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The High-Frequency Response of Energy Prices to Monetary Policy: Understanding the Empirical Evidence

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Abstract

This paper examines the impact of conventional and unconventional monetary policy on energy prices, using an event study with intraday data. Three measures for monetary policy surprises are used: 1) the surprise change to the current federal funds target rate, 2) the surprise component to the future path of policy, and 3) the unanticipated announcements of future large-scale asset purchases (LSAPs). Estimation results show that monetary policy news has economically important and highly significant effects on the level and volatility of energy futures prices and their trading volumes. I find that, on average, a hypothetical unanticipated 100 basis point hike in the federal funds target rate is associated with roughly a 3 percent decrease in West Texas Intermediate oil prices. I also document that, in a narrow window around the Federal Open Market Committee meeting, the Federal Reserve's LSAP1 and LSAP2 programs have a cumulative financial market impact on crude oil equivalent to an unanticipated cut in the federal funds target rate of 155 basis points. Monetary policy affects oil prices mostly by affecting the value of the U.S. dollar exchange rate. Intraday energy prices also respond to news announcements about the U.S. macroeconomy and inventories. The daily responses are never significant, except in the case of inventory news.

Key words: monetary policy, federal funds futures, macroeconomic news, inventory news, oil futures

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1. Introduction

Crude oil prices skyrocketed from \$92 a barrel in January 2008 to hit a record high of \$147 a barrel on July 11, 2008, before suddenly collapsing to less than \$40 a barrel in December 2008. During the financial crisis oil prices have steadily recovered to pre-crisis levels. According to El-Erian (2012), central bank quantitative easing policies can be “seen by some as a contributor to higher commodity prices, especially oil and precious metals” (see also Hamilton, 2009, for a related point). This paper sheds further light on the determinants of energy prices by examining whether, and to what extent, the Federal Reserve conventional and unconventional monetary policy affects energy prices. This relationship is an important topic for several reasons. From a central banking perspective, oil price dynamics affects both inflation and real activity. For instance, in a June 2008 speech Federal Reserve Chairman Bernanke (Bernanke, 2008) singled out the role of energy prices among the main drivers of inflation dynamics, underscoring the importance for policy-makers of understanding the factors that drive those changes. Traders are likely to be equally interested in this topic since monetary policy decisions are often associated with large asset price movements. It is therefore important for retail and institutional investors to understand the link between the Federal Reserve monetary policy and asset prices in formulating effective trading and hedging strategies and portfolio allocation decisions. Finally, for a market monitoring perspective, it is important to decompose changes in energy prices into their fundamental contributors, including monetary policy, U.S. macroeconomic fundamentals and oil supply. Little is known, however, about the real-time effects of conventional and unconventional monetary policy on oil prices using an event-study approach with intraday data.

This paper contributes to the extant literature in three main aspects. First, consistent with the efficient market hypothesis that asset prices only react to new information, this work carefully identifies the *surprise component*, rather than the mere presence, of the Federal Reserve’s Large-Scale Asset Purchases (LSAP) announcements. The distinction between anticipated and unanticipated LSAP announcements is essential to properly estimate, and especially not understate, the effectiveness of asset purchases. For instance, as documented by Krishnamurthy and Vissing-Jorgenson (2011, Figure 4), the response of the 10-year Treasury rate to the FOMC announcement of \$600 billion of Treasury purchases is somewhat muted. This finding suggests that this LSAP announcement was mostly anticipated by market participants, and may have already been priced in before the actual announcement. Second, the LSAP news is incorporated into a formal regression framework, thus controlling for the unanticipated policy rate decision and statement regarding the future policy path. As noted by Woodford (2012), “the two dates considered by Gagnon, Raskin, Remache and Sack (2011) on which there were the largest declines in long-term bond yields - accounting for 73 basis points out of the

cumulative 91-basis-point decline that they report - were both dates on which there were very important statements about the funds rate target.” Specifically, on December 16, 2008, the funds rate target was cut from 1.0 percent to the 0-25 basis point target band, and on March 18, 2009, the FOMC announced that it expected to maintain the low level of the funds rate “for an extended period” (rather than “for some time”). Attributing all of the declines in long-term bond yields on these days to the LSAP news substantially over-estimates the financial market impact of asset purchases. Third, to better understand the transmission channels through which monetary policy affect energy prices (e.g. economic growth and exchange rate channels), I look at the high-frequency response of oil prices quoted in different currencies.

The main findings of the paper can be summarized as follows. First, I show that the release of the FOMC statement induces significant “higher than normal” volatility of crude oil futures prices, and their trading volumes, compared with non-event days. This result suggests that the contents of the FOMC statements are not always completely anticipated. Hence, the release of the statement causes market participants to revise their expectations, and determines considerable portfolio reshuffling. A potential drawback of the above approach is that it cannot determine whether energy prices move in the direction of the Federal Reserve’s monetary policy. To address this shortcoming, I identify *multi-dimensional* indicators of monetary policy news which capture information relating to policy rate decisions, the future path of policy, and announcements of future large-scale asset purchases. Estimation results show that monetary policy news have economically important and highly significant effects. For instance, in a 1-h window around the FOMC press release a hypothetical unanticipated 100-basis-point hike in the federal funds target rate is associated with 2.7% decline in crude light oil price and 1.8% decrease in heating oil price. This paper also documents economically important effects of asset purchases on oil prices. In a narrow window around the FOMC meeting the cumulative financial market impact of the unanticipated announcement of asset purchases in terms of their federal funds-rate-equivalent, i.e. change in the funds rate that would have the same financial market impact as a given quantity of asset purchases, is substantial. Specifically, the impact of asset purchases ranges between 8 (for natural gas), 111 (for heating oil), and 155 basis points (for crude oil). These point estimates are, however, surrounded by considerable uncertainty. Second, I show that monetary policy surprises have no statistically significant effect on energy prices quoted in different currencies. More specifically, the high-frequency impact of monetary policy on the dollar price of oil is exactly offset by the response of the U.S. dollar exchange rate vis-à-vis with any other major currency. This finding suggests that most of the reaction of oil prices can be attributed to the exchange rate channel. Third, high-frequency oil prices significantly react to U.S. macroeconomic surprises, such as industrial production, nonfarm payrolls, and consumer confidence, and to inventory news. The daily response of oil prices is, however, never significantly different from zero (except for inventory news). This finding confirms that by using intraday data the precision of the point estimates is greatly enhanced compared to those obtained by a lower-frequency

(daily) regression model (see, *inter alia*, Andersen, Bollerslev, Diebold and Vega, 2003, and Beechey and Wright, 2009, for similar results). To sum up, the results of this paper are not consistent with the hypothesis that energy prices are predetermined with respect to monetary policy and U.S. economic fundamentals. These findings have important policy implications for macroeconomic modelling. In particular, in a monthly vector autoregression (VAR) model, the recursive identification that assumes no feedback from domestic macroeconomic shocks to the price of energy with the same month (see, *inter alia*, Blanchard and Gali, 2010, and Leduc and Sill, 2004, and the references contained therein) is not supported by the data. Moreover, in contrast to most of the existing literature (see, e.g., Carlstrom and Fuerst, 2006; Kormilitsina, 2011; Natal, 2012) the empirical findings suggest that oil prices should be treated as endogenous variables in dynamic stochastic general equilibrium models.

By looking at the financial market impact of the Federal Reserve's monetary policy, this paper is related to different strands of the literature. A number of studies investigate the influence of the Federal Reserve's unanticipated policy rate decisions on U.S. asset prices.¹ This strand of research has reached a consensus that U.S. asset prices respond strongly to unanticipated fed funds target rate decisions.

A number of recent papers analyze issues relating to monetary policy and commodity prices (see, e.g., Frankel, 2008, and the references therein). Two recent contributions look at the impact of monetary surprises on energy prices using an event-study approach, as I do in this study. Glick and Leduc (2011) study the *daily* response of long-term interest rates, exchange rates, and the Goldman Sachs Commodity Index (GSCI) and its components. They document that on days of LSAP announcements the GSCI, and particularly the GSCI Energy, sharply fell. As I discuss below in panel (b) of Table 1, this surprising result is entirely driven by the use of lower (daily) frequency data. A similar approach has been applied to study the impact of conventional monetary policy by Basistha and Kurov (2012). They find a negative and highly significant response of *intraday* energy prices to target surprises. This paper shares this finding and goes further by considering the impact of both conventional and unconventional, e.g. asset purchases, monetary policy.²

A final area of related research investigates the empirical relationship between U.S. monetary policy and commodity prices by means of a standard VAR model. For instance, Anzuini, Lombardi and Pagano (2010)

¹ Some important studies include Kuttner (2001) for Treasury rates, Beechey and Wright (2009) for Treasury Inflation Protected Securities rates, Bernanke and Kuttner (2005) and Rosa (2011a) for U.S. stocks, Hausman and Wongswan (2011) for international equities, Fatum and Scholnick (2006 and 2008) and Wang, Yang and Simpson (2008) for exchange rates.

² Although I solve a related empirical exercise of Glick and Leduc (2011) and Basistha and Kurov (2012), there remain additional important differences. First, by considering the response of energy prices quoted in different currencies, this work sheds light on the relationship between monetary policy and oil prices. Second, this paper looks not only at the level but also at the volatility of energy prices, and their trading volumes, around FOMC announcements. Finally, I test the null hypothesis that energy prices are predetermined with respect to U.S. monetary policy and macroeconomic aggregates using a novel high-frequency dataset.

document a significant impact of monetary policy on commodity prices, with an expansionary monetary policy shock that is associated to an increase in the commodity price index and all of its major components.

The rest of the paper is organized as follows. Section 2 describes the dataset. Section 3 contains the main results. Section 4 provides extensive robustness analysis and comparison with results in the existing literature. Section 5 offers some concluding thoughts.

2. Data

2.1. Energy futures data

The high-frequency energy prices consist of 5-min quotes of futures data on light sweet crude oil (also known as West Texas Intermediate, WTI), heating oil, and natural gas (Henry Hub), and covers the period January 1999 - June 2011. Midpoints of bid/ask quotes, observed at the end of each 5-min interval, are used to generate the series of (equally-spaced) 5-min continuously compounded energy price returns.³ If no trade occurs in a given 5-min interval, I use the price from the previous interval, as long as the previous price is quoted within the last thirty minutes. All these futures contracts are traded at the New York Mercantile Exchange (NYMEX) from 9:00 AM to 2:30 PM (Eastern Daylight Time, EDT) in the open outcry, and 24-hour in electronic trading. Crude oil is the world's most actively traded commodity, and the WTI oil futures contract is the world's most liquid forum for crude oil trading, as well as the world's largest-volume futures contract trading on a physical commodity, with a daily volume of roughly 900,000 futures and options contracts and a total open interest at roughly 7.5 million lots. The contract trades in units of 1,000 barrels, and the delivery point is Cushing, Oklahoma. At a given point in time, the NYMEX lists roughly 70 monthly contracts that can be actively traded.⁴ The front-month futures contract is, however, the most liquid contract. In this paper, I create a single continuous contract by rolling over to the next contract on expiry date. I also construct a term structure of oil price futures by looking at various expiry dates (1st, 2nd, 3rd and 6th contract). Heating oil is a distillate, and consists of a mixture of petroleum-derived hydrocarbons.⁵

2.2. Monetary policy surprises

³ Andersen, Bollerslev, Diebold and Vega (2003) and Bandi and Russell (2008) argue that 5-min returns provide a reasonable balance between sampling too frequently (and confounding price reactions with market microstructure noise, such as the bid-ask bounce, staleness, price discreteness, and the clustering of quotes), and sampling too infrequently (and blurring price reactions to news).

⁴ The WTI contract specifications are available at http://www.cmegroup.com/trading/energy/crude-oil/light-sweet-crude_contract_specifications.html.

⁵ The RBOB (Reformulated Blendstock for Oxygenate Blending) futures contracts could be another proxy for a derived product of oil. Unfortunately, since these contracts started to trade in late 2005, I do not consider it.

I extract monetary surprises from market-based measures of monetary policy expectations (i.e. federal funds and euro dollar futures), rather than from survey-based expectations. This presents a number of advantages. First, the information is more timely (e.g. based on information available immediately before the meeting rather than the Friday of the previous week), and more precisely measured (see the discussion in Rigobon and Sack, 2008). Second, it is possible to recover the whole term structure of expectations. Finally, expectations are available also for unscheduled FOMC meetings.

Monetary policy surprises are divided into three categories:

- i) A Target shock is defined as the difference between the announced target federal funds rate and market participants' expectations.
- ii) A Path shock captures revisions to the future path of monetary policy.
- iii) An asset purchase shock measures the surprise component of asset purchase announcements.

Since market participants are unlikely to respond to monetary policy actions that are already anticipated, distinguishing between expected and unexpected policy decisions is essential to properly estimate the financial market impact of policy. As standard in the literature (e.g. Kuttner, 2001) I use federal funds futures data to extract market-based measures of monetary policy expectations.⁶ These futures contracts are traded on the Chicago Board of Trade exchange and their settlement price at maturity is based on the average effective overnight federal funds rate that is realized for the calendar month specified in the contract. Since the futures rate on a given date would embody the average of realized funds rates through that date and expectations about the rates prevailing after that date, the unanticipated, or surprise, target funds rate change from federal funds futures contracts can be computed as follows:

$$TS_t = \Delta f_t \frac{D}{D - d} \tag{1}$$

where Δf_t is the change in the current month federal funds futures rate in a narrow window around FOMC announcements (spanning from 5-min prior to 25-min after the policy announcement), d is the day of the month of the meeting, and D is the total number of days in that month. Since at the end of the month the scale factor in Equation (1) becomes very large and could unduly magnify targeting errors or possible changes in the bid-ask

⁶ Gurkaynak, Sack and Swanson (2007) found that among a variety of financial market instruments (term federal funds loans, federal funds futures, term eurodollar deposits, eurodollar futures, Treasury bills and commercial papers) the federal funds futures dominate all the other securities in forecasting U.S. monetary policy at horizons out to six months. Moreover, Piazzesi and Swanson (2008) show that federal funds futures dramatically outperform random walk, AR(1) and Vector AutoRegression forecasts.

spread, in the last five days of the month I define the variable TS as the unscaled change in the next-month federal funds futures contract. Note that by using intraday data to identify the target shock, the endogeneity problem (i.e. policy decisions, backed out from federal funds futures, may be simultaneously influenced by movements in other asset prices) is substantially reduced. The validity in Equation (1) to compute the surprise target rate change critically depends on the assumption that the risk premium is time-invariant. As noted by Piazzesi and Swanson (2008) “the one-day change in the federal funds futures rate around FOMC announcements seems to be much more robust to the presence of risk premia”. Since I consider a 30-min window bracketing the FOMC announcements, I can safely assume that risk premia, which move primarily at lower, business-cycle frequencies, are “differenced out”.

I compute the surprise component about the future path of monetary policy by using the same methodology developed by Gurkaynak, Sack and Swanson (2005). More specifically, let the factor model representation for X be expressed in the following form:

$$X = F\Lambda + \eta \tag{2}$$

where X denotes a $T \times n$ matrix, with rows corresponding to the dates of FOMC decisions, and columns corresponding to asset prices, with each element of X reporting the asset price change in the tight (30-min) window around the corresponding monetary policy announcement. F is a $T \times k$ matrix of unobserved factors (with $k < n$), Λ is a $k \times n$ matrix of factor loadings, and η is a $T \times n$ matrix of white noise disturbances. As in Gurkaynak, Sack and Swanson (2005), I use the price changes of five futures contracts to pin down the X matrix in Equation (2): the current-month federal funds futures rate, the federal funds futures rate for the month containing the next FOMC meeting (with scale adjustment for timing of FOMC meetings within the month), and the two-, three-, and four-quarter-ahead eurodollar futures rates. I find that for the sample period January 1999 – June 2011 the first two factors explain around 96% of the variation in the dependent variables, compared to 92% as originally found by Gurkaynak, Sack and Swanson (2005) for the sample period February 1990 – December 2004. Again, as in Gurkaynak, Sack and Swanson (2005), to allow for a more structural interpretation of these unobserved factors, I rotate them so that the first factor, *Target*, corresponds to surprise component of the current federal funds rate target, and the second factor, *Path*, corresponds to the unexpected change in interest rate expectations over the coming year that are not driven by changes in the current funds rate.

On December 16, 2008, the Federal Reserve lowered the federal funds target rate by 75 basis points to a range of 0-0.25%, representing a cumulative 5.25 percent easing since September 2007. Constrained by the zero-

lower bound on its main operating instrument, to further ease financial conditions and thereby promoting a stronger pace of economic recovery, the FOMC has subsequently purchased a substantial volume of agency debt, agency mortgage-backed securities (MBS) and longer-term Treasury securities in the secondary market. These actions led to a sharp expansion of the Federal Reserve’s balance sheet from \$800 billion at the start of the crisis to nearly \$3 trillion by mid-2011. Asset prices are forward-looking, so the expected component of LSAP announcements should have essentially no effect on energy prices. For instance, some LSAP announcements, such as the November 3rd 2010 announcement of \$600 billion purchases of longer-term Treasury securities, may have already been priced in before the actual announcement took place. If the surprise component of the announcement is not properly taken into account, the financial market impact of asset purchases may be severely understated. Unfortunately, there are no direct measures concerning market expectations about the Federal Reserve’s LSAP announcements. Hence, I rely on a narrative approach to distinguish between the expected and unexpected content of each FOMC announcement about future asset purchases.⁷ More specifically, to identify the surprise component of asset purchase announcements, I read several Financial Times (FT) articles written before and after each FOMC meeting day. Then, I construct a multinomial indicator (i.e., a ternary dummy), $LSAPS_t$, that classifies the LSAP announcements into those that give an inclination of more accommodative versus no change or tighter unconventional monetary policy:

$$LSAPS_t = \begin{cases} +1 & \text{LSAP announcement less expansionary than expected} \\ 0 & \text{No surprise in LSAP announcement} \\ -1 & \text{LSAP announcement more expansionary than expected} \end{cases} \quad (3)$$

Rosa (2012) contains a detailed discussion of the caveats of this methodology, and reports the values of LSAP surprises, together with a few examples based on the FT’s commentaries to provide a brief rationale for the coding of the LSAP announcements. Note that to reduce the chance of potential misclassification, and in line with the work in content analysis (see, e.g., Holsti, 1969), two other persons have coded the FT’s stories independently, producing the same ranking of surprises.

Table 1 (panel A) presents a selection of descriptive statistics for all the variables used in this paper, whereas Table 1 (panel B) displays the intraday and daily crude oil (WTI) futures returns associated with the LSAP announcements used, for instance, by Gagnon, Raskin, Remache and Sack (2011) and Krishnamurthy and

⁷ This approach has been influential in macroeconomics and finance. For instance, Cook and Hahn (1989) rely on newspaper articles to measure target shocks. Romer and Romer (1989) classify monetary shocks based on their readings of Federal Reserve documents, whereas Romer and Romer (2010) identify fiscal shocks using presidential speeches or the Economic Reports of the President. Some recent studies assessing the impact of financial news media on asset prices include Tetlock (2007) and Loughran and McDonald (2011).

Vissing-Jorgenson (2011). The LSAP announcements that are not associated to FOMC meetings are highlighted in grey, and are reported for completeness. Interestingly, the correlation between intraday and daily crude oil futures returns equals -0.24, suggesting that for this specific time series realization the immediate asset price response was reversed in the course of the trading day. On the other hand, the correlation between daily crude oil futures returns and daily returns on the GSCI Energy (cf. panel C of Table 4 in Glick and Leduc, 2011) is 0.99. This finding confirms that by using intraday data the precision of the estimation results is greatly enhanced compared to those obtained by a lower-frequency (daily) data.

Table 1 here

3. The response of energy prices to monetary news

3.1. Volatility and trading volume

To determine whether the Federal Reserve monetary policy affects energy prices, I look at whether, and to what extent, the volatility and trading volumes of oil futures are higher on days of FOMC meetings compared to non-event days for the sample period January 1999 - June 2011. The idea is that if a monetary policy decision causes market participants to revise their expectations, this should then be reflected in higher volatility and trading activity compared with a period free of such an event (Kohn and Sack, 2004). Since the volatility and trading volume may be time-varying, it is important to properly control for both intraday and day-of-the-week effects when gauging whether the Federal Reserve's monetary policy induces elevated price fluctuations and portfolio reshuffling. Figure 1 (panel A) displays *the ratio* between (i) the standard deviation of the 5-min energy futures returns on FOMC meeting days, and (ii) the average 5-min volatility on the same weekdays (of the previous and following week of the FOMC meeting day) and hours but on non-announcement days. To adjust for trend growth in trading volumes, and to avoid overweighting the most recent years, for each FOMC meeting day Figure 1 (panel B) displays the ratio between (i) the 5-min volumes on release days, and the average of (ii) the 5-min volumes on the same weekdays (of the previous and following week of the release day of the FOMC minutes) and hours on non-event days. The vertical line is placed at the release time of the FOMC statements, i.e. 2.15 PM EDT. A ratio above one can be interpreted as the monetary policy news inducing "higher than normal" volatility and trading activity on FOMC meeting days compared to non-event days. Large and small filled squares denote significance of the differences at the two-sided 1 and 5 percent level respectively. Since asset price returns and the ratio of trading volumes may not be normally distributed, the test statistic proposed by Levene (1960) is used to test the null hypothesis of equal variances in each subgroup, and the Wilcoxon signed

ranks test (see Newbold, 1988) is used to test the null hypothesis that the median ratio equals one. In line with the existing literature that documents a positive contemporaneous relation between volume and volatility (see, e.g., Karpoff, 1987, and more recently Giot, Laurent and Petitjean, 2010, for detailed surveys), I expect that also volumes respond to the release of FOMC statements. Two interesting features can be inferred from Figure 1. First, the evidence of volatility increase during the pre-announcement phase is tenuous and not significantly different compared to non-announcement days. On the other side, trading activity tends to be lower prior to announcements, displaying the so called “calm-before-the-storm” effect (Jones, Lamont and Lumsdaine, 1998). Second, news about monetary policy tends to induce significantly “higher than normal” volatility and trading volumes up to 40-min after the monetary policy announcements.⁸

Figure 1 here

3.2. Regression analysis

An important shortcoming of the above approach based on volatility is that it cannot determine whether asset prices move in the direction of the Federal Reserve’s policy surprises. For this reason, another more informative approach consists in estimating the following equations:

$$R_t = \beta_0 + \beta_{TS}TS_t + \varepsilon_t \quad (4)$$

$$R_t = \beta_0 + \beta_T Target_t + \beta_P Path_t + \varepsilon_t \quad (5)$$

$$R_t = \beta_0 + \beta_T Target_t + \beta_P Path_t + \beta_{LSAPS} LSAPS_t + \varepsilon_t \quad (6)$$

where R_t is the intraday futures return, i.e. the percentage change in energy prices from 10-min before to 50-min after the event. This is a conservative choice of window size, and is based on the assumption that the price adjustment in the conditional mean of energy prices is complete within 50-min of the monetary policy announcement. The variable TS stands for the Target shock computed in Equation (1), the variables $Target$ and $Path$ factors are computed in (2), and as indicated by Equation (3) the variable $LSAPS$ stands for the surprise component of LSAP announcements. The error term ε_t represents other factors that affect asset prices on event times. These factors are assumed to be orthogonal to the explanatory variables of the regression. Each regression is estimated using ordinary least squares (OLS) with White-t statistics (White, 1980) to account for heteroskedasticity in the residuals.

⁸ Hayo, Kutan and Neuenkirch (2012) use a GARCH model with daily data, and document the influence of U.S. monetary policy on the price volatility of commodities for the period 1998-2009.

Table 2 reports the estimation results based only on those days associated with FOMC meetings (including unscheduled FOMC meetings).⁹ Standard errors are reported below each coefficient, and coefficients significant at the 10% level or better are indicated with stars. The sign of the estimated coefficients on *TS* is negative and significant: a hypothetical unanticipated 100-basis-point hike in the federal funds target rate is associated with roughly 3% drop in oil prices. The coefficient of the *Target* factor is negative and significant, with a magnitude similar to the *TS* coefficient. On the other side, the coefficient of the *Path* factor is close to zero, and insignificant. This finding may suggest that different asset classes respond to different dimensions of monetary news. For instance, previous studies (e.g. Gürkaynak, Sack and Swanson, 2005, for Treasury rates, and Rosa, 2011a, b, for stock prices and exchange rates) document that the *Path* factor has a much greater impact compared to target surprises, whereas Hausman and Wongswan (2011) find that international stock markets respond mainly to the target surprises. The most interesting aspect of Table 2 is the estimates of the effects of the LSAP news on oil prices. The coefficient of the LSAP shock is negative, and highly significant. An unanticipated dovish LSAP announcement is, on average, associated with an increase in the front-month WTI futures prices of roughly 2%. This result implies that in a narrow window around the FOMC meeting the cumulative financial market impact of the LSAP program in terms of their federal funds-rate equivalent corresponds to an unanticipated cut in the federal funds target rate of 155 basis points. These point estimates are, however, surrounded by considerable uncertainty.¹⁰ To shed further light on the economic importance of the effects of asset purchases on energy prices, I have compared the goodness of fit, as measured by the adjusted R^2 , of Equation (6) to the baseline specification that includes only a constant and the target surprise. By including the surprise component of LSAP announcements, the adjusted R^2 of the crude oil regression substantially increases from 5% to 8%, suggesting that the effect of the LSAP shock is not only statistically different from zero and of the “expected” sign, but also quantitatively important.

Table 2 here

Having determined that oil prices respond to the Federal Reserve monetary policy, there is a key issue that this paper brings to the fore: what are the channels through which monetary policy affect oil prices?

⁹ The null hypothesis that monetary news have the same effects on scheduled and unscheduled (e.g., January 3, 2001; April 18, 2001; August 17, 2007; January 22, 2008; and October 8, 2008) FOMC meetings days cannot be rejected (results available upon request).

¹⁰ The cumulative stimulus of the LSAP program, expressed in federal funds rate-equivalent, is computed as $N \cdot \beta_{LSAPS} / \beta_T$, where N is the sum of LSAP ternary dummies, and I multiply the ratio by 100 to express it in basis points. To assess the degree of uncertainty in this point estimate, I compute empirical confidence bands using simulations. More specifically, I take 10,000 draws from the joint distribution of $\{\beta_T, \beta_{LSAPS}\}$, and compute the above proportion implied for each asset pair. Finally, I take the 5% and 95% percentiles.

Monetary policy can affect oil prices through two different channels: economic growth and exchange rates.¹¹ First, a contractionary monetary policy shock leads to persistent decline of the U.S. economic activity, thus reducing demand for all goods, including commodities and oil, and consequently lowering oil prices. Second, oil, as well as many other commodities, are priced in U.S. dollars. Hence, as noted by Reinhart (2011), oil producers care about the current and expected future purchasing power of the dollar. An unanticipated cut in the federal funds target rate leads to a depreciation of the U.S. dollar, and possibly to higher inflation. These effects erode the purchasing power of the foreign producers of commodities who have to increase the nominal price of oil to keep up with that erosion. To disentangle the relative importance of these two channels, I look at the high-frequency response of oil prices quoted in different currencies. Table 3 shows that monetary policy surprises have no statistically significant effect on oil prices quoted in euro. More specifically, the high-frequency impact of monetary policy on the dollar price of oil is offset by the response of the U.S. dollar exchange rate vis-à-vis with the euro. This finding holds more generally for oil prices quoted in British pound, Canadian dollar, Swiss franc, and Japanese yen (results available from the author upon request), and suggests that most of the reaction of oil prices can be attributed to the exchange rate channel.

Table 3 here

4. Robustness checks

4.1. Comparing intraday and daily results

As argued by Gurkaynak, Sack and Swanson (2005), Beechey and Wright (2009) and others, intraday data may provide more precise point estimates of announcement effects than can be obtained with lower-frequency (daily) data. To assess the extent of the additional information content of employing intraday (5-min) oil price data, I estimate Equations (4)-(6) using daily returns as the dependent variable (Bloomberg ticker: CL1 Comdty) in place of oil price returns computed in a 1-h window around the FOMC announcement time. Specifically, I consider a “daily” window, which begins with the financial market close the day before the policy announcement and ends with the financial market close the day of the policy announcement. Table 4 shows the estimation results. The sign of the *Target* shock coefficient remains, as expected, negative: a hypothetical unanticipated 100-basis-point hike in the federal funds target rate is associated with roughly 1.4% decline in oil

¹¹ There may exist additional transmission channels from monetary policy to energy prices: i) inventory demand (lower interest rates decrease the carrying costs of inventories); ii) supply (lower interest rates decrease the returns on capital, and hence increase the incentives to strategically delay the extraction of crude oil, see Hotelling, 1931); and iii) portfolio balance (by purchasing assets, the Federal Reserve displaces private investors, and induce them to purchase other assets, including commodities).

prices. The coefficient is, however, insignificantly different from zero. Consistent with Table 1 (panel B), the coefficient of the LSAP shock becomes positive, and highly significant: an unanticipated dovish LSAP announcement is associated with a decline in crude oil prices of roughly 2%. This result is consistent with the findings of Glick and Leduc (2011), and indicates that by using intraday data the precision of the point estimates is greatly enhanced compared to those obtained by a lower-frequency (daily) data.

Table 4 here

Kilian and Vega (2011) test the identifying assumption that energy prices are predetermined with respect to U.S. macroeconomic aggregates by using an event-study approach and regressing daily energy price returns on U.S. macroeconomic news. They find no statistical evidence that energy prices respond instantaneously to macroeconomic news, and hence their results support the use of delay restrictions for identification.¹² Given the previous finding about the additional informational content of using intraday data to obtain more efficient point estimates, I reexamine the high-frequency responsiveness of oil crude prices to macroeconomic news using 5-min data.

The selection of macroeconomic announcements includes those that have been singled out in the empirical finance literature (e.g. Andersen, Bollerslev, Diebold and Vega, 2007, and Faust, Rogers, Wang and Wright, 2007) as important drivers of U.S. asset prices. The set of macro news comprises indicators regarding the U.S. real activity (industrial production, retail sales, employment conditions, trade balance), prices (CPI and PCE core), and forward-looking indicators (Institute for Supply Management's Manufacturing Report on Business, in short ISM index, and Conference Board's consumer confidence). The monthly Employment Report contains data from both the household survey and the establishment survey. Consistent with the existing literature, I separate the Report surprises into two parts: the unemployment rate and nonfarm payrolls. This separation is possible because their correlation coefficient is close to zero. I also consider the weekly energy inventory report released by the Energy Information Administration (Department of Energy, DoE) about crude oil, distillate and gasoline. In order to gauge the extent to which economic fundamentals affect energy prices, it is crucial to compute the unexpected, or surprise, component of each release. As standard in the literature, I define "news" or "surprise" as the difference between the actual value announced for a macroeconomic indicator and market participants' prior expectation of what that value would be. I measure the expected macro figure using the median survey expectation from Bloomberg.¹³ A positive surprise represents stronger-than-expected

¹² Chatrath, Miao and Ramchander (2011) control for inventory stocks and confirm that the price of crude oil is predetermined with respect to macro aggregates.

¹³ Many studies (see, for instance, Balduzzi, Elton and Green, 2001) find that the survey expectations are of good quality as they prove to be generally unbiased and efficient.

growth or higher-than-expected inflation. Since the unemployment rate and the initial jobless claims are countercyclical indicators, I flip their sign so that positive shocks also imply stronger-than-expected growth. To make the units comparable across different types of announcements, I divide each macro surprise by its sample standard deviation. This standardization does not affect the statistical significance of the estimated response coefficients nor the fit of the regressions compared to the estimation results based on the raw surprises. More formally, to quantify the impact of macroeconomic news on oil prices, I estimate the following regression in a narrow window around the data release:

$$R_t = \alpha + \beta S_t + \varepsilon_t \quad (7)$$

$$R_t = \alpha + \beta_{NFP} S_{NonfarmPayroll,t} + \beta_U S_{Unempl,t} + \varepsilon_t \quad (8)$$

where R_t stands for the intraday (i.e., the percentage change in energy prices from 10-min before to 50-min after the event) and daily crude oil futures return, the variable S_t stands for the macroeconomic surprise at time t . Equation (7) is estimated for all macro news except for the case of the Employment Report surprises, when Equation (8) is estimated. The rest of the notation is the same as before. The coefficient β represents the average impact of a one standard deviation change in the macroeconomic surprise over the 1-h intraday interval.

Table 5 (left panel) reports the estimation results for the sample period January 1999 - June 2011, including only observations of the macro news releases. A number of U.S. macroeconomic and inventory announcements, such as industrial production, nonfarm payrolls and consumer confidence, have a statistically significant effect on oil price returns. More specifically, better-than-expected job growth and lower-than-expected inventory releases are associated with an increase in oil prices. The most interesting aspect of Table 5 (right panel) is, however, the fact that the corresponding confidence interval using daily data is much larger (bottom table), and no news except inventories remains significant. Hence, the results of Kilian and Vega (2011) seem to be entirely driven by the loss of precision due to use of lower-frequency (daily) data. To take into proper consideration the size distortion due to data mining in asymptotic test (e.g. repeated applications of the same t test to alternative regressors), inferential results are also drawn from bootstrap distributions generated under the null hypothesis that energy prices do not respond to news (see Kilian and Vega, 2011, and White, 2000, for the technical details on this bootstrap procedure).¹⁴ The simulation results are based on 10,000 bootstrap replications. The results remain very similar, indicating that the conclusions reached using heteroskedasticity-robust standard errors are not importantly influenced by the inferential procedure.

Table 5 here

¹⁴ I thank Lutz Kilian and Clara Vega for sharing the code to compute robust p-values.

4.2. Additional sensitivity analysis

I examine the robustness of the baseline estimation results of Section 3 along several dimensions: (i) I look at the effects of potential outliers on the baseline empirical results. (ii) I investigate whether the effects of monetary surprises have changed in periods of heightened financial stress compared to tranquil times by splitting the sample into two subsamples: January 1999 - June 2007 and July 2007 - June 2011. (iii) I examine the high-frequency response of the front-month futures on heating oil and natural gas, and the term structure of WTI oil futures prices up to 12-month maturity to monetary policy news. I show that the main results of Section 3 are fairly robust. Thus this sensitivity analysis is consistent with the main finding that monetary news are a key driver of energy prices, providing an extensive overall amount of evidence. In the interest of space, most of these results can be found in a supplemental Appendix.

Most target and path surprises are small, but a few are large, and these latter observations may significantly affect the baseline empirical results. To analyze the effect of potential influential observations, I compute the influence statistic proposed by Bernanke and Kuttner (2005) and the Cook's (1977) distance measure. For almost all observations of Equation (6) for crude oil (WTI) futures returns are associated with an influence statistic below 0.5, and a Cook's statistic below 0.1, thus suggesting that the findings of the impact of monetary policy on energy prices do not appear to be driven by extreme outliers. The only exceptions are the LSAP announcements of March 18, 2009 and August 10, 2010 that have an influence statistic of roughly 2 and a Cook's distance of 1. This finding indicates that the impact of unanticipated LSAP announcements is highly heterogeneous (cf. Table 1, panel B).

To assess whether the relationship between monetary policy and energy prices has remained stable during the recent financial turbulence that started in August 2007, I estimate Equations (4)-(6) for the subsamples January 1999 - June 2007 and July 2007 - June 2011. Estimation results (available upon request) show that crude oil futures prices significantly react to the target factor and LSAP shock, but not to the path factor. The magnitude of the response to the Target rate shock is marginally larger in the pre-crisis sample. For instance, a hypothetical unanticipated 100-basis-point hike in the federal funds target rate is associated with roughly 4% drop in crude oil prices between 1999 and 2007, and only 1.2% decline during the financial crisis.

Finally, I examine the high-frequency response of the front-month futures on heating oil and natural gas to monetary policy news. The response of energy prices to Target shocks is negative, and significant, whereas the impact of the Path factor and LSAP surprises is insignificant. A hypothetical unanticipated 100-basis-point hike in the federal funds target rate is associated with 1.8% decline in heating oil futures prices and 2.7% decline in natural gas futures. Since the correlation between crude oil and heating oil futures 5-min returns is roughly

0.5, the price of heating oil may respond to monetary policy news because its price is closely tied to the price of crude oil. I also examine the high-frequency response of the term structure of oil prices to monetary surprises by looking at the front-, second-, third- and sixth-month futures contracts. This exercise is interesting because oil futures provide a forward-looking measure of expected future oil prices (see, e.g., Chinn and Coibion, 2010, for evidence that futures prices are unbiased and accurate predictor of subsequent spot prices). Estimation results show that the short-end of the term structure is more sensitive to monetary surprises than the longer-end, suggesting that far-ahead oil prices may not be influenced by monetary policy. An alternative interpretation of this finding is, however, that far-ahead contracts are not very liquid, and thus do not react to news.

5. Conclusions

The high-frequency response of asset prices to monetary and macroeconomic news announcements represents a rich source of information to better understand the financial market impact of economic fundamentals, and may be the closest thing that can be obtained in macroeconomics to a natural experiment. This paper examines the effects of the Federal Reserve conventional and unconventional monetary policy on the level, the volatility, and trading volumes of energy futures using an event study with intraday data for crude light and heating oil, and natural gas. I document that oil prices respond negatively to target surprises and unanticipated asset purchases announcements. For instance, I find that, on average, a hypothetical unanticipated 100-basis-point hike in the Federal funds rate target is associated with roughly a 3% decrease in WTI oil prices. I also show that in a narrow window around the FOMC meeting the cumulative financial market impact of the Federal Reserve LSAP program on crude oil is equivalent to an unanticipated cut in the federal funds target rate of 155 basis points. The channel through which monetary policy affects oil prices is mostly by affecting the value of the U.S. dollar. This study also re-examines the identifying assumption that energy prices are predetermined with respect to U.S. macroeconomic aggregates. In contrast to Kilian and Vega (2011) results (based on daily data), I show that oil prices significantly react to U.S. macroeconomic surprises, such as industrial production, nonfarm payrolls, and consumer confidence, and to inventory news. This finding confirms that intraday data have the potential to give more precise estimates of announcement effects than what can be estimated with daily data.

Building on the results of this paper, a key direction for future research would be to broaden the set of news, including news on weather conditions, geopolitical developments, and the growth outlook of emerging market economies. This allows to better decompose changes in energy prices into several fundamental contributors. Furthermore, the findings of this work, together with the evidence provided in the existing

literature, suggest that the Federal Reserve monetary policy and U.S. macroeconomic news strongly affect oil prices. This implies that diversification and insurance against such shocks is limited. Understanding the implications for optimal portfolio choice and risk sharing is an important area for future research.

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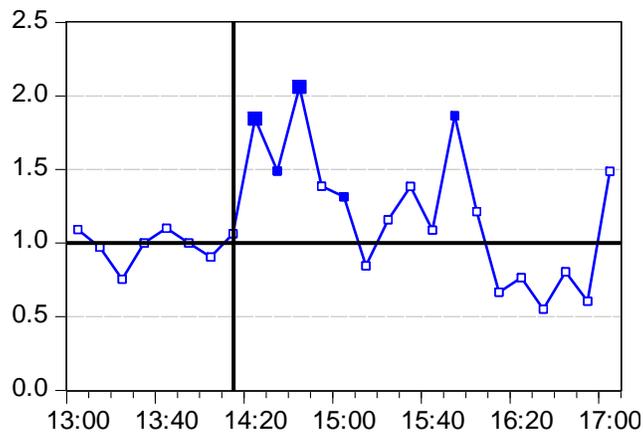
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Figure 1
The volatility and trading volumes of crude oil (WTI) futures around FOMC announcements

The figure (top panel) plots the ratio between (i) the standard deviation of the 5-min crude oil (WTI) futures returns around the FOMC announcement release and (ii) the standard deviation of the 5-min crude oil (WTI) futures returns on control days (the same weekdays and hours of the previous and following week of the FOMC meeting day). The figure (bottom panel) plots the median ratio between (i) the 5-min volumes on release days, and the average of (ii) the 5-min volumes on the same weekdays (of the previous and following week of the release day of the FOMC minutes) and hours but on non-announcement days. The sample is January 1999 - June 2011. The interval spans from 1 h before to 2 h after the event time. The vertical line is placed at the release time of the FOMC statement (see Rosa, 2012, for the exact time stamps of the FOMC meetings). Large and small filled squares denote significance of the differences at the two-sided 1 and 5 percent level respectively.

Panel A - Volatility



Panel B - Trading volume

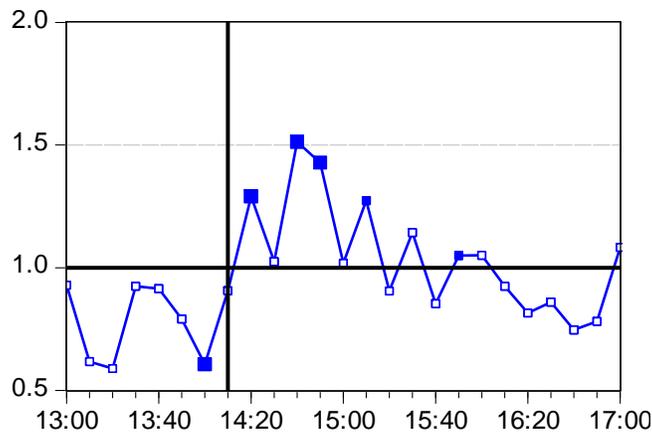


Table 1
Summary statistics and event days

The table reports the summary statistics for the variables used in the econometric analysis. Observations on days of FOMC meetings, January 1999 - June 2011. The asset price return is the percentage change in energy prices from 10-min before to 50-min after the event. The variable *TS* is computed using Kuttner (2001) methodology. The variables *Target* and *Path* factors are computed using Gurkaynak, Sack and Swanson (2005) methodology. The variable *LSAPS* is provided in Rosa (2012). In panel B the LSAP announcements that are not associated to FOMC meetings are highlighted in grey. The acronym “N.A.” stands for Not Available.

Panel A - Summary statistics

Variable	Mean	Std. Dev.	Max	Min	Non-zero observations	Obs.
Federal Reserve						
Federal funds target rate change	-0.04	0.25	0.50	-0.75	45	103
<i>TS</i>	-0.02	0.09	0.14	-0.47	81	103
<i>Target</i> factor	0.00	0.09	0.15	-0.46	103	103
<i>Path</i> factor	-0.00	0.17	0.54	-0.56	103	103
Energy prices						
Crude oil (WTI)	0.01	0.89	2.67	-2.97	96	97
Heating oil	0.06	0.72	2.50	-2.20	92	95
Natural gas	-0.10	1.09	2.19	-5.63	91	95

Panel B - LSAP event days and crude oil (WTI) futures returns

Date	Time	Event	LSAP surprise	Crude oil (WTI) Intraday	Daily
11/25/2008	08:15	Initial announcement	N.A.	4.65	-7.09
12/01/2008	13:40	Chairman speech	N.A.	-1.53	-9.94
12/16/2008	14:15	FOMC statement	0	-1.00	-2.07
01/28/2009	14:15	FOMC statement	0	-2.05	1.39
03/18/2009	14:15	FOMC statement	-1	2.67	-2.10
08/12/2009	14:15	FOMC statement	0	-0.44	1.02
09/23/2009	14:15	FOMC statement	0	0.16	-3.67
11/04/2009	14:15	FOMC statement	0	0.50	1.00
08/10/2010	14:15	FOMC statement	-1	0.69	-1.52
08/27/2010	10:00	Jackson Hole	N.A.	0.14	2.44
09/21/2010	14:15	FOMC statement	-1	N.A.	-1.81
11/03/2010	14:15	FOMC statement	0	0.39	0.94

Table 2
The intraday response of crude oil (WTI) futures prices to the Federal Reserve monetary policy

The table reports the results from a regression of the intraday percentage changes in crude oil (WTI) futures prices (from 10-min before the event to 50-min after) on a constant and monetary policy news. Observations on days of FOMC meetings, January 1999 - June 2011. The variable *TS* is computed using Kuttner (2001) methodology. The variables *Target* and *Path* factors are computed using Gurkaynak, Sack and Swanson (2005) methodology. The variable *LSAPS* is provided in Rosa (2012). The econometric method is Ordinary Least Squares with Heteroskedasticity-Consistent standard errors in brackets. The row “Cum. impact of LSAP” reports the cumulative impact of the unexpected component of the LSAP announcements in a narrow window around the FOMC meetings expressed in federal funds target rate cut (in basis points), whereas the row “90% confidence interval” reports its 90% confidence interval. The superscripts ^{***}, ^{**}, and ^{*} indicate statistical significance at the 1%, 5% and 10% level, respectively.

	Crude Oil (WTI)		
Constant	-0.03 (0.09)	0.02 (0.09)	-0.01 (0.09)
<i>TS</i>	-2.72 ^{***} (1.02)		
<i>Target</i> factor	-2.21 ^{**} -2.27 ^{**} (1.08) (1.09)		
<i>Path</i> factor	0.02 0.16 (0.52) (0.50)		
<i>LSAPS</i>	-1.76 ^{**} (0.73)		
Adj. R ²	0.047	0.012	0.082
Observations	97	97	97
Cum. impact of LSAP	155		
90% confidence interval	[33,591]		

Table 3
The intraday response of crude oil (WTI) futures prices quoted in EUR to the Fed's monetary policy

The table reports the results from a regression of the intraday percentage changes in crude oil (WTI) futures prices (from 10-min before the event to 50-min after) quoted in EUR on a constant and monetary policy news. Observations on days of FOMC meeting days, January 1999 - June 2011. The variable *TS* is computed using Kuttner (2001) methodology. The variables *Target* and *Path* factors are computed using Gurkaynak, Sack and Swanson (2005) methodology. The variable *LSAPS* is provided in Rosa (2012). The econometric method is Ordinary Least Squares with Heteroskedasticity-Consistent standard errors. The row "Cum. impact of LSAP" reports the cumulative impact of the unexpected component of the LSAP announcements in a narrow window around the FOMC meetings expressed in federal funds target rate cut (in basis points), whereas the row "90% confidence interval" reports its 90% confidence interval. The superscripts ^{***}, ^{**}, and ^{*} indicate statistical significance at the 1%, 5% and 10% level, respectively.

	Crude Oil (WTI) in EUR		
Constant	-0.10 (0.09)	-0.06 (0.09)	-0.07 (0.09)
<i>TS</i>	-2.43 (1.67)		
<i>Target</i> factor		-1.33 (1.76)	-1.34 (1.78)
<i>Path</i> factor		1.22 ^{**} (0.55)	1.24 ^{**} (0.55)
<i>LSAPS</i>			-0.33 [*] (0.17)
Adj. R ²	0.037	0.055	0.047
Observations	97	97	97
Cum. impact of LSAP			49
90% confidence interval			[-210,232]

Table 4
The daily response of crude oil (WTI) futures prices to the Federal Reserve monetary policy

The table reports the results from a regression of the daily percentage changes in crude oil (WTI) futures prices (Bloomberg ticker: CL1 COMDTY) on a constant and monetary policy news. Observations on days of FOMC meetings, January 1999 - June 2011. The variable *TS* is computed using Kuttner (2001) methodology. The variables *Target* and *Path* factors are computed using Gurkaynak, Sack and Swanson (2005) methodology. The variable *LSAPS* is provided in Rosa (2012). The econometric method is Ordinary Least Squares with Heteroskedasticity-Consistent standard errors in brackets. The superscripts ^{***}, ^{**}, and ^{*} indicate statistical significance at the 1%, 5% and 10% level, respectively.⁸

	Crude Oil (WTI)		
Constant	-0.09 (0.26)	-0.07 (0.25)	-0.02 (0.26)
<i>TS</i>	-1.41 (3.04)		
<i>Target</i> factor		-0.85 (3.12)	-0.66 (3.16)
<i>Path</i> factor		-0.64 (1.60)	-0.79 (1.62)
<i>LSAPS</i>			1.83 ^{***} (0.34)
Adj. R ²	-0.008	-0.018	-0.013
Observations	102	102	102

Table 5
The intraday and daily response of crude oil futures prices to macroeconomic news announcements

The table reports the results from regressions of intraday percentage changes in crude oil (WTI) futures prices (from 10-min before the event to 50-min after) on a constant, and the standardized macroeconomic or oil news. Observations are on days of scheduled macroeconomic releases, January 1999 - June 2011. The econometric method is Ordinary Least Squares with Heteroskedasticity-Consistent standard errors. The signs of the announcement surprises in the countercyclical indicators (unemployment rate and initial jobless claims) denoted with the [†] symbol have been flipped. The nonfarm payrolls and unemployment rate are always announced simultaneously. Also the inventory figures from the Department of Energy (DoE) are always announced simultaneously. The acronym “SA” stands for seasonally adjusted. Data-mining robust p-values are based on a parametric bootstrap approach under the null hypothesis of no predictability (one-sided test). The “Adj. R²” (aligned with Nonfarm payrolls) stands for the adjusted R² of the estimation of a baseline specification that includes a constant, nonfarm payroll and unemployment rate surprises as explanatory variables. The robust p-values (see Kilian and Vega, 2011) are based on 10,000 bootstrap replications. The superscripts ^{***}, ^{**}, and ^{*} indicate statistical significance at the 1%, 5% and 10% level, respectively.

	Intraday				Daily			
	Coeff.	Robust p-value	Adj. R ²	Obs.	Coeff.	Robust p-value	Adj. R ²	Obs.
Real activity								
Industrial production	0.25 ^{**}	0.129	0.105	126	0.15	0.940	-0.001	146
Retail sales	0.05	0.971	-0.000	127	0.38	0.613	0.019	148
Nonfarm payrolls	0.16 ^{**}	0.128	0.029	126	0.31	0.538	0.009	145
Unemployment rate [†]	0.07	0.955			-0.06	1.000		
Initial jobless claims [†]	-0.00	1.000	-0.002	552	0.14	0.809	0.002	643
Trade balance	0.13 [*]	0.472	0.037	126	0.17	0.953	-0.002	149
Prices								
CPI SA	-0.10	1.000	0.023	122	0.27	0.628	0.009	148
PCE core SA	-0.10	1.000	0.009	73	-0.23	1.000	-0.008	73
Forward-looking								
ISM index	0.03	0.998	-0.007	126	0.33	0.711	0.005	129
Consumer confidence	0.16 [*]	0.335	0.030	129	-0.05	1.000	-0.007	142
Inventories								
DoE U.S. crude oil	-0.53 ^{***}	0.000	0.223	415	-0.52 ^{***}	0.003	0.042	416
DoE U.S. distillate	-0.34 ^{***}	0.000			-0.31 ^{**}	0.146		
DoE U.S. gasoline	-0.20 ^{***}	0.009			-0.13	0.911		