The (in)stability of stock returns and monetary policy interdependence in the US *

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Abstract

To be updated. We investigate the effects of monetary policy on equity returns and vice-versa in the US before, during and after the effective lower bound period (ELB) on interest rates. We use a novel inferential method in a (structural) VAR framework that exploits shifts in the volatility of shocks that affect equity returns and interest rates. Those shifts allow us to disentangle both effects without imposing restrictive assumptions previously used in the literature. We find dramatic changes in the relationship between monetary policy and equity returns over the period. Before the ELB period, policymakers reacted to increases in stock returns by raising the interest rate. This reaction becomes negative or muted since the ELB period. Regarding the stock market response to monetary policy, we find that an expansionary monetary policy increases equity returns before the ELB period. Since then, however, we estimate a negative response of equity prices to a monetary expansion, even after the ELB period.

Keywords: Monetary Policy, Stock Market, Fed Put, Parameter Instability, Structural Break
JEL classification: C12, E44, G10

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1 Introduction

A growing literature suggests that monetary policy exerts a *continuous* influence on asset prices (Bianchi et al., 2024; Lewis, 2023; Neuhierl & Weber, 2019). Yet, much of our understanding of the effect of monetary policy on asset prices is built on event studies that only capture a discrete influence around the time of a policy announcement. Monetary policy affects equity prices by changing market interest rates, which in turn, affect real economic activity, altering the cost of capital for firms' influencing future earnings and expected dividends. An emerging theoretical literature also posits that monetary policy affects the risk premium such that changes in monetary policy influence risk aversion (Kekre & Lenel, 2022; Pflueger & Rinaldi, 2022).

We estimate the effect of U.S monetary policy on stock prices and the equity premium while also allowing for monetary policy to react to stock prices. We identify these effects using all trading day data, which allows us to capture the continuous influence on equity prices. relying on an inferential method that tests the stability restrictions and using market-based interest rates, stock market indices, and a measure of expected equity premium over January 1989 and March 2020, thus covering the effective lower bound (ELB) on the nominal interest rate.

We find evidence that the effect of monetary policy on equity prices and the expected equity premium have shifted during this period. Thus we focus on subsamples before, during and after the ELB.

Our main results are

(i) Before the ELB, we find that an unexpected increase of 100bps in the policy rate reduces equity prices by 2.9%, the FOMC increases the policy rate by 0.5bps when equity returns increase by 1% and the expected equity premium increases by 2% when the policy rate increases by 100bps.

(ii) During the ELB, however, the relationship between monetary policy and stock returns has completely changed: a contractionary monetary policy causes an *increase* in equity returns, and the FOMC is *not* reacting to increments in stock returns.

(iii) After the ELB, monetary policy contractions reduce returns, but the the response of the FOMC becomes muted, and increments in the policy rate increase the expected equity premium.

Our results hold even after we control for intradaily monetary surprises suggesting that indeed we capture the influence of monetary policy on equity prices beyond the monetary policy shocks that occurs on FOMC meeting days.

Our empirical investigation uses the stability restrictions method proposed by Magnusson and Mavroeidis (2014) to a obtain confidence set of the response of equity returns to monetary policy, the FOMC response to stock returns and the effect of monetary policy on expected equity premium. We assume that interest rates, equity returns and the equity premium co-move following a structural VAR (SVAR) model. We derive moment conditions from the SVAR, and then for a candidate value for the responses, we test the joint hypothesis that the moment condition is satisfied on average and sufficiently stable across subsamples. Our confidence set is the collection of candidate parameter values that do not reject the joint hypothesis.

Similar to the identification by heteroskedasticity literature, we explore shifts in the volatilities of the structural shocks to identify the responses. However, different from this literature, we do not need to specify the source of heteroskedasticity in the data nor the dates when shifts in volatilities occur.[1] Kurov et al. (2022) and Rigobon and Sack (2004), for instance, exploit the predetermined shift in the information flow to the market induced by the FOMC calendar, which increases volatility on FOMC meeting days.[2] We use a generalization of this feature: any exogenous shift in the information flow that drives the volatility of shocks is a source of identification.[3]

We also allow for time-varying reactions. In this case, the estimated confidence sets would be empty because the data would reject the underlying model, which assumes

[1]Similar to Lewis (2021), we do not need to specify a parametric form for the shifts in the volatility of the shocks.

[2]More recently, Boehm and Kroner (2021) use the difference in the volatility of the shocks between policy-announcement days and non-announcement days to estimate the "Fed non-yield curve shock" which they relate to textual information in the announcement.

[3]See Veronesi (1999) and Ross (1989) for theoretical models linking the information flow to the market and price volatility.

constant parameters. In turn, if the information arising from the shifts in volatility is not enough to estimate the reactions, we would obtain unbounded confidence sets. This latter case is akin to the weak-instrument problem in the instrumental variable literature, see Staiger and Stock (1997) and Stock and Wright (2000). Ou method is thus robust to weak identification which has been shown to be a problem when using heteroskedasticity to achieve identification (Lewis, 2022).

Disentangling the effects of monetary policy on stock returns and vice versa is challenging because they simultaneously affect each other. Even when FOMC decisions may not react to stock prices on the same day, market expectations of these decisions are formed continuously. Therefore, restrictions are needed to identify those effects separately.

In the event-study approach, the identification strategy assumes that monetary policy shocks occur only around interest rate announcements, and those announcements are the sole cause of movements in equity returns; see Nakamura and Steinsson (2018) and Bernanke and Kuttner (2005) among others. The underlying assumption requires that the market clears rapidly after a central bank announcement with no price reversal afterwards. A growing literature, nevertheless, documents that the stock market does not process macroeconomic news rapidly enough, giving rise to price reversals (Kroencke et al., 2021) and price drifts around the policy announcement (Illeditsch et al., 2020; Lucca & Moench, 2015; Savor & Wilson, 2013). Our approach instead uses all business days in our estimation, allowing for shocks outside any pre-defined monetary policy window.[4]

A different approach to estimate the reactions is to impose short-run (Galí & Gambetti, 2015), long-run (Bjørnland & Leitemo, 2009) or sign restrictions (Breitenlechner et al., 2021; Jarociński & Karadi, 2020). Those restrictions constrain the direction or the magnitude of the central bank's reaction to equity returns, or the reaction of stock returns to changes in monetary policy. Our approach does not impose such restrictions and, therefore, it is agnostic about the direction and magnitude of the reactions.

Another identification method explores the heteroskedasticity of the monetary policy

[4]Our methodology is also immune to other event-study problems like missing events (Greenlaw et al., 2018) or predictability in the fed funds futures market (Neuhierl & Weber, 2019).

and stock market shocks to identify the effects, as proposed by Rigobon (2003).[5] This method requires the reactions to be constant over time.[6]. We find instead that the reaction of monetary policy to stock prices reduced from 3 to 0.5, in line with results in Aastveit et al. (2023), and that the effect of monetary policy on expected equity premium has flipped sign. Our method identifies the responses by testing the stability of the structural parameters.

Our work is related to Neuhierl and Weber (2019) who consider weekly data of the slope of the yield curve, built from fed fund futures, to predict stock returns. They suggest that monetary policy continuously affects the market, which an event-study approach may miss. By using predictive regressions, they avoid dealing with the endogeneity issue as we do. Our paper is also related to Inoue and Rossi (2019) who identify a monetary policy shock as a shift in the whole term structure of interest rates around policy announcements. We do not identify the shocks but the structural parameters, and we do so relying on shifts in the variance of the shocks that can occur at any time.

Our results before the ELB period agree with most of the literature, although we find a smaller response of the FOMC to equity returns, which is around half the value reported by Rigobon and Sack (2003) and a quarter of Bjørnland and Leitemo (2009). Since the ELB, our results differ considerably. While Nakamura and Steinsson (2018), Gu et al. (2018) and Kurov and Gu (2016) find a positive reaction of stock returns to a rate cut, we find that the response of the stock market takes the opposite direction when compared to the pre-ELB period. Considering the period after the ELB from 2015 to March 2020, a rate hike of 1% *increases* stock returns by about 10%. More strikingly, we reject that a monetary contraction decreases stock returns during this period. This reaction of stock prices to monetary policy undermines the applicability of a "leaning-against-the-wind" policy during this period. Regarding the response of the FOMC to increases in stock returns since the ELB, we find a negligible or even negative response suggestive of a Fed

[5]This insight was first employed by Wright (1928) in the context of a demand and supply model. See Lütkepohl and Netšunajev (2017a) for a review on the identification by heteroskedasticity in a SVAR framework and Lütkepohl and Netšunajev (2017b) for the use of heteroskedasticity to identify parameters in a SVAR assuming normality of the shocks. We do not rely on the normality assumption either.

[6]See Bacchiocchi and Fanelli (2015) for a relaxation of constant responses under certain conditions and Lewis (2021, p 3096) for a discussion

put during this period (Cieslak & Vissing-Jorgensen, 2020).

The remainder of the paper is organized as follows. Section 2 presents the underlying structural model that captures the relationship between monetary policy and equity returns. The following section describes our identification strategy and Magnusson and Mavroeidis's method. Section 4 defines the empirical model and data. The main empirical results are in Section 5, which are followed by the robustness check in Section 7. We compare our findings with the literature and evaluate the validity of an event-study identification in Section 6. The algorithm for estimating the confidence sets and detailed information about the data are in the Appendix that accompanies this work.

2 The relationship between monetary policy and stock prices

Monetary policy influences economic variables, such as output or inflation, through the interest rate channel. A change in the stance of monetary policy leads to a change in market interest rates, which, in turn, affects real economic activity, altering the cost of capital for investors and firms' future earnings and expected dividends (Thorbercke, 1997).[7] On the other hand, changes in the value of the stock market have an impact on aggregate demand through two channels: aggregate consumption through the wealth effect, and investment decisions; see, for instance, Bjørnland and Leitemo (2009) for an empirical analysis example. Thus, to the extent that stock valuations affect aggregate demand, movements in the stock market are an inherent factor in monetary policy decisions (Rigobon & Sack, 2003). Additionally, FOMC members could target stock prices, in the sense of Christiano et al. (2010), to prevent any financial disruption, which could undermine the fulfillment of the price stability mandate.[8]

[7] Theoretically, if money neutrality holds in the long-run, the value of the stock market should be independent of monetary policy, given that stocks are claims on real assets. Therefore, a stock market response to movements in monetary policy indicates real effects of monetary policy on either the future cash flows of firms or the cost of capital used to capitalize those cash flows (Bernanke & Kuttner, 2005). In fact, Nakamura and Steinsson (2018) find strong evidence of the non-neutrality of monetary policy.

[8] Explicit targeting of asset prices can be found during times of crisis. See, for example, Kurov and Gu (2016) who revise FOMC transcripts during crises with clear references to the stock market.

The investigation of the relationship between monetary policy decisions and stock prices returns faces two challenges. First, some policy movements are predicted because rational investors use all available information to forecast future movements in economic activity and monetary policy. Therefore, it is essential to distinguish between expected and unexpected policy movements; see Kuttner (2001) and Bernanke and Kuttner (2005). Second, the endogeneity between monetary policy decisions and stock market behavior: investors and FOMC members might share the same information about the state of the economy when it is released, prompting stock prices and, possibly, the central bank to react simultaneously. The central bank could also respond directly to equity prices on the basis that they convey private information about investors, for example, their expectations of the future level of economic activity.

Monetary policy affects equity returns by changing the cost of capital, expected dividends or expected returns. Innovations in the (log) excess returns over the risk-free rate can be decomposed into innovations in future dividends, future interest rates and future excess returns. Define the log of stock returns as $\breve{r}_{t+1}$ and the log of a short-term interest rate as $\breve{i}_{t+1}$ then the realised log excess return is $\breve{e}_{t+1} \equiv \breve{r}_{t+1} - \breve{i}_{t+1}$. Following Campbell (2017) the innovations in the excess returns can be written as

$$\begin{aligned}\breve{e}_{t+1} - \mathbb{E}_t\, \breve{e}_{t+1} = (\mathbb{E}_{t+1} - \mathbb{E}_t) \sum_{j=0}^{\infty} \rho^j\ \Delta\breve{d}_{t+1+j} - (\mathbb{E}_{t+1} - \mathbb{E}_t) \sum_{j=0}^{\infty} \rho^j\ \breve{i}_{t+1+j} \\ - (\mathbb{E}_{t+1} - \mathbb{E}_t) \sum_{j=0}^{\infty} \rho^j\ \breve{e}_{t+1+j},\end{aligned} \tag{1}$$

where $\rho < 1$ is a constant, $\Delta\breve{d}$ is the change in log real dividends.[9] This equation shows that unexpected excess return is the result of news on dividends, news of future interest rates and news of future equity premiums.

In a model, monetary policy influences all three terms on the right-hand side. A surprise tightening of monetary policy reduces future dividends and increases future interest rates depressing excess returns. Furthermore, an unexpected tightening of monetary policy increases future excess returns, the last term on the right-hand side of the

[9]See equation 7 in Campbell (1991) and Campbell (2017).

decomposition, thus depressing current excess return. For example, in Pflueger and Rinaldi (2022), a tightening of monetary policy reduces consumption above the habit level of the representative investor, making her more risk averse and increasing the expected equity premium.

Typically, empirical approaches do not account for the influence of monetary policy on the expected equity premium. An event-study identification relies on estimable news of future interest rates (surprises) and runs a regression of realised returns on this news, assuming that the expected equity premium is constant.[10] Common specifications in the structural VAR literature follow the seminar specification by Rigobon and Sack (2004), which treat movements in the equity premium as shocks to the stock return equation and thus uncorrelated to monetary policy.[11] We show evidence in Section 6.1 that by regarding shifts in equity premium as shocks, this specification confounds the systematic effect of monetary policy on risk-taking, the last-term on the righ-hand side in the decomposition, with revisions on future interest rates.

We consider an SVAR model that accommodates a contemporaneous response of the expected equity premium to monetary policy. Let s_t be the unexpected excess returns at time t on the S&P 500 Index such that $s_t \equiv e_t - \mathbb{E}_{t-1}e_t$ where e_t is the realised (simple) excess return over the risk-free rate at time t and $\mathbb{E}_{t-1}\, e_t$ is the expectation at time $t-1$ of the excess return over the risk-free rate at time t. The left-hand side term in equation (1) corresponds to s_t, ignoring the difference between log and simple returns. Typically, $\mathbb{E}_{t-1}\, e_t$ is estimated but following Martin (2017) we observe this expectation term using an implied volatility index. Let Δi_t be the daily change in an open-market interest rate, and Δe_t is the daily change in the expected equity premium giving rise to the following specification

[10] A related problem is that on days of monetary policy announcements, the expected equity premium could be systematically greater to compensate investors for the resolution of uncertainty that occurs those days, see Savor and Wilson (2013), Gu et al. (2018), and Boehm and Kroner (2021)

[11] More recently this specification is used by D'Amico and Farka (2011), Kurov et al. (2022), Lütkepohl and Netšunajev (2017b), and Nakamura and Steinsson (2018).

$$
\begin{cases}
\Delta i_t = \beta s_t + \boldsymbol{\gamma}_i^{'} \mathbf{x}_t + \epsilon_{i,t} & \text{(2a)} \\
s_t = \alpha \Delta i_t + \chi \Delta e_t + \boldsymbol{\gamma}_s^{'} \mathbf{x}_t + \epsilon_{s,t} & \text{(2b)} \\
\Delta e_t = \eta \Delta i_t + \boldsymbol{\gamma}_{\mathbf{e}}^{'} \mathbf{x}_t + \epsilon_{e,t} & \text{(2c)}
\end{cases}
$$

where $\mathbf{x}$ is a vector of exogenous variables with their associated vectors of parameters $\boldsymbol{\gamma}_i, \boldsymbol{\gamma}_s, \boldsymbol{\gamma}_e$; and $\epsilon_{i,t}, \epsilon_{s,t}, \epsilon_{e,t}$ are the monetary policy, stock market and equity premium shocks. The parameters of interest are β, the response of monetary policy to changes in the value of the stock market, α, the stock market's response to changes in monetary policy and η the influence of monetary policy on the equity premium. The parameter χ captures the influence of expected risk premium on returns. The model includes lagged values of Δi_t, Δe_t and s_t which are suppressed here for exposition purposes.

The equation (2a) is regarded as a high-frequency monetary policy reaction function, which resembles a forward-looking Taylor-type rule, as in Arias et al. (2019). We impose the short-run restriction that monetary policy does not react to shifts in investors' willingness to bear risk itself beyond the impact on equity prices, which is consistent with how policymakers describe their actions (Rigobon & Sack, 2003). The monetary shock $\epsilon_{i,t}$ captures not only deviations of the policymaker from its underlying monetary policy rule but also changes in the rule itself.[12] The monetary shocks $\epsilon_{i,t}$ are innovations to the future interest rate, corresponding to the second term in equation (1), ignoring the different between log and simple returns. The equation (2b) decomposes stock returns into revisions on the interest rate, expected-equity premium and a shock term. The parameter α is the response of equity prices to a movement in the interest rate keeping constant the expected equity premium. As such, it mostly captures the influence of monetary policy on the path of future dividends, the first-term on the right-hand side of (1). The parameter χ is the effect of revisions on the expected equity premium on current returns and we expect

[12] This does not mean that the policymaker reacts in real-time to stock prices. Another interpretation is that any piece of news related to monetary policy, like the release of the employment report, is quickly incorporated into stock prices and open-market interest rates. While policymakers react "slowly', investors do react in a high-frequency manner as described by (2a); see Rigobon and Sack (2003, 2004), Piazzesi (2005), and M. D. Bauer and Swanson (2020). Barakchian and Crowe (2013), for example, find that the monetary policy rule becomes more forward-looking in our sample period.

it to be close to -1. The stock market shock $\epsilon_{s,t}$ comprises unexpected changes in future dividends. Finally, equation (2c) allows changes in the interest rate to influence expected equity premium as predicted by theoretical models as Pflueger and Rinaldi (2022) and Kekre and Lenel (2022). The equation for Δe_t in the model maps into the last term in equation (1), ignoring the difference between log and simple returns. Following this theoretical literature, we do not allow the expected equity premium to respond to current stock prices.

Usually, it is assumed that

$$\mathbb{E}_t\left[\epsilon_{i,t}^2\right] = \mathbb{V}\text{ar}_t(\epsilon_{i,t})$$
$$\mathbb{E}_t\left[\epsilon_{s,t}^2\right] = \mathbb{V}\text{ar}_t(\epsilon_{s,t})$$
$$\mathbb{E}_t\left[\epsilon_{e,t}^2\right] = \mathbb{V}\text{ar}_t(\epsilon_{e,t})$$

where $\mathbb{E}_t[\cdot]$ denotes expectation conditional on the information on time t. Finally, $\epsilon_{i,t}, \epsilon_{s,t}, \epsilon_{e,t}$ are independently distributed and uncorrelated with each other, ensuring that the errors have the required structural interpretation.

Rewriting the structural system (2a - 2c) in matrix form we have

$$A\mathbf{y}_t = \boldsymbol{\epsilon}_t \tag{3}$$

where $A = [1, -\beta, 0 : -\alpha, 1, -\chi \ : \ -\eta, 0, 1]$, $\mathbf{y}_t = [\Delta i_t, s_t, \Delta e_t]'$, and $\boldsymbol{\epsilon}_t = [\epsilon_{i,t}, \epsilon_{s,t}, \epsilon_{e,t}]'$, where we omit the exogenous variables in $\mathbf{x}_t$ to simplify notation. Let $\mathbf{u}_t = A^{-1}\boldsymbol{\epsilon}_t$ be the (3×1) vector of reduced-form errors with the (3×3) reduced-form covariance matrix $\Omega = \mathbb{E}_t[\mathbf{u}_t\mathbf{u}_t']$. Conditional on information at time t, the relation between Ω and the structural covariance Σ is

$$A\ \Omega\ A' - \Sigma_t = 0 \tag{4}$$

where

$$\Omega \equiv \begin{bmatrix} \omega_{ii} & \omega_{is} & \omega_{ie} \\ \cdot & \omega_{ss} & \omega_{se} \\ \cdot & \cdot & \omega_{ee} \end{bmatrix} \tag{5}$$

and Σ_t is the (3×3) structural covariance matrix, potentially time varying.

The relation in (4) defines 6 moment conditions and 7 structural parameters (α, β, χ, η, $\mathbb{V}\text{ar}_t(\epsilon_{i,t})$, $\mathbb{V}\text{ar}_t(\epsilon_{s,t})$, $\mathbb{V}\text{ar}_t(\epsilon_{e,t})$). Focusing on the 3 moment conditions corresponding to the off-diagonal elements of (4) we have,

$$\begin{aligned} \mathbb{E}_t\left[\omega_{is,t} - \beta\omega_{ss,t} - \alpha(\omega_{ii,t} - \beta\omega_{si,t}) - \chi(\omega_{ie,t} - \beta\omega_{se,t})\right] = 0 \\ \mathbb{E}_t\left[\omega_{ie} - \beta\omega_{se} - \eta\omega_{ii} + \eta\beta\omega_{si}\right] = 0 \\ \mathbb{E}_t\left[\omega_{se} - \alpha\omega_{ie} - \chi\omega_{ee} + \eta\left(\alpha\omega_{ii} - \omega_{is} + \chi\omega_{ie}\right)\right] = 0. \end{aligned} \tag{6}$$

where the structural variances are absent.

These moment conditions contain 4 unknown structural parameters, but only 3 (estimable) reduced-form parameters (ω_{is}, ω_{ie} and ω_{se}). Therefore, the identification of the structural parameters requires additional restrictions on the joint dynamics of the SVAR in equation (3). For example, Bjørnland and Leitemo (2009) considers the long-run restriction that a monetary policy shock has no long-run effect on the level of real stock prices, and D'Amico and Farka (2011) and Nakamura and Steinsson (2018) assume that, in tight intervals around the FOMC announcement, only monetary policy shocks occur, implying the short-run restriction of $\beta = 0$.

A second possible strategy for the identification is the use of the instrumental variables (IV) method. As raised by Rigobon and Sack (2003), in the current context, a relevant instrument might not exist at all because almost no macroeconomic variable can satisfy the exogeneity restriction of being correlated with stock prices but uncorrelated with monetary policy decisions (and vice-versa).

A third approach is to explore any exogenous shift in the conditional variance of the structural shocks to identify the structural parameters that remain unchanged over time, as proposed by Rigobon (2003). This approach requires dating the shifts in the (unobservable) structural variance of the shocks. For example, Rigobon and Sack (2003) identify the shifts by estimating Ω over different subsamples while Nakamura and Steinsson (2018) identify regimes based on days in which a FOMC policy decision was made. Even if the regimes are known, a weak identification problem may emerge. Indeed, Lewis (2022) finds evidence of weak identification when using Nakamura and Steinsson (2018) daily data. Our approach circumvents this problem by relying on a weak-identification robust method.

3 Inference strategy

Our identification strategy relies on shifts in the conditional variance of the shocks and it is robust to weak identification. We are agnostic about the source of the heteroskedasticity. It could follow from the FOMC meeting calendar which predetermines the timing of the release of information to the market (Rigobon & Sack, 2003), or, more generally, the heteroskedasticity can follow from exogenous variations in the rate of information arrival to the market (Ross, 1989; Veronesi, 1999). We are also agnostic about when the shifts in the volatilities occur.

Consider that the structural variances are potentially time-varying, taking the form $\{\mathbb{V}\text{ar}(\epsilon_{i,t}), \mathbb{V}\text{ar}(\epsilon_{s,t}), \mathbb{V}\text{ar}(\epsilon_{e,t})\}_{t=1}^{T}$. From equation (4), changes in the structural volatilities induce changes on the reduced-form variances even though the vector of structural parameters $\boldsymbol{\theta} = [\alpha, \beta, \chi, \eta]$ remains invariant across time. Then, let $\boldsymbol{f}_t(\boldsymbol{\theta})$ the value of the moment conditions in (6) at time t such that

$$\boldsymbol{f}_t(\boldsymbol{\theta}) = \begin{bmatrix} \omega_{is,t} - \beta\omega_{ss,t} - \alpha(\omega_{ii,t} - \beta\omega_{si,t}) - \chi(\omega_{ie,t} - \beta\omega_{se,t}) \\ \omega_{ie,t} - \beta\omega_{se,t} - \eta\omega_{ii,t} + \eta\beta\omega_{si,t} \\ \omega_{se,t} - \alpha\omega_{ie,t} - \chi\omega_{ee,t} + \eta\left(\alpha\omega_{ii,t} - \omega_{is,t} + \chi\omega_{ie,t}\right) \end{bmatrix}. \tag{7}$$

We are interested in the structural parameter vector $\boldsymbol{\theta}$. We can investigate if the moment conditions (7) are satisfied by some value of this parameter vector, let us say $\boldsymbol{\theta}_0$.

Formally, we would like to test the following null and alternative hypotheses

$$H_0 : \boldsymbol{\theta} = \boldsymbol{\theta}_0 \text{ and } H_a : \boldsymbol{\theta} \neq \boldsymbol{\theta}_0.$$

by verifying if

$$\mathbb{E}\left[\boldsymbol{f}_t(\boldsymbol{\theta}_0)\right] = 0 \text{ for all } t \leq T,\, T \geq 1. \tag{8}$$

If condition (8) is not satisfied for a hypothesized $\boldsymbol{\theta}_0$, then the true parameter $\boldsymbol{\theta}$ cannot be $\boldsymbol{\theta}_0$. By collecting all points in the parameter space that do not reject the above null assumption at a 10% significant level, we construct the 90% confidence set for $[\alpha, \beta, \chi, \eta]$.

Usually, testing condition (8) is performed by verifying if the empirical average moment condition $T^{-1}F_T(\boldsymbol{\theta}_0) = T^{-1}\sum_{t=1}^{T} \boldsymbol{f}_t(\boldsymbol{\theta}_0)$ is not statistically significant. Stock and Wright (2000) propose to test H_0 by using the value of the objective function of a generalised method of moments estimator giving rise to the S statistic

$$S(\boldsymbol{\theta}_0) \equiv \frac{1}{T} F_T(\boldsymbol{\theta}_0)'\, \hat{V}_{ff}(\boldsymbol{\theta}_0)^{-1}\, F_T(\boldsymbol{\theta}_0) \tag{9}$$

where $\hat{V}(\boldsymbol{\theta}_0)_{ff}$ is a consistent estimator of the variance of $T^{-1/2}F_T(\boldsymbol{\theta})$. In our case, exclusively relying on the S statistic has a major drawback: $F_T(\boldsymbol{\theta})$ contains three equations with four unknown parameters, leaving $\boldsymbol{\theta}$ unidentified.

Magnusson and Mavroeidis (2014) suggest exploring not only the average moment condition $T^{-1}F_T(\boldsymbol{\theta}_0)$, but also the partial sum of the moment functions which are obtained from condition (8) as well. Let us denote the partial sum of the moment function in equation (7) as

$$F_{sT}(\boldsymbol{\theta}) = \sum_{t=1}^{[sT]} f_t(\boldsymbol{\theta}),$$

where $s \in [0, 1]$. The symbol $[\cdot]$ denotes the integer part of a scalar. Next, define the following statistic

$$\tilde{F}_{sT}(\boldsymbol{\theta}) = F_{sT}(\boldsymbol{\theta}) - sF_T(\boldsymbol{\theta}) \text{ for all } s \in [0, 1]\,, \tag{10}$$

which captures the deviation of the partial-sample mean from the full-sample mean. If moment conditions in (8) hold, it must be the case that $\mathbb{E}_t\left[\tilde{F}_{sT}(\boldsymbol{\theta}_0)\right] = 0$ for *all* $s \in [0,1]$ under the null assumption $H_0 : \boldsymbol{\theta} = \boldsymbol{\theta}_0$. Therefore, large deviations of $F_{sT}(\boldsymbol{\theta}_0)$ from $sF_T(\boldsymbol{\theta}_0)$ would indicate a violation of some of the conditions in (8), resulting in the rejection of the null hypothesis. Magnusson and Mavroeidis (2014) propose the "quasi Local Level" $qLL - \widetilde{S}$ test, which is a combination of the set of T statistics $\tilde{F}_{sT}(\boldsymbol{\theta}_0)$ into a single one, to determine the stability of $\tilde{F}_{sT}$ along time under the null hypothesis.

The qLL-$\widetilde{S}$ test has power against different types of instabilities, such as those modeled by step functions with a finite number of discontinuities, instabilities representing a realization of a continuous stochastic process, or a smooth deterministic function of time representing transitions between regimes. This test also has three desirable properties. First, it is not necessary to assume that the break dates are known. Second, no assumption is required regarding the distribution of shocks, including the homoskedasticity of the structural shocks within a volatility regime, as needed in Rigobon and Sack (2003) and (2004). Third, the qLL-$\widetilde{S}$ test is still valid in the presence of weak instruments thus making inference reliable. In this problem, weak instruments emerge as the co-movement of variances after a regime change, see also Lewis (2022).

The structural parameter vector $\boldsymbol{\theta}$ may possibly change over time. For example, the response of returns to a shift in the policy instrument might be asymmetric because the stock market reaction to a raise of the policy instrument might be different when compared to a decrease of the same rate. Conversely, the response of monetary policy can be asymmetric if the policymaker is more concerned about a bear than a bull market.[13] In both cases, the confidence sets derived from the qLL-$\widetilde{S}$ test would be empty because, by construction, this set should contain only points that are stable over time, satisfying the moment condition in (8).

Finally, one can combine information emerging from the full-sample moment conditions captured by the S statistic with information from the stability restrictions captured

[13] Bernanke and Kuttner (2005) and Ravn (2012) find no and modest evidence of asymmetry, respectively.

in $qLL\text{-}\widetilde{S}$ to form a new statistic

$$gen\text{-}S(\boldsymbol{\theta}_0) \equiv qLL\text{-}\widetilde{S}(\boldsymbol{\theta}_0) + \frac{10}{11}S(\boldsymbol{\theta}_0) \tag{11}$$

where *gen*-S stands for generalised S. The *gen*-S tests the joint hypothesis that the full-sample moment conditions are sufficiently close to zero *and* that the partial-sample moment conditions are zero on average. We use the *gen*-S statistic to perform our analysis. For each $\boldsymbol{\theta}_0$, we compute the *gen*-S and use the critical values as tabulated by Magnusson and Mavroeidis (2014). Details of the procedure are in Section 9.2 in the Appendix.

4 Baseline specification and variables

The reduced-form VAR representation obtained from the system (2a-2c) is

$$\mathbf{y}_t = \sum_{j=1}^{p} \Phi_j \mathbf{y}_{t-j} + \Gamma \mathbf{x}_t + \mathbf{u}_t \tag{12}$$

with $\mathbf{y}_t = (\Delta i_t, s_t, \Delta e_t)'$ all three variables measured in basis points. The vector $\mathbf{x}_t$ contains all other control variables, including a constant, which are detailed below. Detailed information on the sources of all variables is in Section 10 of the Appendix. We use daily data on all trading days which allows incorporating changes in expectations of market participants about monetary policy on days outside the FOMC meetings.[14] Additionally, a daily frequency may better capture the heteroskedasticity of the shocks, improving the power of the *gen-S* test.

The variable Δi_t is the scaled daily change of the front-month fed funds future contract (the first future contract) for all periods but the ELB. This contract captures short-term expectations of the monetary policy instrument, the effective Fed funds rate, and has been used since Kuttner (2001), see also Bernanke and Kuttner (2005).[15] The settlement price of the fed funds futures contract is the monthly average of the effective Fed funds rate

[14] Neuhierl and Weber (2019) and Cieslak et al. (2019) emphasize the relevance of non-announcement days in the estimating the impact of monetary policy on long-term yields or stock prices, also see Gürkaynak et al. (2018), Lucca and Moench (2015), and Thornton (2017)

[15] Gürkaynak et al. (2007) find that the fed funds futures are the best predictor of monetary policy.

rather than the rate at a specific date. We scale the daily changes in the contract price by a variant of Kuttner (2001) scaling factors as employed by Nakamura and Steinsson (2018). [16] During the ELB period, we consider a composite policy indicator of short and medium-term market rates. The composite rate is the first principal component (PCA) of the daily change in 5 future rates: the front-month fed fund future (appropriately scaled by Kuttner's factor), the next-month fed fund future, and the 3-month eurodollar future at horizons of two, three and four quarters.[17] Henceforward, we refer to the composite rate as the PCA rate. The ELB period is characterized by the virtual shutdown of the conventional monetary policy in favour of forward guidance and quantitative easing, which influence longer-term rates.[18]

For the expected equity premium, we rely on implied volatility indexes, which are readily available and do not require estimation. As demonstrated by Martin (2017), an implied volatility index built from option prices on the S&P 500 index is a valid measure of the expected equity premium. We use the VIX index, which captures the annualised 30-day expected equity premium in basis points such that

$$\mathbb{E}_{t-1}\, e_t \equiv \mathbb{E}_{t-1}(1+r_t) - (1+r_{f,t-1}) = \left[(1+r_{f,t-1})(VIX_{t-1}/100)^2\right] \times 10,000$$

where r_t is the annualised 30-day return on the S&P 500 index, $r_{f,t-1}$ is the 1-month risk-free rate from Kenneth French's website and VIX_{t-1} is the daily close in the VIX index.[19] We use the daily change of e_t in our regressions, which capture the innovations in the expected equity premium, see the last-term in equation (1).

To compute the unexpected excess return s_t at the daily frequency, we derive the compound daily rate over the course of 30 days that is equivalent to the expected 30-day return in $\mathbb{E}_{t-1}\, e_t$. Then $s_t = (r_t - r_{f,t-1}) - \mathbb{E}_{d,t-1}\, e_t$ where r_t is the daily simple return on

[16] Section 10.2.2 of the Appendix contains a detailed description of the adjustment.

[17] These are the rates used by Gürkaynak et al. (2005), Nakamura and Steinsson (2018), Lakdawala (2019), and M. D. Bauer and Swanson (2020).

[18] For a textbook discussion on forward guidance when the nominal rate is not constrained, see D. Romer (2018, Chap. 12). A list of key monetary events during the ELB period appears in Exhibit 2.1 from Greenlaw et al. (2018). For an overview of unconventional monetary policies in the USA and Europe, see Buraschi and Whelan (2015).

[19] See equation (15) in Martin (2017) and equation (1) in Lof (2019).

the S&P 500 index and $\mathbb{E}_{d,t-1}\, e_t = [1 + (\mathbb{E}_{d,t-1}\, e_t)/12]^{1/30}$.

Our results are almost identical when we instead define s_t as the simple daily return on a stock index. This is not surprising given the low predictability of returns at a daily frequency. To facilitate comparison with the literature we present results when s_t is the simple daily return.

Among the contemporaneous control variables, we have the day-of-the-week dummies to capture within-week seasonality, the dummy for the week following the 9/11 terrorist attacks controls for the operational problems that markets faced in that week, see Sultan (2011) and the flight-to-safety indicator variable of Baele et al. (2019) which equals 1 on days a flight-to-safety episode and 0 otherwise. A flight-to-safety can be interpreted as a common shock moving both, returns and the interest rate for reasons other than monetary policy.

The remaining controls are the five-lagged values of the following variables: the Aruoba-Diebold-Scotti economic activity index, which is a daily measure of economic activity computed by Aruoba et al. (2009), the risk-free rate, the slopes of the yield curve in the Fed fund futures market, and the US Treasury bonds.[20] The inclusion of the slope from the fed funds futures market captures forward guidance or the future path of monetary policy (Neuhierl & Weber, 2019). The relationship between stock market returns and monetary policy could also depend on the expected state of the economy (recession or expansion). Including the slope of the US Treasury bonds slope controls this expectation, given its predicting power for recessions; see Estrella and Mishkin (1998), and M. Bauer and Mertens (2018). Additionally, this slope can also control for investor sentiment (Kurov, 2010).

Table 1 presents the summary statistics of daily data from 1989-01-01 to 2020-03-14 for the main variables. The beginning of the sample coincides with the availability of the fed funds futures rates, the main variable for capturing monetary policy expectations. We report the statistics for three subperiods: before ELB (1989-01-01 to 2008-12-15), during ELB (2008-12-16 to 2015-12-15), and after ELB (2015-12-16 to 2020-03-14) periods. The

[20]See definition of these variables in Subsection 10.2 of the Appendix.

summary illustrates changes in the means and the standard deviations of the variables across periods. The shifts in volatilities will be explored by our inferential method.

Variable	Before ELB	During ELB	After ELB
Δ Interest rate (bps)	-0.234	-0.001	-0.066
	(3.784)	(1.807)	(1.559)
S&P 500 return (bps)	2.847	5.507	3.158
	(112.16)	(114.042)	(100.553)
Δ Expected equity premium (bps)	0.57	-1.579	2.742
	(112.201)	(113.217)	(143.251)
Flight-to-safety	0.034	0.018	0.01
	(0.182)	(0.134)	(0.101)
ADS index	-0.147	-0.251	-0.186
	(0.61)	(0.792)	(0.806)
Risk-free rate (bps)	1.652	0.019	0.49
	(0.774)	(0.039)	(0.318)
Fed funds futures slope	0.069	0.049	0.043
	(4.381)	(0.69)	(2.217)
US Treasury yield curve slope	1.536	2.503	0.941
	(1.226)	(0.611)	(0.649)
Observations	5011	1762	1067

Table 1: MAIN VARIABLES DESCRIPTIVE STATISTICS. Mean and standard deviation (in parenthesis) of daily variables before ELB (1989-01-01 to 2008-12-15) during ELB (2008-12-16 to 2015-12-15), and after ELB (2015-12-16 to 2020-03-14). Δ Interest rate is the scaled change in current-month Fed fund futures for all periods except during ELB which is the first component of a PCA of five market rates. bps stands for basis points.

5 EMPIRICAL RESULTS: THE LOCATION OF MONETARY POLICY AND RETURNS REACTIONS

We report results based on a VAR(5), which corresponds to a one-week trade.[21] The changes in policy instruments and equity returns are measured in basis points, see Table 3 in the Appendix for the properties of the parameter space. To facilitate the interpretation of the confidence sets, we report $100 \times \beta$, that is, the effect of a change of 1 percentage point in the interest rate. As argued by Mavroeidis (2021) and references therein, the

[21]This encompasses the 24 hours pre-FOMC announcement drift documented by Savor and Wilson (2013) and Lucca and Moench (2015), and as big as Neuhierl and Weber (2019) who consider weekly changes in fed fund futures as a predictor of weekly stock returns.

underlying structural VAR may have shifted when transiting from the conventional to unconventional monetary policy periods. Therefore, we estimate confidence sets for three distinct periods: before, during, and after ELB.

Figure 1 shows the 85% and 90% confidence sets for the parameters (α, β) and projected confidence intervals for χ and η based on the *gen-S* statistic.[22] Only points in the parameter space in which the *gen-S* statistic is below the critical value at 15% and 10% confidence are included in the confidence sets; that is, only points that do not reject the partial-sample moment conditions underlying the equation (10) and the full-sample conditions in equation (9).

The first result is that none of the sets are empty, implying that the moment conditions in (7) are not rejected by the data. Across all periods, we estimate $\chi < 0$. This is a minimum condition for a measure of expected equity premium: an increase in expected equity premium reduces current returns, in terms of equation (1), the last term on the right-hand side enters negatively. This result reinforces the evidence from Martin (2017), which uses predictive regressions instead. Across all periods, monetary policy influences the equity premium: we reject the null that monetary policy has no contemporaneous effect on the expected equity premium. At the same time, we do not find evidence that the response of the FOMC to stock prices is asymmetric, as in Kurov et al. (2022). If that were the case, our sets would be empty, implying that there is no unique and stable value of β that satisfies the stability restrictions.

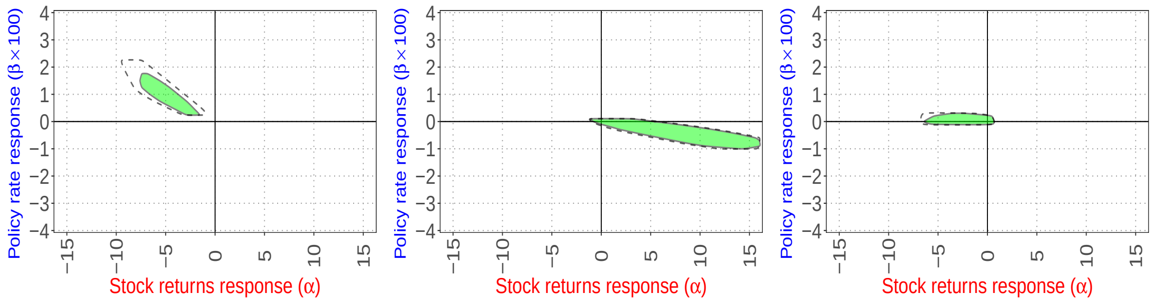
The shape of the set differs considerably in each period. Before the ELB period, the confidence set comprises negative values for α and positive values for β. In this period, a tightening of monetary policy depresses stock returns, and a surge in equity returns increases the policy rate.

Focusing on the lowest value for the gen-S implies that stock returns drop by 2.9% to an unexpected increase of 1% in the policy rate while the policy rate increases by 0.5bps as a response to surge in stock returns of 1%. The result is symmetric for market downturn; for example, the largest daily drop in stock returns was on 2008-Oct-15 when the S&P

[22] See computational details of the test in Section 9.2 of the Appendix.

	Before ELB (1989-2008)	During ELB (2008-2015)	After ELB (2015 to 2020-03)

PANEL A. CONFIDENCE SETS



PANEL B. CONFIDENCE INTERVALS

	Before ELB (1989-2008)	During ELB (2008-2015)	After ELB (2015 to 2020-03)
χ	[-1.2, -0.8]	[-1.2, -0.7]	[-1.3, -0.6]
η	[1, 8.5]	[-20, 0]	[-17.4, -4.6]

Figure 1: CONFIDENCE SETS BEFORE, DURING AND AFTER THE ELB PERIOD. Panel A shows the *gen*-S confidence sets for the reaction of stock returns to monetary policy shock (α) and the reaction of monetary policy to stock returns (β). The confidence level is 85% for the green area and 90% for the dashed area. The policy instrument is the daily change in the current-month fed funds future rate adjusted by Kuttner (2001) factors outside the ELB period, whereas it is the first component of a PCA of five interest rates during ELB period. The stock return is the daily return on the S&P 500 index. Before ELB: 1989-01-01 to 2008-12-15, During ELB: 2008-12-16 to 2015-12-15, After ELB: 2015-12-16 to 2020-03-14. Panel B contains the projected confidence intervals at 85% confidence for the response of returns to expected equity premium (χ) and response of expected equity premium to monetary policy (η).

500 dropped by 9.03%; our result implies a corresponding reduction on the policy rate of 0.05%. That the policy rate falls when stock returns drop coincides with the notion of the "Fed put" (Diamond & Rajan, 2012).

From the 85% confidence sets, we estimate that before the ELB stock returns would drop between 7.9% and 1.6% to an unexpected increase of 100bps in the policy rate while the response of the policy rate to a one-day surge in stock prices of 1% ranges between 0.25bps to 1.75bps. The reduction in returns to a monetary contraction keeps the expected equity premium fixed. Thus the reduction is mostly driven by revision on the path of future dividends rather than a revision of future expected returns, see equation (1). [23] For this period, we estimate η to be positive with our preferred estimate, given by the lowest

[23]The parameter α can also capture the effect of revisions of the path of monetary policy. We partially controlled for this by incorporating the lag values of the slope of the future contracts of the fed funds, which are known predictors of the future path of monetary policy.

value of the gen-S, implying that the equity premium increases by 2% when the policy rate increases by 100bps. Our confidence interval only admits positive values with the expected equity premium increasing between 1% to 8.5% for a 100bps hike in the policy rate. Positive values for η are in line with theoretical models like Pflueger and Rinaldi (2022), where an interest rate hike reduces consumption and makes investors more risk averse.

During the ELB, the confidence set only comprises positive values of α, meaning that an increase in the policy instrument *raises* stock returns. This response, which is the opposite of the previous period, contradicts the traditional transmission mechanism: a higher policy rate should reduce the present value of expected dividends and, consequently, stock returns. Note that a positive α implies that the central bank cannot pursue a "leaning-against-the-wind" type of policy, deflating asset prices with increases in the policy instrument. Our estimates imply that lifting the policy rate from zero, a normalization of monetary policy, increases stock prices during this period. The monetary policy reaction to equity returns (β) is close to or below zero, suggesting that the monetary policy is either slightly reacting to stock market movements or not reacting at all during this period. Since this is a period with only an expansionary cycle of monetary policy, we are reluctant to draw defining conclusions from it, except that our evidence suggests that this period should be treated separately in the analysis.

Finally, even after the normalization of monetary policy since December 2015, the after-ELB confidence set does not retain the same shape as before the ELB: the response for both stock returns and monetary policy is lower, particularly noticeable for β, which is tightly estimated to be around -0.1 to 0.3 (at 85% confidence) with a point estimate of 0. At 85% confidence, we estimate that a rate hike of 1%, stock returns decrease between 6.4% to 0.4%. In this period, the confidence interval for η flips sign indicating that an increase in the policy rate increases the expected equity premium. This contradicts theoretical models, which posit a positive comovement between risk premia and interest rate.

6 COMPARISON WITH THE LITERATURE

Our results emerge after imposing less stringent identifying conditions that are commonly used in the literature: we are sign-agnostic about the direction of the monetary policy response to stock returns and vice-versa, not imposing any short- or long-run restrictions to estimate the confidence sets. We compare our findings with those previously reported, which are summarized in Table 2. This table contains estimated values of the responses, including the underlying identifying assumptions, sample periods, and monetary policy proxies. To facilitate the comparison, the bottom of the table presents our 85% confidence intervals for parameters α and β, which are obtained by projecting the respective confidence sets into the α and β axes. Recall that our α is the response of stock returns while keeping constant the contemporaneous change in the expected equity premium. Since most of the studies in the table do not control for this, it is equivalent to assuming a constant risk premium.

We classify the different identifying restrictions into five categories: event study, heteroskedasticity, short-run restriction, long-run restriction, and sign restriction. Event-study identifies the stock market response to monetary policy using observations surrounding the policy announcements. Identification through heteroskedasticity explores pre-determined shifts in the variances of the structural shocks, while short-run, long-run, and sign restrictions constrain the responses of the endogenous variables to a structural shock in a SVAR framework.

Before the ELB period, our findings of the stock market response to monetary policy (α) are in line with previous evidence. For example, D'Amico and Farka (2011)'s estimate of -5.11 for the period 1994-2006 is almost in the middle of our (projected) confidence interval. For this period, our estimated FOMC response to returns (β) is positive agreeing with the "Fed put". Sudying a similar period, Kurov (2010) finds that the reaction of investor sentiment to monetary surprises in bear markets is consistent with the notion that investors believe in the Federal Reserve's ability to put a "floor"under stock prices in periods of market stress by easing monetary policy, also see Cieslak and Vissing-Jorgensen (2020). Bianchi et al. (2022) find that monetary policy became more dovish during the

Table 2: LITERATURE COMPARISON. Panel A: estimates of the impact of a monetary shock on stock returns (α) and stock returns on the policy instrument (β). Point estimates are presented for constant parameter models and the minimum and maximum for time-varying parameters (TVP) models. Whenever possible, $\hat{\alpha}$ is normalized to the impact of a monetary shock that increases the respective proxy for monetary policy expectations by 1 bps. Panel B: projected 90% confidence intervals based on the $qLL\text{-}\widetilde{S}$ confidence sets.

Paper	Ident.[1]	Sample from	Sample to	Proxy[2]	Returns response $(\hat{\alpha})^3$	Policy response $(\hat{\beta} \times 100)^3$	Notes
PANEL A: Non-TVP models: point estimates / TVP models: min. and max.							
Rigobon and Sack (2003)	H	1985-03-01	1999-12-31	3-mth T-bill		2.14	p. 656.
Rigobon and Sack (2004)	H	1994-01-03	2001-11-26	1-quarter ED	-7.19		p. 1567.
Bernanke and Kuttner (2005)	ES	1989-06-01	2002-12-31	FFF1	-2.55		p. 1226.
Bjørnland and Leitemo (2009)	LR	1983-01-01	2002-12-31	Effective FF	-9.00	3.40	
Furlanetto (2011)	H	1988-01-01	2003-12-31	3-mth T-bill		0.78	p. 104.
		2003-03-01	2007-07-31			0.18	p. 105.
D'Amico and Farka (2011)	ES	1994-01-01	2006-09-30	FFF1	-5.11	1.85	pp. 132-133.
Galí and Gambetti (2015)	SR	1960-Q1	2011-Q4	Effective FF	-5.00, -1.00		p. 247.
Aastveit et al. (2017)	SR	1975-Q2	2008-Q4	Effective FF		-0.25, 2.00	p. 21
Gu et al. (2018)	ES	2012-01	2016-12	8-quarter ED	-4.32		p. 5.
Nakamura and Steinsson (2018)	H	1995-01-01	2014-04-01	2-year forward	-6.50		p. 1322.
Paul (2020)	ES	1988-11	2017-09	FFF1	-5.20, -3.80		p. 35.
Alessi and Kerssenfischer (2019)	ES	1976-06	2017-12	2-year T-bond	-0.28[4]		p. 665.
Jarociński and Karadi (2020)	Sign R	1990-02	2016-12	3-mth FFF	-17.30, -3.83		p. 13.
M. D. Bauer and Swanson (2020)	ES	1990-02	2007-06	FFF1	-4.24		p. 26.
M. D. Bauer and Swanson (2020)	ES	1990-02	2019-06	PCA	-7.82		p. 26.
Kurov et al. (2022)	H	1997-10	2019-12	ED	-7.4	0.68	p. 9, 14.
PANEL B: $gen\text{-}\tilde{S}$ 85% confidence intervals							
Before ELB		1989-01-01	2008-12-15	FFF1	[-7.60, -1.60]	[0.25, 1.75]	
During ELB		2008-12-16	2015-12-15	PCA	[-1.00, 16]	[-1, 0.10]	
After ELB		2015-12-16	2020-03-14	FFF1	[-6.40, 0.40]	[-0.10, 0.30]	

[1]H: heteroskedasticity, ES: event study, LR: long-run restrictions, SR: short-run restrictions, Sign R: sign restrictions

[2]ED: Eurodollar future, FFF1: front-month fed fund futures, FF: Fed funds.

[3]Response to a 1 percentage point change in the variable. For time-varying models, the minimum and maximum are reported.

[4]The coefficients for the S&P 500 divided by the respective fed funds future response from the same table.

'90s and 2000s due to the near collapse of Long-Term Capital Management, the tech bust in the stock market, and the 9/11 terrorist attacks. Although positive, we find β to be lower than in Rigobon and Sack (2003) and Bjørnland and Leitemo (2009), whose samples end around 2000. The magnitude of our response is similar to those in Furlanetto (2011) and Aastveit et al. (2017), with samples ending around 2008. Our lower β for the period 1989-2008 is compatible with a shift in the monetary policy reaction function over the period 2003 to 2007, as argued by Furlanetto (2011). Similarly, using a time-varying model, Aastveit et al. (2017) reveal a reduction in β since the 1990s. Note that we still estimate $\beta > 0$ when our sample starts in 1994 implying that the FOMC response to stock prices is not only the result of the market crashes of the 80's. Finally, in this period, we find that increment in the policy rate increases the expected equity premium ($\eta > 0$) which coincides with Bianchi et al. (2022) who find a positive commovement between the real interest rate and their measure of equity premium derived from a forecasting equation. They argue that this positive commitment it's driven by shifts in investors' perception of the conduct of monetary policy, even if monetary policy is unchanged.

During the ELB period, our (projected) confidence interval for α lies mostly on the positive side which α is not in line with the negative values estimates of this parameter, as reported in Nakamura and Steinsson (2018), Gu et al. (2018), and, more recently, M. D. Bauer and Swanson (2020). Although these studies do not specifically study the ELB period, the drastic change in α warrants caution in lumping this period with others with no bidding ELB. We can uncover this change in α since we do not restrict α to be negative[24] and use information outside the monetary policy announcement, in contrast to event-study identification as in Paul (2020) and M. D. Bauer and Swanson (2020). Using all-trading days allows us to capture changes in monetary policy expectations outside meeting days and, thus, avoid missing events in event studies.

Three hypotheses can explain the positive values of α since the ELB period: the Fed information effect, a rational bubble, and expected deflation. The Fed information hypothesis, initially proposed by C. D. Romer and Romer (2000), assumes a monetary

[24] See Jarociński and Karadi (2020)

authority that has more information than the market about the state of the economy. A monetary tightening could signal to private investors that the economy is strong enough to withstand a higher policy instrument and, therefore, raise expectations about future growth, profits, and inflation; see also Lakdawala (2019). Symmetrically, lowering the rate signals weaker economic conditions ahead and hence lower future earnings. Nakamura and Steinsson (2018) remark that "Recent discussions of monetary policy have noted the Fed's reluctance to lower interest rates for fear it might engender pessimistic expectations that would fight against its goal of stimulating the economy." They use this hypothesis to explain their finding that during the GFC, an increase in the real interest rate is followed by a rise in output forecasts.[25] Another literature in line with the Fed information effect argues that what prompts the market to update its expectation for growth it is not the central bank action but the information released as an argument for the action. Hansen et al. (2020) develop a theoretical model in which the central bank produces a more precise forecast of economic activity than the market. When that information is released, private investors update their estimates of economic activity, and that, in turn, can affect expectations of long-run interest rates. Cieslak and Schrimpf (2019) document that around 30% of FOMC announcements feature a positive and significant stock and policy rate co-movement. They argue this is due to news about economic growth which are embedded in the announcement.[26] An information shock, conveyed either through central bank communication or actions, drives a positive co-movement between the policy rate and returns, that is, $\alpha > 0$. Jarociński and Karadi (2020) and Breitenlechner et al. (2021) impose this positive co-movement using sign restrictions on a SVAR to separately identify the conventional policy shock from the information shock. Our results stem from the combination of both shocks and hence, under the Fed information hypothesis, our $\alpha > 0$ is interpreted as an information shock that is greater than the policy shock.

A second hypothesis is the presence of a rational stock market bubble that would increase stock market prices with increases in the policy instrument as in Galí (2014).

[25]See also M. D. Bauer and Swanson (2020) for a critique of Nakamura and Steinsson (2018) results about the effect of policy shocks on private forecasts.

[26]See also Boehm and Kroner (2021) who link the unexplained variation of stock returns on event days to the text in the announcement.

In this model, the response α is decomposed into two parts: a fundamental component and a bubble, rendering $\alpha = \alpha^F + \alpha^B$. Galí and Gambetti (2015) estimate $\alpha^B > 0$ and $\alpha \approx 0$ towards the end of their sample, see Table 2. These results crucially hinge upon the value of β, which is assumed to be zero. We, on the other hand, estimate β to be around zero, and $\alpha > 0$ since the ELB, suggesting that $\alpha^B > \alpha^F$ in this period. Notably, when Galí and Gambetti assume $\beta > 0$, their results are reversed, with $\alpha^B < 0$ and α moving towards negative territory. This coincides with our pre-ELB results, where $\alpha < 0$ is estimated along with $\beta > 0$.

The last hypothesis is about the efficacy of monetary policy at the ELB period. As the policy instrument approaches its lower bound, the central bank has limited space to influence the price level through conventional monetary policy and, therefore, to avoid a recession (Brassil et al., 2022). This should reflect in lower equity prices. Additionally, inflation innovations are interpreted as a signal of future economic activity (Perras & Wagner, 2020). David and Veronesi (2013), for instance, develop a model in which investors expectation of revenue growth depend on the level of inflation and its innovations. In a low-inflation environment, a lower than expected inflation figure signals weaker revenue growth.[27] In our context, in a low-policy-rate environment a reduction in the policy rate signals weaker-than-expected economic conditions.

Finally, we find mostly a negative reaction of the FOMC to an increase in returns during the ELB period, and no clear direction in the FOMC's reaction after the ELB period, despite FOMC's concerns about stock prices (Cieslak & Vissing-Jorgensen, 2020). During the ELB period, an ineffective UMP could explain this result. In this period, the policy rate measure is the first-component of a PCA with short and medium-term future contracts. If UMP was ineffective in persistently driving down yields on these futures, we should observe no reaction of our policy measure to stock prices. The evidence on the effectiveness of UMP in lowering yields, however, is not conclusive. On the one hand, Greenlaw et al. (2018), in an event-study setting, find limited effect of monetary policy

[27] While before the ELB period the average expected inflation has been around 2.9%, since the ELB expected inflation has been around 1.7%, which is below the target. See information about inflation expectations at the Federal Reserve Bank of Cleveland - https://www.clevelandfed.org/our-research/indicators-and-data/inflation-expectations.aspx.

at the ELB. On the other hand, Inoue and Rossi (2019), for instance, argue that UMP is as powerful as conventional monetary policy using a combination of event study and a redefinition of monetary shocks as a shift in a function instead of a random variable.[28]

A striking result in this period is that the expected equity premium increases pari pasu with the interest rate; in fact, we reject any negative value for η. This is the opposite as predicted by theoretical models on the influence of monetary policy shocks on the equity premium like Kekre and Lenel (2022) and Pflueger and Rinaldi (2022). Since this period is characterised by the normalisation of the monetary policy, we suspect this result is related to a reduction in deflationary risk as the interest rate moves up from zero while inflation is picking up, see Cieslak and Pflueger (2023) for a distinction between "good" and "bad" inflation for asset prices. We left this question as a future avenue for research.

6.1 Ignoring the effect on the expected equity premium

Since Rigobon and Sack (2004) many authors have relied on a 2-equation representation (Kurov et al., 2022; Nakamura & Steinsson, 2018). We find that this representation confounds the effect of monetary policy on the expected equity premium as a monetary policy shock leading to a positive α.

The structural model is

$$\begin{cases} \Delta i_t = \beta s_t + \gamma z_t + \epsilon_{i,t} & \text{(13a)} \\ s_t = \alpha \Delta i_t + z_t + \epsilon_{s,t} & \text{(13b)} \end{cases}$$

where z_t is an unobservable common shock intended to capture shocks that drive a correlation between the interest rate and stock returns. For example, if there is an increment in an investor's risk aversion, the equity premium goes up, returns fall and the market interest rate goes up as investors fly to quality. The variance of the common shock is assumed to be constant.

In matrix form the model is $A\boldsymbol{y}_t = \boldsymbol{b}\boldsymbol{z}_t + \boldsymbol{\epsilon}_t$ with Σ, the (2×2) structural covariance matrix Σ and reduced-form covariance matrix Ω. The moment conditions are given by

[28] For an updated meta-analysis on the effectiveness of UMP, see Fabo et al. (2021).

$A\Omega A' - \Sigma$ where the off-diagonal element is

$$f_t(\boldsymbol{\theta}) = (1 + \alpha\beta)\omega_{is,t} - \alpha\omega_{i,t} - \beta\omega_{s,t} - \lambda \tag{14}$$

where $\lambda \equiv \gamma\,\mathbb{V}\text{ar}(z_t)$. As in our baseline model, we focus on this moment condition because the unobservable structural variances $\mathbb{V}\text{ar}(\epsilon_{i,t})$ and $\mathbb{V}\text{ar}(\epsilon_{s,t})$ are absent.

The confidence sets from the bivariate representation appear in Figure 2. While the sets before and during the ELB agree with the 3-equation SVAR, the set after the ELB is notoriously different. The set after the ELB implies that keeping constant the EEP, stock returns increase when the policy rate does. From the 3-equation model, we can write $s_t = (\alpha + \chi\eta)\Delta i_t \ldots$ by replacing the EEP equation (2c) into the stock returns equation (2b). Whenever $\eta \neq 0$ the bivariate specification confounds the effect of monetary policy on realised returns with the effect on expected future returns. If monetary policy affects the quantity or the price of risk in the economy, $\eta \neq 0$.

6.2 Comparison with event-study results

In the event-study approach, a change in the interest rate around the time of the policy announcement is the monetary shock $\epsilon_{i,t}$. Since this change is unexpected, it is labelled as the monetary policy surprise. Therefore, one can identify α by regressing returns on monetary policy surprises (and controls) using only observations corresponding to FOMC meeting days.

We investigate whether the monetary policy surprises on event days are the monetary policy shocks ε. If the surprise series were the monetary policy shocks, including the surprises as a variable in the VAR in $\boldsymbol{x}_t$ would undermine the identification of α resulting in a larger confidence set. When the surprises are the structural shocks the residuals $\hat{u}_{i,t}, \hat{u}_{s,t}$ from a VAR that controls for them become white noise and contain no useful information to pin down the structural parameters On the other hand, if the surprises are not the monetary policy shocks but white noise, whether controlling for them or not, the confidence set should remain unchanged.

Before ELB (1989-2008)	During ELB (2008-2015)	After ELB (2015 to 2020-03)

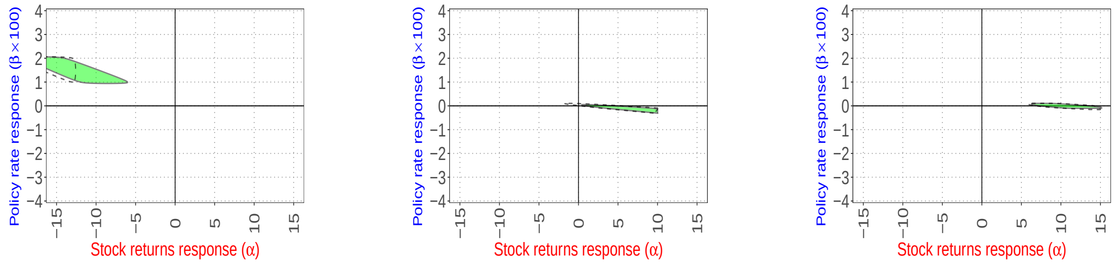


Figure 2: CONFIDENCE SETS USING A BIVARIATE SVAR. *gen*-$\widetilde{S}$ confidence sets for the reaction of stock returns to monetary policy shock (α) and the reaction of monetary policy to stock returns (β). The confidence level is 85% for the green area and 90% for the dashed area.

We build the surprise series on event days using intraday data of the baseline policy rates, following Gertler and Karadi (2015) and Nakamura and Steinsson (2018). Using data available since 1996, we compute surprises on event days for both policy rates, the front-month fed fund future and the PCA rate. Outside FOMC meeting days, surprises are set to zero. Outside the ELB period the surprise variable corresponds to the change in the front-month fed fund future which is included as a control variable in $\boldsymbol{x}_t$ in the baseline specification; during the ELB period, the surprise variable is the change in the PCA rate.[29]

Results are reported in Figure 3 where the top panel A shows the sets when including the surprises series as a contemporaneous regressor, while the baseline specification sets starting in 1996 are reported in the lower panel B.

Before the ELB period, the confidence sets on the top and lower panels are markedly different. The baseline set in the lower panel covers mainly the first quadrant, indicating that monetary policy shocks negatively affect stock returns, and an increase in returns triggers a contractionary monetary policy. The confidence set after controlling by the surprise variable in the top panel is instead unbounded along both parameters. This means that the reactions become unidentifiable after controlling for the surprises. The introduction of the surprises brings a reduction in the heteroskedasticity of the reduced-

[29]Section 10.2.3 in the Appendix for details.

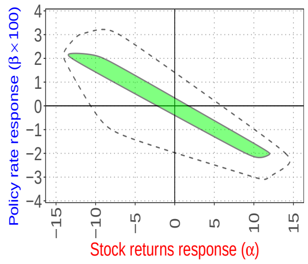
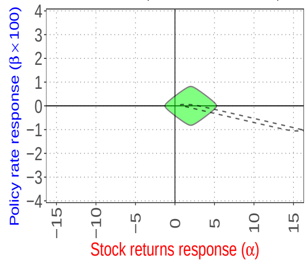
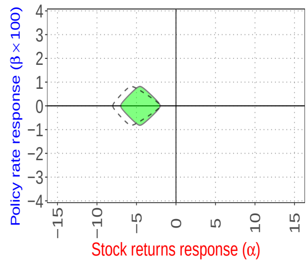
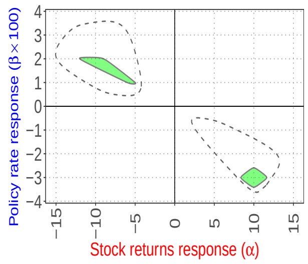
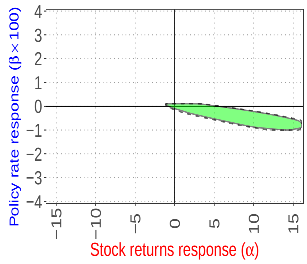
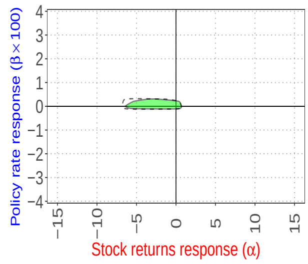
	Before ELB (1996-2008)	During ELB (2008-2015)	After ELB (2015 to 2020-03)
		Panel A: Monetary policy surprises	
	TODO: I'm still computing better pictures (finer grid) for the results with the monetary surprises		
			
χ	-1	-1	-1
η	[-19, -14] ∪ [-10, -7] ∪ [10, 20]	-3	[-19, -9]
		Panel B: Baseline	
			
χ	-1	[-1.2, -0.7]	[-1.3, -0.6]
η	-20 ∪ [4, 6] ∪ [10, 17]	[-20, 0]	[-17.4, -4.6]

Figure 3: MONETARY POLICY SURPRISES. The qLL-$\widetilde{S}$ 90% confidence sets for the reaction of stock returns to monetary policy shock (α) and the reaction of monetary policy to stock returns (β). The policy instrument is the daily change in the current-month fed funds future rate adjusted by Kuttner (2001) factors outside the ELB period and the PCA rate during the ELB period. The stock return is the daily return on the S&P 500 Index. Before ELB:1996-01-01 to 2008-12-15. During ELB: 2008-12-16 to 2015-12-15. After ELB: 2015-12-16 to 2020-03-14.

form residuals, see equation (7), affecting the power of the qLL-$\widetilde{S}$ test.[30]

Since the ELB, nevertheless, the confidence sets on the top and lower panels are almost indistinguishable from each other. Therefore monetary policy surprises are relatively irrelevant to pin down the structural parameters. These surprises have been shown to have low explanatory power for returns (Boehm & Kroner, 2021) and macroeconomic variables (Tchatoka & Haque, 2021). Quantitative easing (QE) and forward guidance could explain the irrelevance of monetary policy surprises. For example, some QE events

[30]The reduced-form variances ω_{ii}, ω_{is}, and ω_{ss} are functions of both monetary policy and equity returns variances, σ_ε^2 and σ_η^2 respectively. Including monetary policy surprises leaves the reduced-form variances only as a function of σ_η^2.

took place outside FOMC meetings; see Cieslak and Schrimpf (2019) and Rossi (2020) for an extensive review of UMP shock identification.

Taken together, the results suggest that only before the ELB period, monetary policy surprises on FOMC meeting days are informative about the reaction of the stock market to monetary policy changes.

Surprises have likely became less informative about structural parameters in later periods as the FOMC increased its transparency of monetary policy. Greater transparency made monetary decisions well-known in advance of the policy announcement, reducing the relevance and size of surprises. Figure 4 documents a downward trend in the absolute value of the surprise on event days which occurs almost concomitant with changes in the FOMC communication that increased transparency. Transparency in the conduct of monetary policy undermines event-study identification.

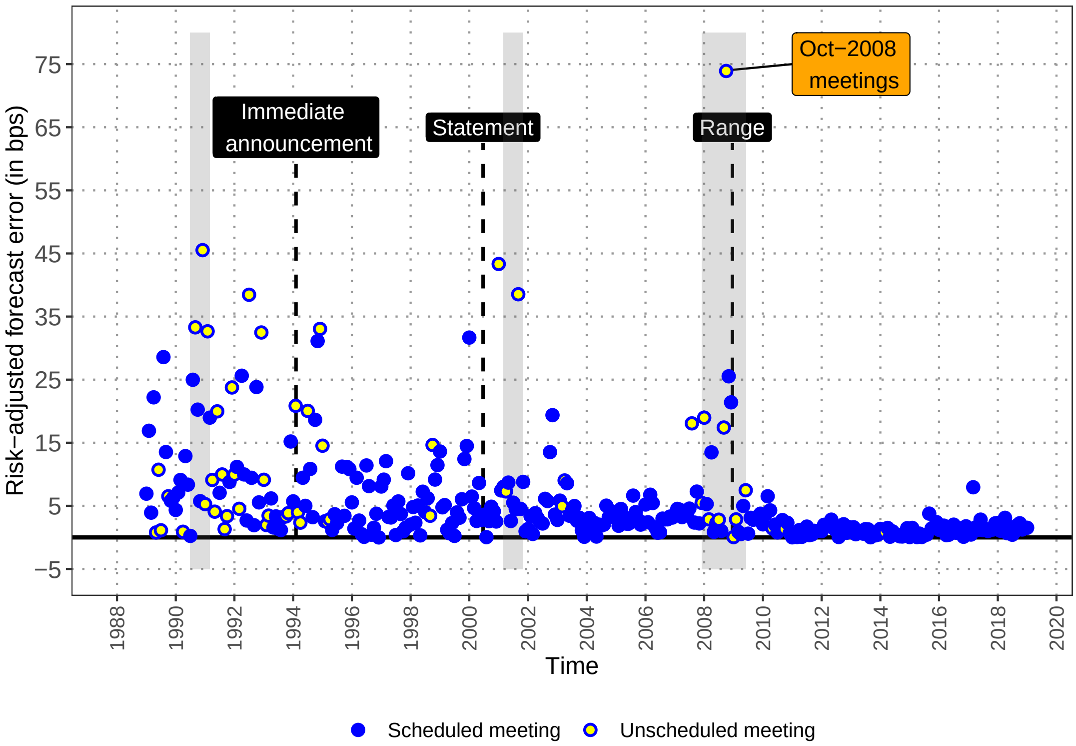
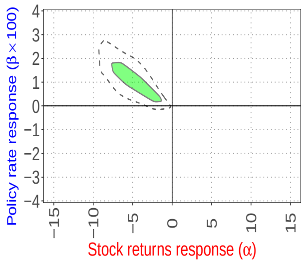
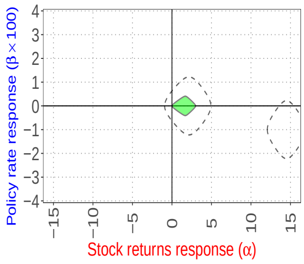
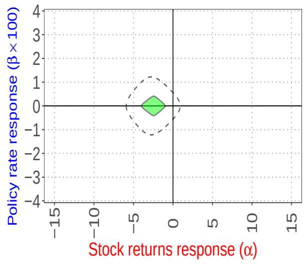
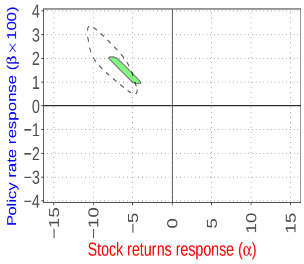
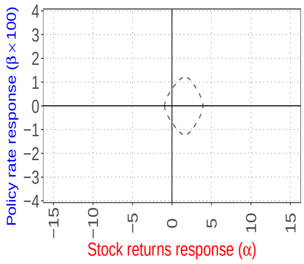
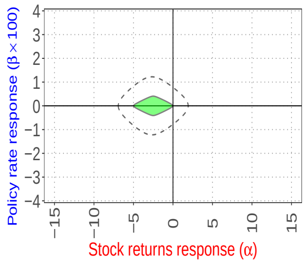


Figure 4: Downward trend in the size of monetary policy surprises on the policy announcement day and changes in the FOMC communication. Transparency in the conduct of monetary policy makes monetary decisions on FOMC meeting days more predictable and the surprises computed those days less useful in identifying the responses.

7 ROBUSTNESS ANALYSIS

We consider several robust exercises by departing from the baseline specification: consider alternative proxies for the equity returns and policy rates, use the reduced-form VAR with 30 lags, and add more control variables (which only became available after 1999). Generally, the results support the decrease in the FOMC's response to stock returns after the GFC and, since the ELB, and the change in the direction of the response of expected equity premium to a monetary policy shock.

	Before ELB (1989-2008)	During ELB (2008-2015)	After ELB (2015 to 2020-03)
		Panel B: Wilshire 5000	
			
χ	[-1.2, -0.6]	-1	-1
η	[2, 9]	[-20] ∪ [-7, -5] ∪ [-3, 0]	[-14, -7]
		Panel C: VAR(30)	
			
χ	[-1]	-1[a]	-1
η	[3, 5]	[-3, 1][a]	[-10, -2]

[a] At 95% confidence level.

Figure 5: ROBUSTNESS ANALYSIS. The *gen-*$\widetilde{S}$ confidence sets for the reaction of stock returns to monetary policy shock (α) and the reaction of monetary policy to stock returns (β). Panel A uses the daily return on the Wilshire 5000 Total market return index. Panel B estimates the reduced-form VAR with 30 lags. In this case, results for the during ELB period are at 95% confidence. Before ELB: 1989-01-01 to 2008-12-15, During ELB: 2008-12-16 to 2015-12-15, After ELB: 2015-12-16 to 2020-03-14.

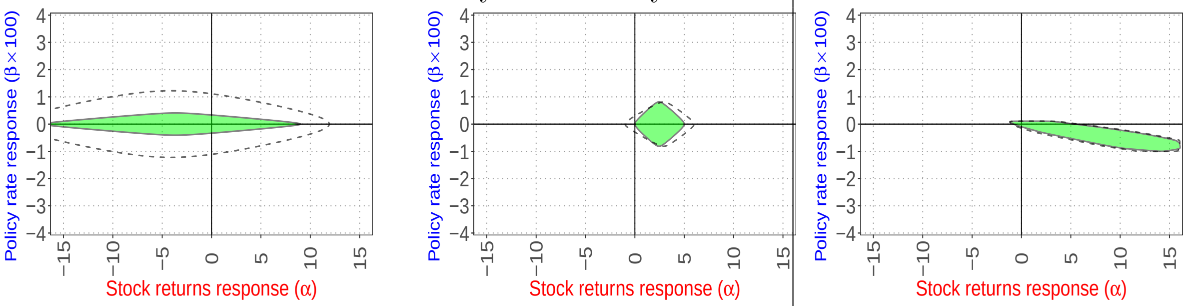
Alternative proxy for equity returns We replace the S&P 500 index with the Wilshire 5000 total index, when computing the stock market returns proxy, keeping the same policy instrument and controls used in the baseline specification. The Wilshire index includes reinvested dividends and more firms than the S&P 500 index. Confidence sets using the Wilshire index appear in Panel B of Figure 5. These sets are almost the same as the baseline ones in Panel D.

VAR lags We re-estimate the confidence sets using the reduced-form model in (12) with 30 lags which is equal to a 6-week trade, the average time between FOMC meetings. This allows economic agents to incorporate not only the information available in the week before a monetary policy decision but also all the information between FOMC meetings. Panel C of Figure 5 shows the confidence sets based on the VAR with 30 lags, while the sets from the baseline specification with 5 lags appear in Panel D. The VAR(30) confidence sets retain their shape and location across subperiods when compared to VAR(5) sets. This similarity is not surprising given the high-frequency monetary reaction function in (2a): in efficient markets, asset prices quickly incorporate all the available information and, hence, 5 days seems to be enough time for the market to form expectations about monetary policy changes.

Alternative proxies for policy rates We consider tow alternative measures of the policy rate: the current-month fed funds future rate and the yield on the 1-year constant maturity US Treasury bond as in Lakdawala (2019) and Kekre and Lenel (2022) We present the confidence sets only for the ELB period when unconventional monetary policies (UMP) were adopted in Figure 6.

The confidence set obtained using the fed fund rate as monetary policy is tightly centred around zero for β, representing no response of the FOMC to stock returns, together with an unidentified effect of monetary policy on stock returns, denoted by the unbounded confidence set along the horizontal axis. This result is expected since the fed fund future was constrained in this period, illustrating the limitation of this short-term

	During ELB		
	Fed fund future	1-year Treasury bond	Baseline



	Fed fund future	1-year Treasury bond	Baseline
χ	-1	-1	[-1.2, -0.7]
η	[-20, 20]	[-11, -2]	[-20, 0]

Figure 6: USING ALTERNATIVE POLICY INSTRUMENTS DURING ELB. The *GEN-*$\widetilde{S}$ 90% and 85% confidence sets for the reaction of stock returns to monetary policy shock (α) and the reaction of monetary policy to stock returns (β). The stock return is the daily return on the S&P 500 Index. During ELB: 2008-12-16 to 2015-12-15.

rate to proxy monetary policy expectations when UMP is in place.[31] The 1-year Treasury bond confidence set qualitatively reproduces baseline findings: a monetary contraction increases stock returns and monetary policy may not react to stock prices.

Additional controls Asset prices may not reflect their fundamental value but their illiquidity in days when trade is sparse due to high transaction costs (Gibson & Mougeot, 2004). We build two proxies for liquidity: one based on the front-month Fed fund future market and the other based on the front-month CBOE E-mini S&P 500 Index future market.[32] Since liquidity itself can be affected by monetary policy announcements, we include lagged values of both liquidity measures as control variables in the reduced-form VAR. We also include lagged values of daily inflation compensation from the Fed NY based on Gürkaynak et al. (2010)'s model for the Treasury inflation-protected securities (TIPS). Adding lagged inflation expectations purges returns and the interest rate from predictable changes due to revisions to expected inflation. Panel A of Figure 7 contains the results, including these additional controls, which became available from 1999 onward.

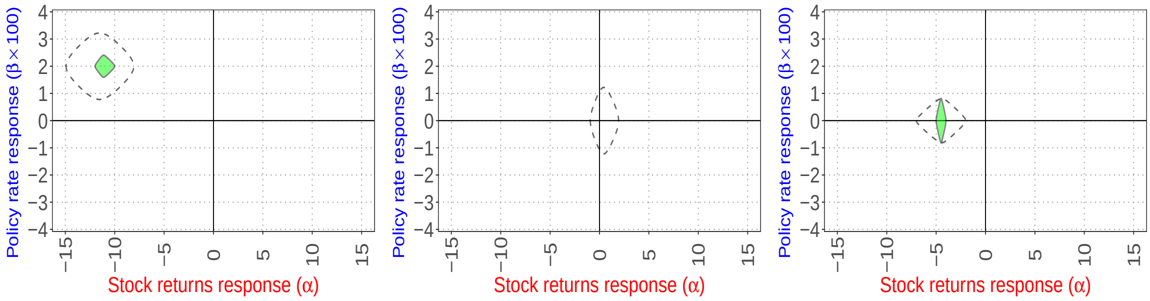
[31]Conversely, when conventional monetary policy is in place, the PCA rate becomes an inappropriate measure. Indeed, outside the ELB period, we find empty sets when the PCA rate is used as a policy instrument.

[32]Section 10.2.1 in the Appendix details the construction of the liquidity proxies.

Therefore, to facilitate comparison, Panel B replicates the baseline specification sets using the same subperiod before the ELB.

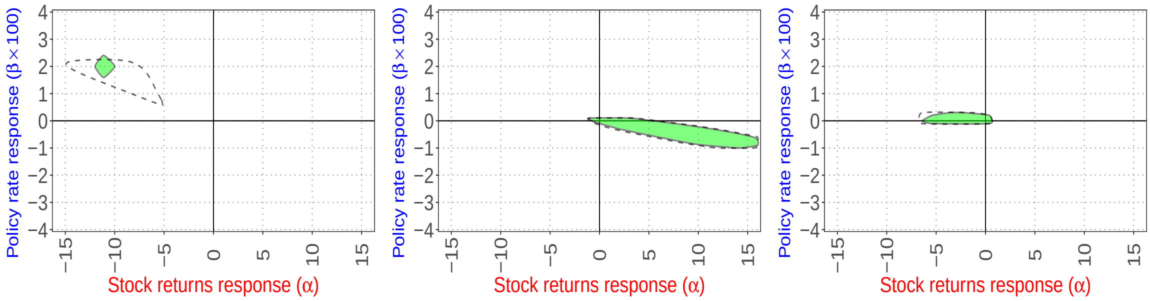
	Before ELB (1999-2008)	During ELB (2008-2015)	After ELB (2015 to 2020-03)

Panel A: Liquidity measures and inflation compensation



	Before ELB	During ELB	After ELB
χ	[-1]	[-1][a]	[-1]
η	[12, 18]	[-5, -2][a]	[-16, -7]

Panel B: Baseline



	Before ELB	During ELB	After ELB
χ	[-1]	[-1.2, -0.7]	[-1.3, -0.6]
η	[12, 18]	[-20, 0]	[-17.4, -4.6]

[a] At 95% confidence level.

Figure 7: INCLUSION OF LIQUIDITY MEASURES AND INFLATION COMPENSATION. The *gen*-$\widetilde{S}$ confidence sets for the reaction of stock returns to monetary policy shock (α) and the reaction of monetary policy to stock returns (β). The policy instrument is the daily change in the current-month fed funds future rate adjusted by Kuttner (2001) factors outside the ELB period, whereas it is the first component of the PCA rate during ELB period. The stock return is the daily return on the S&P 500 Index. Refer to the text about the two liquidity measures and inflation compensation. Before ELB: 1999-01-09 to 2008-12-15, During ELB: 2008-12-16 to 2015-12-15, After ELB: 2015-12-16 to 2020-03-14.

For the before-ELB period most of the area of the set covers positive values of β and negative values of α, which is in line with the baseline set. The set for during the ELB shrinks and it is empty at 90% confidence, we report the 95% confidence set. The remaining period retains its baseline location altough is smaller along α. and shapes.

Overall, the inclusion of these controls barely changes the location of the confidence sets except in the case of during the ELB subsample.

Alternative subperiods We investigate two other subperiods. The first one, started in February 1994, refers to the change in the communication scheme of the FOMC. In the new scheme, the FOMC releases an immediate announcement every time the target rate is modified. Before 1994 the opacity of monetary policy decisions led to a volatile fed funds market.[33] The second subperiod ends on the 1^{st} December 2019, that is, before the onset of the covid.[34] . Figure 8 shows the confidence sets of these alternative subperiods.

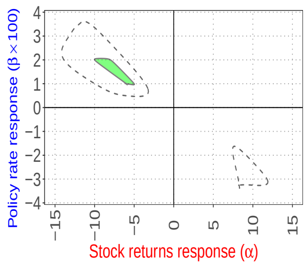
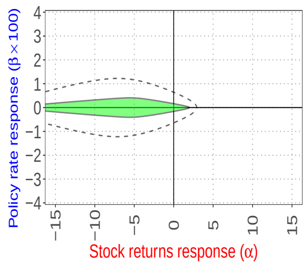
	FOMC Immediate Announcement (1994-2008)	Before COVID (2015-2019)
		
χ	-1	[-11, -1]
η	[4, 6] $\cup$ [8, 13]	[-8, -1]

Figure 8: ALTERNATIVE SUBPERIODS. The *gen*-$\widetilde{S}$ 85% and 90% confidence sets for the reaction of stock returns to monetary policy shock (α) and the reaction of monetary policy to stock returns (β). The policy instrument is the daily change in the current-month fed funds future rate adjusted by Kuttner (2001) factors outside the ELB period. The stock return is the daily return on the S&P 500 Index. FOMC immediate announcement: 1994-02-05 to 2008-12-15. Before covid period: 2015-12-16 to 2019-12-01.

Although the size and the shape of the confidence sets differ from the baseline one, they retain their location, corroborating the previous results: in the pre-ELB period, the stock market reacts negatively to a monetary tightening, and the FOMC raises the policy instrument when confronted with increases in stock returns. In the case of the subsample before covid the interval for χ becomes large even tough it only contains negative values.

[33]See Lindsey (2003, p. 163) for a history of FOMC communication describing the immediate announcement, and Poole et al. (2002) for an empirical analysis of the implications that this change has for event-study identification.

[34]On the 12^{th} December 2019 a cluster of patients in China's Hubei Province, in the city of Wuhan, begin to experience the symptoms of an atypical pneumonia-like illness that does not respond well to standard treatments.

When we fix χ to be close to 1, the 85% confidence interval for α shrinks to [-4, 2] in line with baseline results.

8 CONCLUSION

We study the interdependence of US monetary policy and equity prices without restricting the analysis to days of monetary policy announcements. We jointly estimate the effect of monetary policy on stock returns and the equity preimum as well as the effect of stock returns on FOMC decisions. We do so by fully exploring the heterogeneity of the monetary policy and stock return shocks. Our method is agnostic about the direction of these effects and robust with respect to time-varying parameters.

A 100bps increment in the policy rate depresses stock returns by about 1% to 7%, outside the period of the effective lower bound (ELB) on interest rates (2008-2015).

We evidence that monetary policy influences the expected equity premium tough this influence has changed since 2015. Between 1989 and 2015, increments in the policy rate increased the equity premium amplifying the depressing effect of monetary policy on the economy; after 2015 we find the opposite such that increments in the policy rate reduce the expected equity premium, dampening the effect of monetary policy. We left as a future area of research the mechanisms for this shift.

Finally, we only find evidence of the "Fed put" before 2015. In this period, we estimate that the FOMC reacted to a surge in stock prices by increasing the policy rate. Since then, however, this reaction changed: the monetary policy rate does not react to equity returns. Our results are robust to different measures of the policy instrument and stock returns, the inclusion of intraday monetary surprises, movements in the equity premium, alternative subperiods and time-varying parameters.

APPENDIX

Supplement to "The (in)stability of stock returns and monetary policy interdependence in the US"

9 Computational details

9.1 Grid search

When conducting the grid search over the 4-dimensional parameter space we set the boundaries in the grid as per Table 3. Note that in the Results section, the parameter β is reported scaled by 100.

Parameter	Minimum	Maximum
α	-20	20
β	-0.030	0.030
χ	-20	20
η	-20	20

Table 3: PROPERTIES OF THE PARAMETER SPACE.

9.2 Procedure for calculating the *gen*-S statistic

This section outlines the calculation of the *gen*-$\widetilde{S}$ statistic used to build the confidence sets. The SVAR system is

$$A_0 \mathbf{y}_t = \sum_{j=1}^{p} A_j \mathbf{y}_{t-1} + B\mathbf{x}_t + \boldsymbol{\epsilon}_t \tag{15}$$

with $A = [1, -\beta, 0 : -\alpha, 1, -\chi \ : \ -\eta, 0, 1]$, $\mathbf{y}_t = [\Delta i_t, s_t, \Delta e_t]'$, B is a (3×3) matrix of parameters and $\boldsymbol{\epsilon}_t = [\epsilon_{i,t}, \epsilon_{s,t}, \epsilon_{e,t}]'$ the structural shocks. Define $\boldsymbol{\theta} \equiv [\alpha, \beta, \chi, \eta]$, our interest lies in testing

$$H_0 : \boldsymbol{\theta} = \boldsymbol{\theta_0} \text{ against } \boldsymbol{\theta} \neq \boldsymbol{\theta_0}.$$

The required confidence region is the collection of points $\boldsymbol{\theta}$ that do not reject the above null hypothesis. In order to calculate the *gen*-S test for a given $\boldsymbol{\theta_0}$, the following steps are taken.

Let k denote the number of moment conditions, $\mathbf{f}_t$ the $(k \times 1)$ vector of the value of the moment conditions under the null in period t and $A^{1/2}$ denotes the symmetric square root of a positive definite matrix A. Let the $(k \times k)$ matrix $\widehat{V}_{ff}(\boldsymbol{\theta}_0)$ be the HAC estimate of the variance-covariance matrix of the moment conditions under the null. We use the estimator of Newey and West (1987) with automatic bandwidth selection as described in Newey and West (1994).

1. Estimate the residuals of the reduced-form VAR derived from SVAR (15) as in equation (12). Let $\{\hat{u}_{i,t}, \hat{u}_{s,t}, \hat{u}_{e,t}\}_{t=1}^{T}$ be a sequence of such residuals.

2. Generate the values of the moment conditions under the null by fixing the structural parameter at the candidate values $\boldsymbol{\theta}_0$ as in (6) in the main text at time t, such that

$$\boldsymbol{f}_t(\boldsymbol{\theta_0}) = \begin{bmatrix} \omega_{is,t} - \beta_0\omega_{ss,t} - \alpha_0(\omega_{ii,t} - \beta_0\omega_{si,t}) - \chi_0(\omega_{ie,t} - \beta_0\omega_{se,t}) \\ \omega_{ie,t} - \beta_0\omega_{se,t} - \eta_0\omega_{ii,t} + \eta_0\beta_0\omega_{si,t} \\ \omega_{se,t} - \alpha_0\omega_{ie,t} - \chi_0\omega_{ee,t} + \eta_0\left(\alpha_0\omega_{ii,t} - \omega_{is,t} + \chi_0\omega_{ie,t}\right) \end{bmatrix}. \tag{16}$$

where the ωs are defined in equation (5) of the main text and are functions of the residuals.

3. Compute the $S(\boldsymbol{\theta_0})$ statistic as

$$S(\boldsymbol{\theta}_0) = \frac{1}{T}\left[T^{-1}\sum_{t=1}^{T}\boldsymbol{f}_t(\boldsymbol{\theta}_0)\right]' \hat{V}_{ff}(\boldsymbol{\theta}_0)^{-1}\left[T^{-1}\sum_{t=1}^{T}\boldsymbol{f}_t(\boldsymbol{\theta}_0)\right]. \tag{17}$$

4. Compute $\mathbf{v}_t = \widehat{V}_{ff}(\theta_0)^{-1/2}\mathbf{f}_t(\theta_0)$. Denote the ith element by $v_{i,t}$, $i = 1, \ldots, k$.

5. For $i = 1, \ldots, k$, generate the series $\{w_{i,t}\}_{t=1}^{T}$ as $w_{i,1} = v_{i,1}$ and $w_{i,t} = \tilde{r}w_{i,t-1} + \Delta v_{i,t}$, for $t = 2, \ldots, T$, with $\tilde{r} = 1 - \frac{10}{T}$.

6. Regress $\{w_{i,t}\}_{t=1}^{T}$ on $\{\tilde{r}^t\}_{t=1}^{T}$ and obtain the squared residuals, sum over all $i = 1, \ldots, k$, and multiply by $\tilde{r}$.

7. Compute $\sum_{i=1}^{k}\sum_{t=1}^{T}(v_{i,t}-\bar{v}_i)^2$, where $\bar{v}_i = T^{-1}\sum_{t=1}^{T} v_{i,t}$, and subtract the quantity in step 6 from it to get $qLL\text{-}\widetilde{S}_T(\boldsymbol{\theta_0})$.

8. Compute *gen*-S using the formula

$$gen\text{-}S(\boldsymbol{\theta}_0) = qLL\text{-}\widetilde{S}(\boldsymbol{\theta}_0) + \frac{10}{11}S(\boldsymbol{\theta}_0). \tag{18}$$

9. Determine if the calculated value of *gen*-S($\boldsymbol{\theta}_0$) is less than the critical value at the 10% level of significance. If so, the value of $(\alpha_0, \beta_0, \chi_0, \eta_0)$ belongs to the 90% confidence set. The corresponding critical value at the 10% significance level and when no parameter is estimated under the null is 21.8 for $k = 3$ while it is 8.59 for $k = 1$, see Table S.I from the Appendix in Magnusson and Mavroeidis (2014).

10 Data

10.1 Data sources

- ***Policy rate expectations***

  Fed funds futures. Bloomberg. Ticker code: FF1, FF2.

  1-month eurodollar deposit rate. Thomson Reuters Refinitiv Eikon. RIC: USD1MFSR.

  CBOE eurodollar futures rates. Refinitiv DataScope Select. RICs: EDcm2, EDcm3, EDcm4.

  US Treasury bond rates. FRED. IDs: DGS3MO, DGS1.

  Shadow rate and effective monetary stimulus. Obtained from Leo Krippner website

- ***Stock market returns***

  S&P500. S&P500 Price index. Yahoo! Finance.

  Wilshire 5000 Price Index. Wilshire 5000 Total Market Index. FRED. Code: WILL5000PR.

Wilshire 5000 Total Market Index. Total market returns which includes reinvested dividends. FRED. Code: WILL5000IND.

- ***Risk premium***

  CBOE VIX. Implied volatility index based in S&P500 option prices. We join the series VXO and VIX rescaling the VIX as per Whaley (2008) footnote 9. Chicago Board Options Exchange.

  SVIX. Ian Martin's website

- ***Yield slope***

  10-Year rate minus 3-month US Treasury rate. 10-Year US Treasury constant maturity rate minus 3-month US Treasury constant maturity rate. FRED. Codes: T10Y3M.

- ***Risk-free rate***

  Daily risk-free rate. Obtained from Kenneth French. It is the daily rate that, over the number of trading days in the month, compounds to a 1-month T-Bill rate.

- ***Inflation expectations***

  Inflation compensation from TIPS. Obtained from Fed NY. We use the instantaneous 2-year forward inflation (BKEVENF02).

- ***Liquidity proxy***

  Intraday BID-ASK. Refinitiv DataScope Select. RICs: ESc1, FFc1.

- ***Economic activity***

  Aruoba-Diebold-Scotti (ADS) Business Conditions Index. Obtained from Fed Philadelphia (Aruoba et al., 2009).

- ***FOMC meetings time***

  Since 1994-02-04 to 2011-03-15. Obtained from Lucca and Moench (2015), Online Appendix Table IA.I.

  Since 1994-02-04 to 2011-03-15. Obtained from Lucca and Moench (2015), Online Appendix Table IA.I.

From 2011-04-27 to 2015-12-16. Factiva, timestamp from the first Down Jones newswire.

From 2016-01-27 to 2021-03-17. Fed website

- ***Intraday futures prices***

  Fed funds and eurodollar futures. RICs: FFc1, FFc4, EDcm2, EDcm3, EDcm4, EDcm5.

- ***Special days***

  Dates of flight-to-safety days. From Baele et al. (2019).

10.2 Data transformations

The **fed funds futures market slope** is defined as $Slope_t^{(ff)} = (ff_t^{(4)} - ff_{t-1}^{(4)}) - \kappa_d(ff_t^{(1)} - ff_{t-1}^{(1)})$ where $ff^{(1)}$ and $ff^{(4)}$ are, respectively, the implied rates of the front-month and the 3-month ahead future contracts (that is, the fourth contract) and κ_d is the Kuttner factor for day d in the month which adjusts the first-difference in the front-month contract, see Subsection 10.2.2 for details. [35] Finally, the spread between the 10-year U.S. bond and the 3-month U.S. Treasury bill is the measure of the **Treasure yield curve slope**.

10.2.1 Liquidity measures based on the effective spread

As a measure of market liquidity we use the effective bid-ask spread. We build a daily proxy for the effective spread using intraday data. Since we do not have access to the order book we consider the bid-ask spread at 15-minute intervals and then use the volume-weighted average of these spreads to obtain a daily measure. Let d be a 15-minute interval during day t and ES_t be the spread for day t defined as:

$$ES_t = \sum \left(\frac{\text{vol}_d}{\text{VOL}_t} \right) (2 \times |\ln P_d - \ln M_d|) \,. \tag{19}$$

[35] Note that we only scale the first-difference in the front-month contract, which is slightly different from Neuhierl and Weber (2019) and Gürkaynak et al. (2005) who are instead interested in identifying the effect of the slope separately from the level of the target rate.

The first parenthesis is the weight, given by the ratio of traded volume during interval d to total trade on day t. The second parenthesis contains the effective spread at the end of interval d where P_d is the last price at the end of the interval and M_d is the midprice, defined as the midpoint of the bid and ask at the end of the interval.[36] See Goyenko et al. (2009) for definitions of effective spreads and a review of liquidity measures and Chung and Zhang (2014) for an analysis of the bid-ask spread as an approximation to the effective spread using order book data.

We compute ES_t for the fed fund future contracts and the front-month CBOE E-mini S&P 500 future, Figure 9 plots the series for both contracts. Fed fund future data are only available since November 2003.

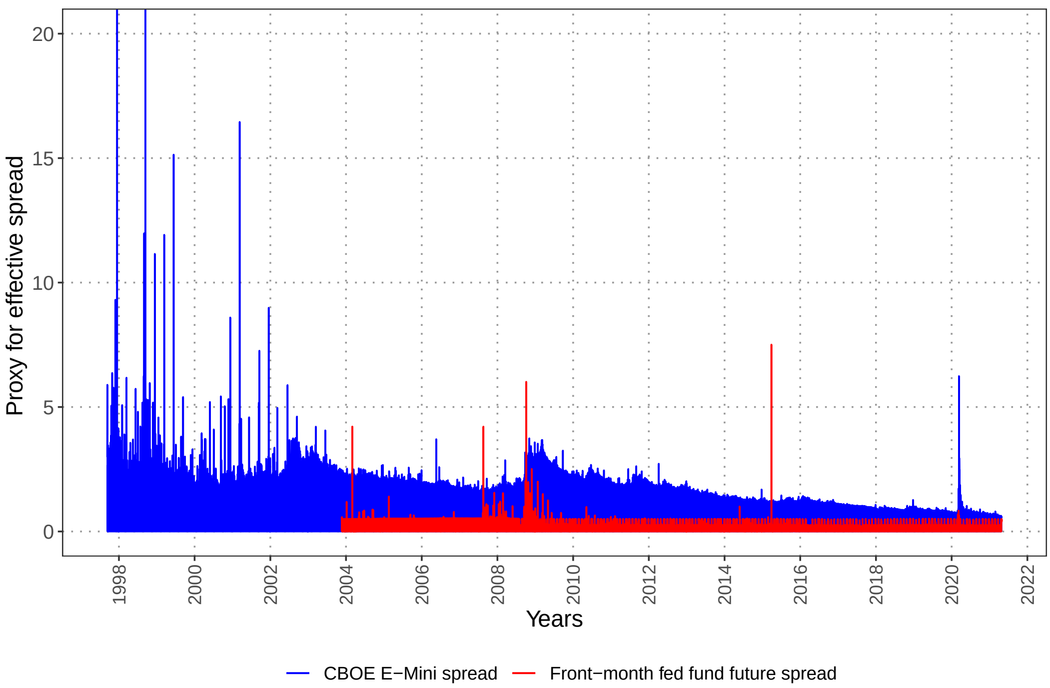


Figure 9: Proxy for effective spread using 15-minutes intervals quote data.

10.2.2 Building measures of monetary policy expectations

Our baseline measure of expectations on the policy rate are the implied rates from five future contracts. Outside the effective lower bound period, the policy rate is the adjusted change in the front-month fed fund futures (FF1). During the ELB, the policy rate is

[36]We also consider a version in which the midprice is lagged one interval.

the first component from a principal component analysis (PCA) of the daily changes in five futures: FF1, the 3-month ahead fed funds future (FF4), 1, 2 and 3 quarters ahead futures on the 3-month eurodollar deposit rate (ED2, ED3, ED4). We also use the intraday change in these measures to compute event-study shocks, see below.

Let $f_t^{(n)}$ be the implied rate for the n-future, where $n = 1, 4$ for monthly fed funds futures and $n = 2, 3, 4$ for eurodollar quarterly contracts, d the age of the contract in days and N the maturity of the contract in days. Then, for all five contracts we compute the daily change Δi_t as follows:

$$\Delta i_t = \begin{cases} f_t^{(n)} - f_{t-1}^{(n+1)} & \text{if } d = 1 \\ f_t^{(n)} - f_{t-1}^{(n)} & \text{if } d \leq 7 \\ \frac{N}{N-d}\left(f_t^{(n)} - f_{t-1}^{(n)}\right) & \text{if } d > 7 \text{ and } f_t^{(n)} = f_t^{(1)} \\ f_t^{(n+1)} - f_{t-1}^{(n+1)} & \text{if } d \geq N - 7. \end{cases} \tag{20}$$

where the third line only applies to FF1.

For a new contract ($d = 1$), the difference is computed using the previous day price of the next future, $f_{t-1}^{(n+1)}$. For "young" contracts ($d \leq 7$) the raw first-difference is used. For FF1, the difference is adjusted by the Kuttner (2001) factor $N/(N-d)$ when the contract age is greater than 7 days. Notice that the factor is equal to 1 for the 7 first observations within the month to avoid extreme weights for these observations, as in Gürkaynak (2005), Gürkaynak et al. (2005), and Nakamura and Steinsson (2018). Fed funds futures settlement price is for the *monthly* average of the effective fed funds rate. This implies that in order to obtain expectations of the effective rate, daily changes must be appropriately scaled: the same change in the future price at the beginning of the month implies a different expectation that at the end of the month when most of the uncertainty regarding the monthly average has been resolved. In particular, the variance of the future price is changing during the month, see Hamilton (2008) for a detailed description.

Finally, for all contracts, observations close to the contract maturity date ($d \geq N - 7$) are replaced by the first-difference from the closest maturity contract, that is, we rollover the contract 7 days before the last trading day. This avoid introducing spurious volatility[37]. For fed funds futures, the last trading day is the last day of the month, whereas for eurodollar contracts, it is the second London bank business day before the 3rd Wednesday of the contract month. These adjustments are similar to M. D. Bauer and Swanson (2020), Gertler and Karadi (2015), and Nakamura and Steinsson (2018).

During the ELB, our policy rate is the first component of a PCA that contains the first-difference of the five contracts, that is Δi_t for each contract, as in M. D. Bauer and Swanson (2020) and Nakamura and Steinsson (2018).

10.2.3 Intraday monetary surprises

We define the intraday monetary surprises or event-study monetary shocks as the intraday change for both of our policy instruments, front-month fed funds futures and the PCA rate, surrounding scheduled FOMC announcements. We compute them following the methodology of Gürkaynak et al. (2005) and Nakamura and Steinsson (2018).

The data sources about announcements and the intraday prices are in the Table 10.1.

We compute the intraday change as the difference between the price of the contracts in the policy instruments about 10 minutes before the announcement and around 20 minutes after. Strictly, the value before can be between 5 and 20 minutes before the announcement, while the value after can be between 15 and 25 minutes after, since we only have data in 15-minute intervals and we allow a distance of at least 5 minutes before and after the event. When no trade occurs before the event, the last available price is used and when no trade occurs after the event, the first available price.

To obtain the change in the policy instruments, we adjust the above raw changes in prices following equation (20), likewise the daily data. However, no adjustment is made for a new contract ($d = 1$) since with intraday data there is always trade before the event. Finally, the intraday PCA rate is the first component of a PCA of all intraday (adjusted) changes in prices, alike done for daily data.

The intraday surprises thus computed appear in Figure 10 where the front-month fed fund future is the policy instrument outside the ELB and the PCA rate during the ELB.

[37]The volatility of a future contract changes as does its time to maturity. This follow from Samuelson's hypotehsis, see Bessembinder et al. (1995) and Duong and Kalev (2008)

The observation in 2008 with a value -93 is omitted so as not to distort the plot.

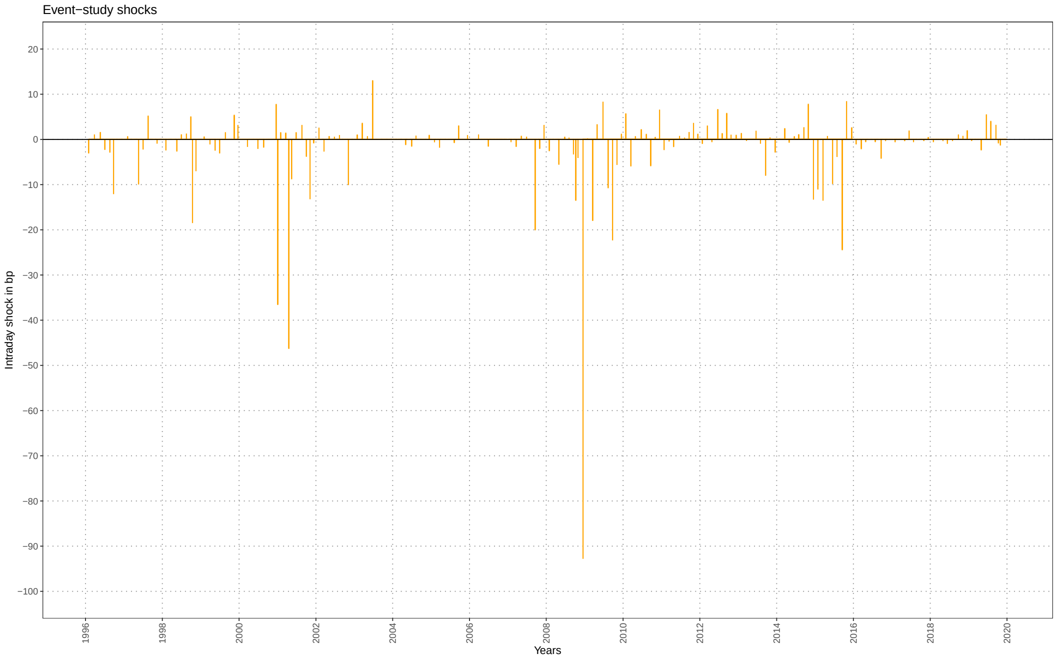


Figure 10: EVENT-STUDY SHOCKS. Computed as the intraday change in the policy instruments surrounding the FOMC announcement

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