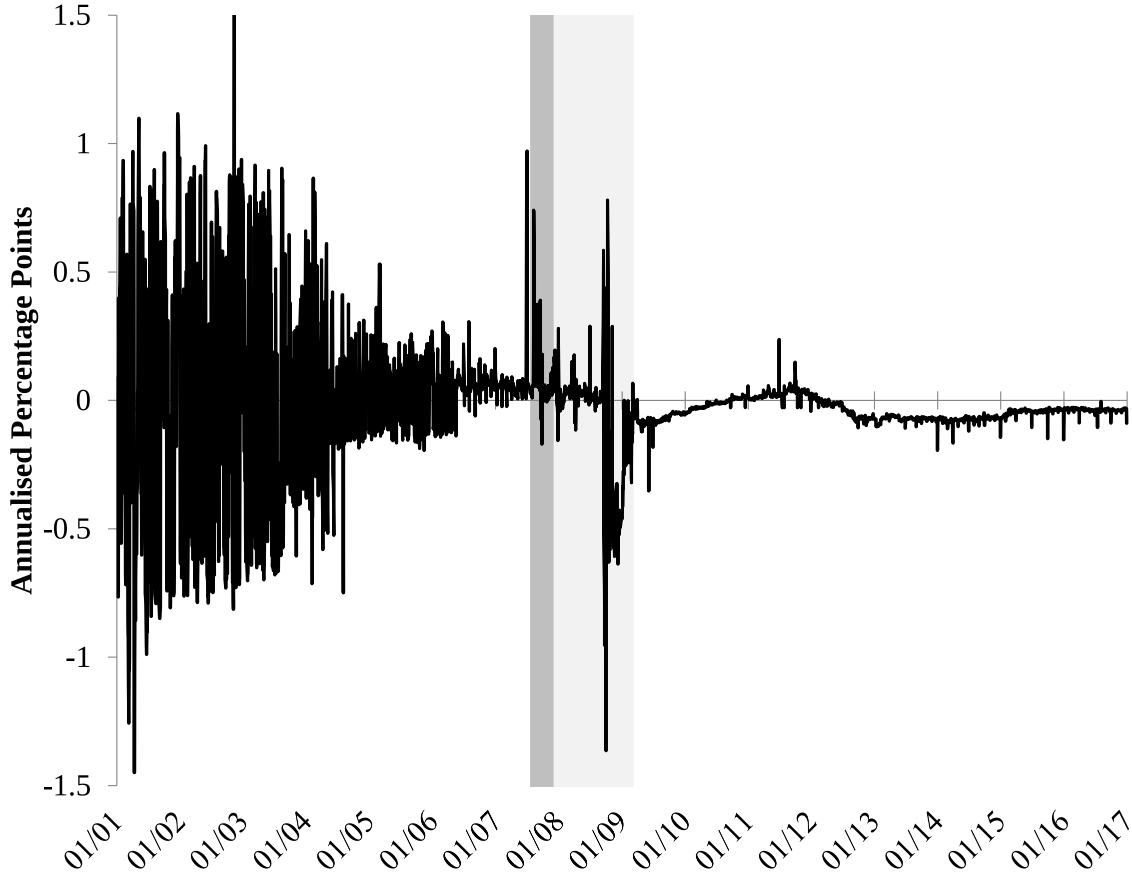
Note: Results from regression (8) for daily frequency UK OIS contracts. Hodrick (1992) t-statistics are reported in square brackets. An excess return is significantly different from zero at the 1%, 5% and 10% significance level when the absolute value of the t-statistic exceeds 2.33, 1.96, 1.645 respectively. These are denoted with asterisks ***, ** and * for the 1%, 5% and 10% significance levels respectively. All figures are reported in basis points to two decimal places. Sample: January 1, 2001 to December 31, 2016; daily frequency; the 'Mon. Pol. Loosening Dummy' is set equal to unity on dates where the OIS contract horizon overlaps with the December 6, 2007 to March 5, 2009 UK monetary policy loosening.

market operations are used to try and minimise the difference between Bank Rate, the policy rate, and SONIA, the OIS reference rate. Figure 7 plots this difference. It illustrates that, from 2001 to mid-2004, differences were extremely large, peaking at almost 1.5 percentage points in late-2002. The largest absolute difference between the effective federal funds rate and the federal funds target rate in the 2002-2016 period was less than a third of this (figure 5). Bank of England (2004) acknowledge that, during this period, sterling overnight rates were considerably more volatile than for other countries. Figure 6 demonstrates that *ex post* excess returns on OIS contracts were also highly volatile at this time, mirroring movements in figure 7. The differences between SONIA and Bank Rate were narrowed by two changes to the Bank of England's money market operations on July 22, 2004,[34] and May 17, 2006.[35]

To assess the extent to which volatility of overnight rates between 2001 and July 2004 can explain the significant *ex post* excess returns on 1 to 3 and 24-month OIS contracts, I regress the unconditional *ex post* excess returns on UK OIS contracts on a constant, the monetary policy loosening dummy used in table 6, and a money market volatility dummy. The money market volatility dummy is set equal to unity on dates where the OIS contract overlaps with the period spanning January 1, 2001 to July 22, 2004, the date of initial UK money market reform. This reform substantially reduced the volatility of UK overnight rates.

[34]See: `www.bankofengland.co.uk/archive/Documents/historicpubs/news/2004/082.pdf`.
[35]See: `www.bankofengland.co.uk/archive/Documents/historicpubs/news/2006/055.pdf`.

Figure 7: SONIA Minus UK Bank Rate



Note: This figure depicts the difference between the SONIA and the UK Bank Rate at a daily frequency from January 2001 to December 2016. The left-hand dark grey area denotes the first period of money market turbulence in 2007 — August 9 to December 5, 2007. The right-hand light grey area denotes the period of monetary policy loosening — December 6, 2007 to March 5, 2009. *Data Source*: Bank of England.

The results are presented in panel A of table 7. Money market volatility from 2001 to 2004 does help to explain the significance of the 24-month tenor in tables 5 and 6. In panel A of table 7, the average *ex post* excess return on the 24-month contract is statistically insignificant at 21.47 basis points. However, the money market volatility dummy does not reverse the significance of the short-horizon excess returns. Although quantitatively small, the average *ex post* excess returns on the 1 to 5-month contracts, outside of the periods covered by the two dummy variables, are significantly negative.

Panel B of table 7 assesses whether the significantly negative *ex post* excess returns on short-horizon contracts have changed over time. Here, I estimate the unconditional average *ex post* excess return on 1 to 5-month contracts for the post-2008 period only, beginning the sample on April 1, 2009. Although the 1 to 3-month $\widehat{\alpha}_n^{OIS}$ estimates are significant at the 1% level, they are quantitatively small. Average *ex post* excess returns on 1 to 5-month contracts are less than 1.20 basis points in magnitude, around a third of their size in panel A of table 7. The

Table 7: Average *Ex Post* Excess Returns on UK OIS Contracts at Daily Frequency with Controls for UK Monetary Policy Loosening and UK Money Market Volatility

Panel A: UK OIS Contracts with Two Dummy Variables					
Maturity in Months	**1**	**2**	**3**	**4**	**5**
$\widehat{\alpha}_n^{OIS}$	−3.29***	−3.44***	−3.40***	−3.34***	−3.30*
[t-statistic]	[−6.00]	[−4.39]	[−3.44]	[−2.58]	[−1.93]
Mon. Mkt. Volatility Dummy	0.17	2.05	3.42	4.74	6.31
[t-statistic]	[0.09]	[0.88]	[1.30]	[1.49]	[1.36]
Mon. Pol. Loosening Dummy	6.32	15.28	24.23	33.45	42.81*
[t-statistic]	[0.96]	[1.10]	[1.19]	[1.39]	[1.68]
Maturity in Months	**6**	**7**	**8**	**9**	**10**
$\widehat{\alpha}_n^{OIS}$	−3.13	−2.80	−2.47	−1.96	−1.40
[t-statistic]	[−1.39]	[−0.97]	[−0.70]	[−0.47]	[−0.28]
Mon. Mkt. Volatility Dummy	7.81	9.51	11.37	13.16	15.12
[t-statistic]	[1.13]	[1.02]	[0.96]	[0.94]	[0.94]
Mon. Pol. Loosening Dummy	51.25**	58.96**	66.00***	71.96***	78.09***
[t-statistic]	[2.01]	[2.32]	[2.54]	[2.64]	[2.90]
Maturity in Months	**11**	**12**	**18**	**24**	
$\widehat{\alpha}_n^{OIS}$	−0.67	0.41	7.71	21.47	
[t-statistic]	[−0.12]	[0.06]	[0.64]	[1.42]	
Mon. Mkt. Volatility Dummy	16.90	17.91	18.17	11.62	
[t-statistic]	[0.94]	[0.91]	[1.03]	[−0.69]	
Mon. Pol. Loosening Dummy	83.85***	87.57***	97.75***	98.39***	
[t-statistic]	[3.41]	[3.89]	[−3.10]	[−2.27]	
Panel B: UK Short-Horizon OIS Contracts with Post-2008 Sample					
Maturity in Months	**1**	**2**	**3**	**4**	**5**
$\widehat{\alpha}_n^{OIS}$	−1.08***	−1.20***	−1.14***	−0.91	−0.52
[t-statistic]	[−7.03]	[−3.87]	[−2.33]	[−1.39]	[−0.62]

Note: Results from regression (8) for daily frequency UK OIS contracts. Hodrick (1992) t-statistics are reported in square brackets. An excess return is significantly different from zero at the 1%, 5% and 10% significance level when the absolute value of the t-statistic exceeds 2.33, 1.96, 1.645 respectively. These are denoted with asterisks ***, ** and * for the 1%, 5% and 10% significance levels respectively. All figures are reported in basis points to two decimal places. Panel A: January 1, 2001 to December 31, 2016 sample; daily frequency; the 'Mon. Pol. Loosening Dummy' is set equal to unity on dates where the OIS contract horizon overlaps with the December 6, 2007 to March 5, 2009; 'Mon. Mkt. Volatility Dummy' is set equal to unity on dates where OIS contract horizon overlaps with January 1, 2001 to July 22, 2004. Panel B: April 1, 2009 to December 31, 2016 sample; daily frequency.

fact these excess returns are smaller in magnitude in this period is consistent with a reduction in UK money market volatility and a narrowing of the spread between SONIA and Bank Rate following changes to sterling money market operating procedures in March 2009 (Jackson and Sim, 2013; Osborne, 2016). Thus, the results indicate that the accuracy of very short-horizon contracts as measures of UK interest rate expectations have improved since the financial crisis. This is further supported in figure 6, where excess returns are visibly close to, but slightly below, zero for most of the period after the financial crisis, following sizeable spikes in late-2008.

4.3 Eurozone OIS Contracts

EONIA is the overnight floating reference rate used to calculate unconditional *ex post* excess returns on Eurozone OIS contracts. As per market convention, the contracts have a two-day spot lag and obey the *Actual 360* dating norm. I use Eurozone OIS rates, between January 2000 and December 2016, of the following maturities: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 15, 18, 24 and 36 months.[36]

Table 8 presents the estimated average *ex post* excess returns on Eurozone OIS contracts for the whole 2000-2016 sample. These unconditional average *ex post* returns are significant at all horizons, at the 10% level at least. Although the average *ex post* excess returns at short-term horizons are small — the 1-month estimate is just 1.12 basis points — there is no distinction in the significance of short and long-term horizon tenors. At first sight, these findings challenge the claim that 1 to 24-month Eurozone OIS rates provide useful measures of investors' expectations of future short-term interest rates. However, this average result for the whole 2000-2016 sample masks variation within the period.

Accounting for Eurozone Money Market Developments from August 2007 To investigate these results, I conduct sensitivity analysis to assess whether developments in Eurozone money markets and European Central Bank (ECB) monetary policy from 2007 onwards might bias the average *ex post* excess returns reported in table 8.

Eurozone money markets were immediately affected by the August 2007 money market turmoil.[37] Like the Federal Reserve, the ECB responded by injecting liquidity to money markets to preserve their proper functioning, which served to reduce the level of EONIA without adjusting the ECB's main refinancing (refi) rate.[38] On October 15, 2008, the ECB began to loosen monetary policy, reducing the refi rate from 4.25% to 3.75%. By May 13, 2009, the ECB refi rate had reached 1%.

However, as a result of ECB liquidity operations, EONIA fell persistently below the refi rate from October 2008 onwards, as shown in figure 8. Between June 2009 and April 2011, the ECB's key interest rates (the refi rate, and the interest rates on the deposit and marginal

[36]The selection of maturities and tenor-specific sample periods are, again, determined by data availability — see appendix A.

[37]The difference between EONIA and the ECB's main refinancing (refi) rate increased from 9 basis points on August 8, 2007 to 22 basis points on August 9, 2007.

[38]By August 28, 2007, EONIA was 28 basis points below the refi rate.

Table 8: Average *Ex Post* Excess Returns on Eurozone OIS Contracts at Daily Frequency

Maturity in Months	**1**	**2**	**3**	**4**	**5**
$\widehat{\alpha}_n^{OIS}$	1.12***	2.24***	3.51**	4.98**	6.61**
[t-statistic]	[2.48]	[2.55]	[2.17]	[2.06]	[2.02]
Maturity in Months	**6**	**7**	**8**	**9**	**10**
$\widehat{\alpha}_n^{OIS}$	8.44**	10.36**	12.41**	14.57**	16.84**
[t-statistic]	[2.01]	[2.00]	[2.00]	[1.99]	[1.98]
Maturity in Months	**11**	**12**	**15**[a]	**18**	**21**[a]
$\widehat{\alpha}_n^{OIS}$	19.19**	21.64*	28.17**	35.29**	43.15***
[t-statistic]	[1.98]	[1.99]	[2.05]	[2.23]	[2.48]
Maturity in Months	**24**	**36**[b]			
$\widehat{\alpha}_n^{OIS}$	51.26***	80.08***			
[t-statistic]	[2.83]	[5.00]			

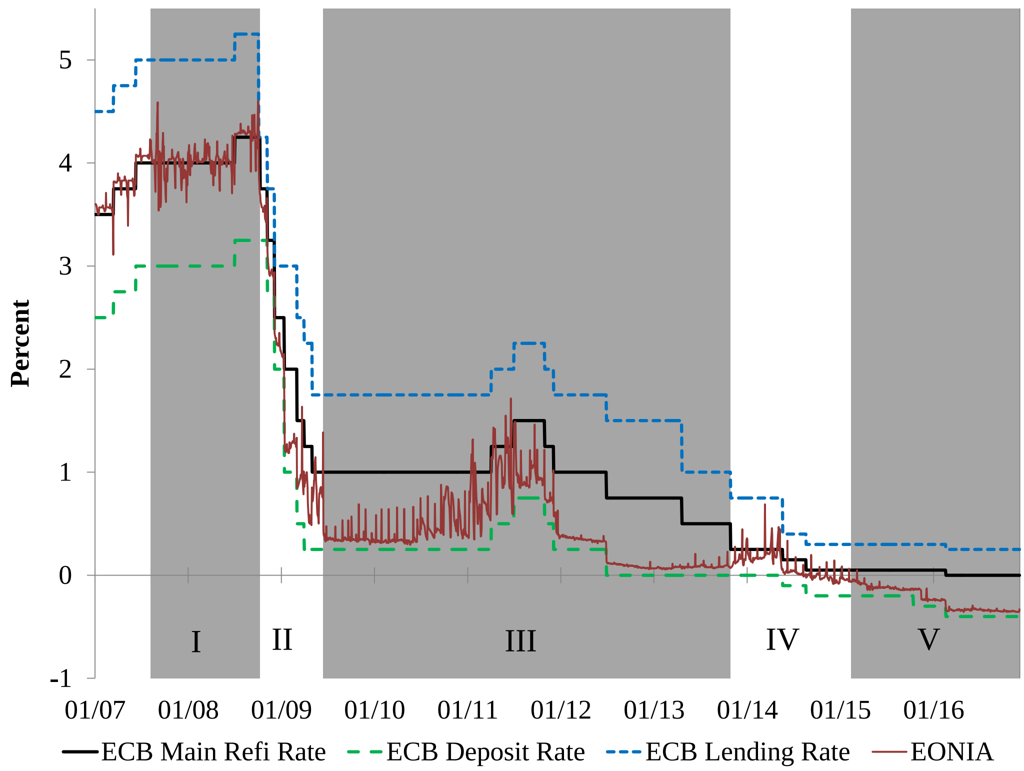
Note: Results from regression (8) for Eurozone OIS contracts. Sample: Daily Frequency, January 3, 2000 to December 31, 2016, but for those indicated by [a] August 22, 2001 to December 31, 2016 and [b] March 3, 2004 to December 31, 2016 (due to OIS rate availability). Hodrick (1992) t-statistics are reported in square brackets. An excess return is significantly different from zero at the 1%, 5% and 10% significance level when the absolute value of the t-statistic exceeds 2.33, 1.96, 1.645 respectively. These are denoted with asterisks ***, ** and * for the 1%, 5% and 10% significance levels respectively. All figures are reported in basis points to two decimal places.

lending facilities) were unchanged. EONIA was well below the refi rate during this period, closer to the ECB's standing deposit facility rate, indicating that the effective monetary policy stance was much looser than suggested by the main policy rate. Geraats (2011) labels this a period of 'monetary policy by stealth'. Although the ECB increased its refi rate twice in 2011, before reducing it five times between November 2011 and November 2013, EONIA continued to remain significantly below the headline policy rate. During this period the difference between the refi and deposit rates reduced from 75 basis points to 25 basis points, and the gap between EONIA and the refi rate narrowed, but widened again following cuts in the ECB deposit rate and an expanded asset purchase programme which was announced on January 22, 2015 and began on March 9, 2015. Because these developments significantly influenced the reference rate on Eurozone OIS contracts, I account for these periods in sensitivity analysis.

Table 9 provides summary statistics for the differences between EONIA and the refi rate in five sub-samples from 2007 onwards. Prior to the money market turmoil — between January 2, 2007 and August 8, 2007 — EONIA was, on average, 5.8 basis points above the refi rate. During the period of money market turmoil — between August 9, 2007 and October 14, 2008 — the spread fell to 0.4 basis points on average, following ECB liquidity interventions that sought to stabilise EONIA around the refi rate. However, the spread was over twice as volatile.

From October 15, 2008, the ECB began to cut its refi rate, while also providing unlimited liquidity on demand through a fixed-tender procedure with full allotment at the refi rate. Between October 15, 2008 and June 24, 2009, EONIA was, on average, 40.8 basis points below the refi rate; the standard deviation of the difference was almost twice that in the period of initial money market turmoil. On June 24, 2009, the ECB initiated one-year longer-term refi-

Figure 8: Eurozone Money Market Turmoil



Note: This figure depicts the ECB's refi, deposit and lending rates, and EONIA at a daily frequency from January 2, 2007 to December 31, 2016. The refi rate refers to the minimum bid or fixed rate for ECB main refinancing operations. The deposit rate refers to the rate on the ECB's deposit facility, which banks may use to make overnight deposits with the Eurosystem. The lending rate refers to the rate on the ECB's marginal lending facility, which offers overnight credit to banks from the Eurosystem. Area I denotes the initial period of money market turbulence, beginning on August 9, 2007 and ending on October 14, 2008. Area II represents the period of monetary policy loosening between October 15, 2008 and June 24, 2009. Area III denotes the period in which EONIA remained persistently below the refi rate, from June 25, 2009 to November 12, 2013. Area IV is an intermediate period between November 13, 2013 and March 8, 2015. Area V denotes the period in which EONIA remained persistently below the refi rate during the ECB's quantitative easing operations, from March 9, 2015 and December 31, 2016. *Data Source*: European Central Bank.

nancing operations. From June 25, 2009 to November 12, 2013, EONIA was, on average, 54.2 basis points below the refi rate, marking the first period of monetary policy by stealth. On November 13, 2013, the ECB's refi rate was cut by 25 basis points to 25 basis points. Between this date and March 8, 2015, the difference between EONIA and the ECB refi rate diminished — over the period, the average difference was just -7.6 basis points and the standard deviation of this difference was more comparable to that seen prior to the initial money market turmoil. However, when the ECB enacted its expanded asset purchase programme on March 9, 2015, EONIA fell further below the refi rate. Between March 9, 2015 and December 31, 2016, EONIA was, on average, 25.9 basis points below the refi rate.

Because the difference between EONIA and the refi rate differs across sub-samples, I account for these five distinct periods in the sensitivity analysis indicated in figure 8 and table 9: (i) the

Table 9: Eurozone Money Market Turmoil: The Difference Between EONIA and the ECB Refi Rate in Percent Points

Dates	Mean	Standard Deviation	# Obs.
Pre-Turmoil (02/01/2007-08/08/2007)	0.058	0.063	154
I: Money Market Turmoil (09/08/2007-14/10/2008)	0.004	0.137	303
II: Monetary Policy Loosening (15/10/2008-24/06/2009)	-0.408	0.246	175
III: Monetary Policy By Stealth I (25/06/2009-12/11/2013)	-0.542	0.178	1128
IV: Intermediate Period (13/11/2013-08/03/2015)	-0.076	0.072	334
V: Monetary Policy By Stealth II (09/03/2015-31/12/2016)	-0.259	0.086	467

Note: Average difference between EONIA and the ECB refi rate in percent points using daily frequency data. The ECB refi rate is the minimum bid or fixed rate for main refinancing operations. The final column, "# Obs." denotes the number of observations in each sub-sample. *Data Source*: European Central Bank.

initial money market turmoil beginning on August 9, 2016; (ii) the period of Eurozone monetary policy loosening, beginning on October 15, 2008; (iii) the initial period of monetary policy by stealth, beginning on June 25, 2009; (iv) the intermediate period, beginning on November 13, 2013; and (v) the second period of monetary policy by stealth, beginning on March 9, 2015 and running to the end of the sample. To do this, I augment the baseline regression with five dummy variables. As before, the dummy variables are set to unity on dates where the OIS contract horizon overlaps with the relevant period.

Table 10 presents the results of the augmented regression, where the estimated α_n^{OIS} coefficients can be interpreted as the average *ex post* excess returns on Eurozone OIS contracts between January 3, 2000 and August 8, 2007.[39] The estimated dummy variable coefficients represent the increase in average *ex post* excess returns associated with the specific periods they pertain to. Importantly, the estimated α_n^{OIS} coefficients are insignificantly different from zero for the 1 to 3 and 7 to 24-month tenors, implying that these OIS contracts provide accurate information about investors' expectations of future short-term interest rates. Although the 4 to 6-month coefficients are statistically significant, they are small, ranging from just 1.56 to 3.79 basis points.

The estimated dummy variable coefficients indicate that ECB monetary policy loosening between October 15, 2008 and June 6, 2009 had the largest positive impact on *ex post* excess returns. The estimated coefficients on this dummy variable are significantly positive at the 10% level, at least, for all tenors. This finding reflects the *ex ante* unexpected nature of the post-financial crisis monetary policy loosening, rather than risk premia within OIS contracts that undermine their use as measures of monetary policy expectations.

Interestingly, the coefficient on the first monetary policy by stealth dummy is significantly positive, at the 5% level at least, for the 1 to 3-month tenors. This indicates that the discrepancy between EONIA and the ECB's refi rate that arose in these periods did have implications for the information contained in OIS rates, and their use as a measure of monetary policy expectations.

[39] Because of the definition of the dummy variables, and the limited availability of 36-month Eurozone OIS rate data, I do not present estimates for this tenor in table 10.

Table 10: Average *Ex Post* Excess Returns on Eurozone OIS Contracts at Daily Frequency with Controls for Money Market Turmoil, Monetary Policy Loosening and Stealth

Maturity in Months	**1**	**2**	**3**	**4**	**5**	**6**
$\widehat{\alpha}_n^{OIS}$	−0.14	0.12	0.64	1.56*	2.63**	3.79*
[t-statistic]	[−0.25]	[0.19]	[1.28]	[1.91]	[2.07]	[1.82]
Mon. Market Dummy	3.11*	4.69	5.63	6.20	6.51	6.82
[t-statistic]	[1.66]	[1.49]	[1.29]	[1.01]	[0.95]	[0.93]
Mon. Pol. Dummy	6.24*	17.19**	27.61***	37.64***	46.02***	52.79***
[t-statistic]	[1.76]	[2.25]	[2.66]	[3.95]	[8.52]	[−7.99]
Policy by Stealth I Dummy	2.31**	2.62***	2.36***	1.51	0.70	0.43
[t-statistic]	[1.98]	[3.20]	[2.39]	[0.71]	[0.19]	[0.09]
Intermediate Dummy	−0.33	−0.66	−1.09	−1.47	−1.89	−2.58
[t-statistic]	[−0.40]	[−0.53]	[−0.66]	[−0.80]	[−0.96]	[−1.05]
Policy by Stealth II Dummy	0.05	−0.35	−0.66	−1.29	−1.93	−2.55
[t-statistic]	[0.10]	[−0.54]	[−0.96]	[−1.18]	[−1.35]	[−1.29]
Maturity in Months	**7**	**8**	**9**	**10**	**11**	**12**
$\widehat{\alpha}_n^{OIS}$	4.83	5.52	5.51	4.64	4.24	3.89
[t-statistic]	[1.52]	[1.25]	[0.94]	[0.58]	[0.41]	[0.29]
Mon. Market Dummy	7.50	9.07	11.17	13.41	14.85	15.45
[t-statistic]	[0.90]	[0.91]	[0.87]	[0.79]	[0.72]	[0.66]
Mon. Pol. Dummy	58.09***	61.19***	61.86***	64.09***	65.41***	66.55***
[t-statistic]	[−5.86]	[−5.14]	[−4.23]	[−4.22]	[−4.04]	[−4.04]
Policy by Stealth I Dummy	0.70	2.22	6.01	11.41	16.34	21.62
[t-statistic]	[0.12]	[0.35]	[0.91]	[1.23]	[1.28]	[1.27]
Intermediate Dummy	−3.37	−4.39	−5.89*	−7.63***	−10.68***	−14.53***
[t-statistic]	[−1.15]	[−1.37]	[−1.83]	[−2.99]	[−4.18]	[−3.91]
Policy by Stealth II Dummy	−2.62	−1.90	−0.27	2.61	6.29	10.48
[t-statistic]	[−0.91]	[−0.47]	[−0.05]	[0.36]	[0.63]	[0.79]
Maturity in Months	**15**[a]	**18**	**21**[a]	**24**		
$\widehat{\alpha}_n^{OIS}$	4.20	10.85	18.06	26.66		
[t-statistic]	[0.20]	[0.43]	[0.63]	[0.88]		
Mon. Market Dummy	9.47	−5.73	−20.14	−38.15		
[t-statistic]	[0.34]	[−0.20]	[−0.63]	[−1.01]		
Mon. Pol. Dummy	73.62***	87.67***	94.43***	98.84***		
[t-statistic]	[−9.54]	[4.42]	[3.30]	[3.12]		
Policy by Stealth I Dummy	33.71	35.05	40.23	47.12		
[t-statistic]	[1.32]	[1.36]	[1.48]	[1.51]		
Intermediate Dummy	−27.19***	−36.06***	−48.18***	−58.59***		
[t-statistic]	[−2.63]	[−3.50]	[−12.75]	[−7.33]		
Policy by Stealth II Dummy	23.43	26.50	33.33	32.00*		
[t-statistic]	[1.00]	[1.07]	[1.58]	[1.68]		

Note: Results from regression (8) for Eurozone OIS contracts. Sample: Daily Frequency, Jan. 3, 2000 to Dec. 31, 2016, but for those indicated by [a] Aug. 22, 2001 to Dec. 31, 2016. Hodrick (1992) t-statistics in square brackets. 1%, 5% and 10% significance denoted by ***, * and *, respectively. All figures in basis points to two decimal places. 'Mon. Market Dummy': equal to 1 on dates where the OIS contract horizon overlaps with the Aug. 9, 2007 to Oct. 14, 2008 money market turmoil. 'Mon. Pol. Dummy': equal to 1 on dates where the OIS contract horizon overlaps with the Oct. 15, 2008 to Jun. 24, 2009 ECB monetary policy loosening. 'Policy by Stealth I Dummy' ('Intermediate Dummy'): equal to 1 on dates where the OIS contract horizon overlaps with the Jun. 25, 2009 to Nov. 12, 2013 (Nov. 13, 2013 to Mar. 8, 2015) period. 'Policy by Stealth II Dummy': equal to 1 on dates where the OIS contract horizon overlaps with Mar. 9, 2015 to Dec. 31, 2016.

Overall, although events in the Eurozone call for a more nuanced study of *ex post* excess returns on OIS contracts, the above results indicate that, on average, 1 to 24-month tenors provide accurate measures of investors' interest rate expectations.

4.4 Japanese OIS Contracts

To calculate unconditional *ex post* excess returns on Japanese OIS contracts, I use TONAR as the overnight floating reference rate. The contracts have a two day spot lag and obey the *Actual 365* dating convention. I use Japanese OIS rates, between July 2003 and December 2016, of the following maturities: 1, 2, 3, 4, 5, 6, 9, 12, 18 and 24 months. [40]

Table 11 presents the estimated average *ex post* excess returns on Japanese OIS contracts. The most striking finding is that average *ex post* excess returns on Japanese contracts are much smaller quantitatively than those on US, UK and Eurozone contracts. This is, most likely, due to the smaller degree of variation in the Japanese policy rate during the 2003-2016 period, with Japanese policy bound by the ELB for most of this epoch. Average *ex post* excess returns are insignificantly different from zero for all maturities from 1 months to 2 years; these contracts accurately reflect investors' expectations of future short-term interest rates.

Table 11: Average *Ex Post* Excess Returns on Japanese OIS Contracts at Daily Frequency

	Panel A: Japan OIS Contracts				
Maturity in Months	**1**	**2**	**3**	**4**	**5**
$\widehat{\alpha}_n^{OIS}$	−0.00	0.19	0.40	0.64	0.86
[t-statistic]	[−0.00]	[0.59]	[0.80]	[0.97]	[1.13]
Maturity in Months	**6**	**9**	**12**	**18**[a]	**24**[a]
$\widehat{\alpha}_n^{OIS}$	1.28	2.61	4.12	8.04	12.94
[t-statistic]	[1.47]	[1.57]	[1.52]	[1.41]	[1.52]

Note: Results from regression (8) for Japanese OIS contracts. Sample: Daily Frequency, July 24, 2003 to December 31, 2016, but for those indicated by [a] December 7, 2005 to December 31, 2016 (due to OIS rate availability). Hodrick (1992) t-statistics are reported in square brackets. An excess return is significantly different from zero at the 1%, 5% and 10% significance level when the absolute value of the t-statistic exceeds 2.33, 1.96, 1.645 respectively. These are denoted with asterisks ***, ** and * for the 1%, 5% and 10% significance levels respectively. All figures are reported in basis points to two decimal places.

5 Conclusion

Three main results emerge from this paper. First, and most importantly, 1 to 24-month US OIS rates, on average, provide accurate measures of investors' short-term interest rate expectations, an indicator of the *de facto* monetary policy stance. Average *ex post* excess returns on the majority of these contracts are insignificantly different from zero, and any significant results can be explained by unanticipated monetary policy loosening and money market turmoil in

[40] The selection of maturities and horizon-specific sample periods are, again, determined by data availability. See appendix A.

2007-2008. These findings suggest that US OIS rates can be used as empirical measures of investors' expectations of future short-term interest rates out to 2 years in advance. Moreover, this result supports the joint use of US OIS rates and the term structure of government bond yields to estimate longer-horizon monetary policy expectations (Lloyd, 2017a).

Second, 1 to 11-month US OIS contracts provide measures of investors' interest rate expectations that are as good as those from comparable-horizon FFFs contracts. Excess returns on these OIS contracts are quantitatively similar to those on comparable-horizon portfolios of FFFs contacts.

Third, much of the accuracy of US OIS rates as financial market-based measures of future short-term interest rate expectations carries over to UK, Eurozone and Japanese OIS markets. OIS contracts with maturities of up to 2 years in the UK, Eurozone and Japanese OIS rates provide accurate measures of investors' interest rate expectations, with some exceptions for very short-maturity UK OIS contracts during the first half of the 2000s.

This has important implications for the understanding of monetary policy shocks on a global scale. To date, many methods used by monetary economists rely on FFF data to measure expectations of the future monetary policy stance (e.g. Gürkaynak et al., 2005a; Gertler and Karadi, 2015). This has limited the application of these methods to US data only. Motivated by the results in this paper, researchers can look to OIS rates as a globally-comparable measure of monetary policy expectations that enables them to apply these methods to a wider set of countries. These results should serve as a useful reference for, *inter alia*, a developing literature on the global effects of domestic monetary policy shocks (e.g. Rey, 2016).

Appendix

A Data Sources

Data Series	Source
- US OIS Rates	*Bloomberg*, with codes: USSOA 1 month; USSOB 2 months; ...; USSOK 11 months; USSO1 12 months; USSO1C 15 months; USSO1F 18 months; USSO1I 21 months; USSO2 2 years; USSO3 3 years; USSO4 4 years; and USSO5 5 years.
- US Federal Funds Futures	*Bloomberg* with codes: FF1 which settles based on current calendar month, FF2 which settles based on the subsequent calendar month, ..., FF12 which settles based on the 11th calendar month ahead, and www.quandl.com/data/OFDP/FUTURE_FFX where X should be replaced by the horizon of the contract in months (X= 1, 2, ..., 11).
- US Effective Federal Funds Rate	Federal Reserve Statistical Release H.15: www.federalreserve.gov/releases/h15/data.htm.
- UK OIS Rates	*Bloomberg*, with codes: BPSWSA 1 month; BPSWSB 2 months; ...; BPSWSK 11 months; BPSWS1 12 months; BPSWS1C 15 months; BPSWS1F 18 months; BPSWS1I 21 months; BPSWS2 2 years; BPSWS3 3 years; BPSWS4 4 years; and BPSWS5 5 years.
- UK SONIA	Bank of England: www.bankofengland.co.uk/boeapps/iadb/index.asp?first=yes&SectionRequired=I&HideNums=-1&ExtraInfo=true&Travel=NIxIRx.
- Eurozone OIS Rates	*Bloomberg*, with codes: EUSWEA 1 month; EUSWEB 2 months; ...; EUSWEK 11 months; EUSWE1 1 year; EUSWE1C 15 months; EUSWE1F 18 months; EUSWE1I 21 months; EUSWE2 2 years; EUSWE3 3 years; EUWE4 4 years; and EUSWE5 5 years.
- Eurozone EONIA	European Central Bank: sdw.ecb.europa.eu/quickview.do?SERIES_KEY=198.EON.D.EONIA_TO.RATE.
- Japanese OIS Rates	*Bloomberg*, with codes: JYSOA 1 month; JYSOB 2 months; ...; JYSOK 11 months; JYSO1 1 year; JYSO1C 15 months; JYSO1F 18 months; JYSO1I 21 months; JYSO2 2 years; JYSO3 3 years; JYSO4 4 years; and JYSO5 5 years.
- Japanese TONAR	Bank of Japan: www.boj.or.jp/en/statistics/market/short/mutan/index.htm/.

Availability of US OIS Rate Data On *Bloomberg*, the availability of daily US OIS rate data varies with the maturity of the contract. 1, 2, 3, 4, 5, 6, 9, 12 and 21-month OIS rates are available at a daily frequency from December 5, 2001. 15, 18 and 24-month OIS rates are available at a daily frequency from December 21, 2001. 7, 8, 10 and 11-month OIS rates are available at a daily frequency from May 7, 2002. 3, 4 and 5-year OIS rates are available from February 14, 2002. 13, 14, 16, 17, 19, 20, 22 and 23-month OIS rates are only available from March 3, 2010 to June 14, 2011. Because of the lack of coverage at these maturities, I omit them from this study.

Availability of UK OIS Rate Data On *Bloomberg*, the availability of daily UK OIS rate data varies with the maturity of the contract. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 18 and 24-month

OIS rates are available at a daily frequency from December 14, 2000. 15 and 21-month OIS rates are available at a daily frequency from January 25, 2006. 3 and 4-year OIS rates are available at a daily frequency from September 4, 2008. 5-year OIS rates are available at a daily frequency from May 23, 2008. Because data at these latter five maturities — 15 and 21-months, and 3, 4 and 5-years — is not available prior to 2006 and 2008 respectively, I omit them from this study.

Availability of Eurozone OIS Rate Data Remolana and Wooldridge (2003) document the growth of the Eurozone OIS market since the inception of the Euro in 1999 to 2003. On *Bloomberg*, the availability of daily Eurozone OIS rate data varies with the maturity of the contract. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 and 12-month OIS rates are available at a daily frequency from January 3, 2000, at least. 15 and 21-month OIS rates are available at a daily frequency from August 22, 2001. Although observations for 18 and 24-month OIS rates are available from as early as January 3, 2000, a regular daily series of observations begins on July 9, 2001 at these maturities. 3-year OIS rates are available at a daily frequency from March 3, 2004. 4 and 5-year OIS rates are available at a daily frequency from July 19, 2005 and June 13, 2005, respectively. Because data at these latter two maturities — 4 and 5-years — is not available prior to 2005, I omit them from this study.

Availability of Japanese OIS Rate Data Baba, Nagano, and Ooka (2006) describe the growth in Japanese OIS markets during the years preceding 2006. On *Bloomberg*, the availability of daily Japanese OIS rate data varies with the maturity of the contract. Observations for 1, 2 and 3-month OIS rate data begin on March 15, 2002, but the daily series are sporadic. The first observations for the 6, 9 and 12-month OIS contracts is March 22, 2002, but the time series are also sporadic. Regular daily observations for the 1, 2, 3, 4, 5, 6, 9 and 12-month OIS rates are available from July 24, 2003. 7, 8, 10 and 11-month OIS rates are available from November 16, 2004. 15 and 21-month OIS rates are available from May 5, 2007. 18 and 24-month OIS rates are available from December 7, 2005. 3-year OIS rates are regularly available at a daily frequency from November 19, 2007. 4-and 5-year OIS rates are available from August 6, 2009. I do not present results for the 7, 8, 10 and 11-month, and 3, 4 and 5-year OIS rates in this study.

B Pure FFFs Contracts

To ensure that the data transformations described in section 3, used to create 'portfolios' of FFFs contracts that are comparable in horizon to OIS contracts, are not driving the above conclusions, I also estimate the average *ex post* excess returns on 'pure' FFFs contracts on the penultimate business day of each month. That is, I estimate the following regression

$$rx_{t,t+n}^{FFF} = \alpha_n^{FFF} + \varepsilon_{t+n}^{FFF} \tag{10}$$

Table 12: Unconditional *Ex Post* Excess Returns on FFFs Contracts

Panel A: FFFs Contracts						
Maturity in Months	**1**	**2**	**3**	**4**	**5**	**6**
$\widehat{\alpha}_n^{FFF}$	1.22***	3.65**	6.52*	9.64*	12.98*	16.69*
[t-statistic]	[2.39]	[2.03]	[1.93]	[1.88]	[1.82]	[1.73]
Maturity in Months	**7**	**8**	**9**	**10**	**11**	
$\widehat{\alpha}_n^{FFF}$	20.98*	25.00	29.52	47.22	56.39	
[t-statistic]	[1.67]	[1.59]	[1.54]	[1.64]	[1.59]	
Panel B: FFFs Contracts with 2008 Dummy						
Maturity in Months	**1**	**2**	**3**	**4**	**5**	**6**
$\widehat{\alpha}_n^{FFF}$	0.54*	1.87*	3.45*	3.64	5.72	7.04
[t-statistic]	[1.82]	[1.76]	[1.67]	[1.55]	[1.34]	[1.23]
2008 Dummy	9.71*	23.26	37.00	66.67***	75.85***	94.26***
[t-statistic]	[1.77]	[1.41]	[1.52]	[2.84]	[4.35]	[19.94]
Maturity in Months	**7**	**8**	**9**	**10**	**11**	
$\widehat{\alpha}_n^{FFF}$	8.79	10.23	11.68	32.37	40.25	
[t-statistic]	[1.19]	[1.11]	[1.04]	[1.21]	[1.17]	
2008 Dummy	111.78***	128.26***	146.31***	113.09***	115.94**	
[t-statistic]	[35.29]	[9.55]	[6.81]	[2.60]	[2.29]	

Note: Results from regression (10) for FFFs contracts. Sample: January 2002 to December 2016, Monthly Frequency. Hodrick (1992) t-statistics are reported in square brackets. An excess return is significantly different from zero at the 1%, 5% and 10% significance level when the absolute value of the t-statistic exceeds 2.33, 1.96, 1.645 respectively. These are denoted with asterisks ***, ** and * for the 1%, 5% and 10% significance levels respectively. All figures are reported in basis points to two decimal places.

for untransformed FFFs rates. Table 12 presents the results from this analysis. These results can be viewed simply as updating the results from Piazzesi and Swanson (2008), with the only difference coming from the fact that I use FFFs rates on the penultimate business day of each month and Piazzesi and Swanson (2008) use FFFs rates on the final day of each month.

As in table 1, the average *ex post* excess returns on FFFs contracts of 1 to 7 months in maturity is found to be statistically significant at the 10% level, at least. Sensitivity analysis suggests that this significance is predominantly driven by the unexpected monetary policy easing associated with the 2007-2008 financial crisis, at the 4 to 11-month horizons especially.

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