Central Bank Tone and Currency Risk Premia

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Abstract

I analyze how the tone of central bank press conferences impacts risk premia in the currency market. I measure tone as the difference between the number of hawkish and dovish phrases made during a press conference. I consider two measures of risk premia. The first measure is implied risk aversion. This is based on the relationship between the option implied, or risk neutral distribution of returns, and the physical, or actual distribution of returns. I find that implied risk aversion increases when central banks are hawkish, and decreases when central banks are dovish. The second measure is the variance risk premium. This is the difference between option implied and realized variance, and reflects the cost of insuring against an unexpected increase in variance. I find that variance risk premia increase when central banks are hawkish, and decrease when central banks are dovish. The magnitudes are economically and statistically significant. A one standard deviation increase in the hawkishness of a press conference increases implied risk aversion by 1.4%, and increases the one month variance risk premium by 4.1% per year, relative to the average of 28.8% per year.

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1 Introduction

Central bank press conferences move markets. Press conferences are live, partially unscripted, and provide market participants clues on future policy actions. Press conferences can reveal news not previously available to the markets.\(^1\) This paper asks how the tone of central bank press conferences impacts risk premia in the currency market.

I measure tone as the difference between the number of hawkish and dovish phrases made during a press conference, using the method in Apel & Grimaldi (2014).\(^2\) I examine the impact of tone on two measures of risk premia. The first measure is implied risk aversion, as defined in Jackwerth (2000). It is based on the relationship between the option implied, or risk neutral distribution of returns, and the physical, or actual distribution of returns. The former is estimated using a cross section of option prices, while the latter is estimated using a historical time series of returns. I find that implied risk aversion increases when central banks are hawkish, and decreases when central banks are dovish. A one standard deviation increase in the hawkishness of a press conference increases implied risk aversion by 1.4%. This is a contemporaneous result, meaning that central bank tone explains the contemporaneous change in implied risk aversion.

The second measure is the variance risk premium. This is the difference between option implied and realized variance. The variance risk premium reflects the cost of insuring against an increase in variance. Using the method in Carr & Wu (2009), I construct one month variance risk premia for each currency. I find that variance risk premia increase when central banks are hawkish, and decrease when central banks are dovish. The magnitudes are economically and statistically significant. A one standard deviation increase in the hawkishness of a press conference increases the one month variance risk premium by 4.1% per year, relative to the average of 28.8% per year. This is a predictive result, meaning that central

\(^1\)For example, Hansen & McMahon (2016) show that FOMC communication over future monetary policy decisions has a significant impact on both financial and real variables.

\(^2\)A hawkish central bank is likely to increase interest rates or tighten monetary policy. A dovish central bank is likely to lower interest rates or loosen monetary policy.
bank tone predicts future realized variance risk premia.

The two risk aversion measures are related in the following way. When implied risk aversion is higher, it means that options are more expensive, relative to their value if investors were risk neutral. When options are relatively expensive, the expected return from shorting a variance swap is higher. This intuition is confirmed by the empirical results. Hawkish central bank tone contemporaneously increases implied risk aversion, and also predicts higher realized variance risk premia.

In addition, I analyze the impact of separate portions of the press conference: the introductory statement and the questions & answers. The introductory statement is prepared beforehand, while the questions & answers are unscripted. I find that the impact of the press conference comes primarily from the questions & answers, or the unscripted portion of the press conference.

This paper makes two contributions. The first is a joint analysis of the impact of central bank press conferences on risk premia across a range of countries and currencies. The second is the use of central bank tone to explain changes in implied risk aversion, and to predict variance risk premia. To the best of my knowledge, these contributions are novel.

This paper adds to the recent literature on the impact of central bank tone on financial markets. Calomiris & Mamaysky (2019) analyze the impact of monetary policy on exchange rates, and how this varies across risk regimes. They use a natural language based measure of monetary policy stances and document spillover effects from the Bank of England, Bank of Japan, and the ECB, to exchange rate returns of other currencies against the dollar. They find that the relationship between interest rate differentials and future currency returns varies across risk regimes. My paper differs from theirs in two ways. First, I study the impact of monetary policy on currency option markets, and measures of risk premia derived from option markets. Second, I analyze the immediate market impact of press conferences, rather than long term effects.

Schmeling & Wagner (2019) analyze the tone of European Central Bank press conferences,
and find that positive tone is associate with higher bond yields, lower implied equity volatility, lower variance risk premia, and lower credit spreads. They use the method in Loughran & McDonald (2011) to measure tone, which based on the proportion of negative words contained in the text.³ My paper differs from theirs in the two ways: First, I specifically analyze currency markets across a range of central banks, whereas Schmeling & Wagner (2019) analyze the European central bank’s impact across a range of European financial markets. Second, I use a two sided measure of tone (hawkish and dovish), whereas they use a one sided measure of tone. This turns out to matter considerably. I report results using their method, and this is discussed further in section 4.2.

Why is central bank tone important for asset prices? It is well documented that central bank policy decisions impact asset prices.⁴ However, the impact of their words is relatively understudied. In part, this is because central bank use of words as a policy tool is relatively recent. Following the financial crisis of 2007-08, many countries lowered interest rates close to zero. Since then, they have increasingly relied on forward guidance as a policy tool. Forward guidance is communication to the public about the future course of monetary policy.⁵ Individuals, firms, and investors incorporate this information into their decisions. Consequently, forward guidance has an immediate impact on the economy and financial markets.⁶

Why do risk premia change in response to the tone of central bank press conferences?

³Alternative approaches to analyze central bank text are in proposed Lucca & Trebbi (2009) and Acosta (2015).

⁴For example, Lucca & Moench (2015) document large average excess returns on U.S. equities in anticipation of monetary policy decisions made at FOMC meetings. Cieslak et al. (2018) show that most of the U.S. equity risk premium is earned over the weeks corresponding to the FOMC cycle. Boyarchenko et al. (2016) show that Federal Reserve announcements impact markets independent of changes in conventional monetary policy.

⁵In the early 2000s, the US Federal Reserve began using forward guidance. For example, in December 2008, the Fed lowered interest rates close to zero. Additionally, they stated that the Federal Funds rate would remain exceptionally low for some time due to weak economic conditions. By communicating its intention to keep future interest rates low, the Fed was hoping to influence then-prevailing decisions. Seven years later, in December 2015, the Fed raised interest rates. At the same time, they communicated their intention to raise interest rates over the coming year.

⁶Campbell et al. (2012) and Filardo & Hofmann (2014) examine the impact of forward guidance on macroeconomic variables and asset prices. Del Negro et al. (2012) and McKay et al. (2016) show that the impact of forward guidance is small in practice, relative to theoretical predictions. Swanson (2017) shows that forward guidance has significant impacts on Treasury yields, stock prices, and exchange rates.
One explanation is that the tone of a press conference indicates to investors the likelihood of central bank intervention, conditional on the state of the economy. Suppose that the central bank has a reaction function defined over various future economic states, and this is not known to the investor. Instead, the investor has some expectations. These are then updated in response to new information, such as press conferences.

A hawkish central bank is less likely to provide monetary stimulus in bad states of the world. A dovish central bank is more likely to provide monetary stimulus in bad states of the world. For example, Belke & Klose (2010) compare how the Fed and the ECB reacted to the financial crisis of 2007-08. The Fed was more aggressive in easing monetary policy, relative to the ECB. This is partly attributed to the difference in their respective mandates. The Fed has a dual mandate of stable prices and maximum employment, whereas the ECB’s mandate is price stability. This means the Fed is more dovish than the ECB. As a result, the Fed puts a greater weight on the output gap, and is more likely to provide monetary stimulus in response to a crisis.

Following a press conference, suppose the investor believes that the central bank is more likely to provide monetary stimulus in bad states of the world, i.e. the central bank is dovish. Then the investor has less incentive to pay for insurance in those states, and risk premia decrease. Now suppose instead the investor believes that the central bank is less likely to provide monetary stimulus in bad states of the world, i.e. the central bank is hawkish. Then the investor has more incentive to pay for insurance in those states, and risk premia increase. A well known example of this phenomenon is the Greenspan put. Alan Greenspan, the former chairman of the Federal Reserve, would decrease interest rates when the stock market fell by a certain amount. The central bank essentially provided a put option to investors, protecting them when markets declined.\footnote{A put option’s payoff is decreasing in the price of the underlying asset. Index put options are often used by investors to insure against a fall in the stock market.}

Why are currencies the best channel to analyze the impact of central banks on risk premia? The first reason is data availability. I have access to option data traded on the
Chicago Mercantile Exchange (CME). A prerequisite for this paper’s analysis is liquid option markets, and currencies meet this criteria. In addition, currencies allow the incorporation of data from multiple central banks, each corresponding to its own currency. As the CME is a US based exchange, for any other asset class, the CME option data is relevant only for the Fed, and not other central banks. For example, treasury bond options or S&P 500 options are not significantly impacted by foreign central banks. The Fed data consists of 32 press conferences, while the sample size of all central banks is 224 press conferences.

The second reason is that currencies are disproportionately affected by interest rates, and hence central bank behavior, relative to stocks or commodities. This holds true even if central banks do not directly attempt to influence exchange rates, as they may do with bonds or equities. Like currencies, bonds are also primarily impacted by interest rates and central bank behavior. However, they suffer from the data limitation discussed earlier. Currencies are impacted by the interest rate differential between the home and foreign currency. Currencies typically appreciate in response to a current or an expected future increase in interest rates. And they depreciate in response to a current or an expected future decrease in interest rates. Other macroeconomic data matter for currency markets, and can be interpreted through the lens of how it might impact central banks and interest rates. On the other hand, for stocks and commodities, interest rates matter, but they aren’t necessarily the most important factor.

The remainder of this paper is organized as follows: Section 2 describes the data. Section 3 presents the methodology. This includes the construction of central bank tone, implied risk aversion, and variance risk premia. An empirical example is presented for exposition,

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8 Asset classes include stocks, bonds, currencies, and commodities.
9 An important result in this literature is the forward premium puzzle, documented in Fama (1984) and Hansen & Hodrick (1980). The puzzle is that higher interest rates currencies earn excess returns over lower interest rate currencies.
10 For example, if inflation or GDP growth is high, the central bank is likely to tighten monetary policy and increase interest rates. Alternatively, if inflation is low or the economy is weakening, the central bank is likely to loosen monetary policy and decrease interest rates.
11 Stocks are impacted by expectations of future cash flows. Commodities are impacted by their own fundamentals.
followed by the proposed regression specification. Section 4 presents and discusses the results. Section 5 concludes.

2 Data

This section describes the data. The data consist of currency futures and option contracts, and central bank press conference transcripts.

2.1 Currency Futures and Options

2.1.1 Currency Futures

Currency futures are traded on the Chicago Mercantile Exchange (CME). I use data on four currency futures contracts: the British pound (GBP), the Canadian dollar (CAD), the euro (EUR), and the Swiss franc (CHF). Prices are sampled at five minute intervals. The data come from DTN IQFeed.\(^\text{12}\) Prices are quoted as the number of US dollars (USD) per unit of foreign currency.\(^\text{13}\) Returns on the US dollar are constructed as a weighted average of the returns on each of the currency contracts.\(^\text{14}\)

The currency futures market trades 23 hours per day, 5 days per week. Trading begins at 6.00pm EST on Sunday, and stops at 5.00pm EST on Friday. There is a 1 hour trading break from 5.00pm EST to 6.00pm EST each day. Closing prices are at 5.00pm EST from Monday to Friday. Currency contracts trade in a quarterly cycle, with expiries in March, June, September, and December each year. For all contracts other than the Canadian dollar, they expire the business day preceding the third Tuesday of the contract month, which is usually a Monday. The Canadian dollar contracts expire the business day preceding the

\(^{12}\)DTN IQFeed is an online provider of live and historical financial market data. Their currency futures data is sourced directly from the CME.

\(^{13}\)A price increase is an appreciation of the foreign currency, and a depreciation of the US dollar. A price decrease is a depreciation of the foreign currency, and an appreciation of the US dollar.

\(^{14}\)The weights correspond to the proportions in the US dollar index DXY, and are as follows: 14.4% (GBP), 11.1% (CAD), 70.1% (EUR), and 4.4% (CHF). These are intended to reflect relative trading volumes of each currency to the dollar.
third Wednesday of the contract month, which is a usually a Tuesday.

The raw data take the form of continuous futures contracts. This is necessary in order to ensure that returns are correctly calculated. Prices are back-adjusted to create a continuous contract. This works by removing price gaps caused by a contract roll. The process starts at the end of the price series, and works its way back. This leaves current prices intact. Prices prior to the last roll date are adjusted. All currency contracts except for the Canadian dollar are rolled two days prior to expiry. The Canadian dollar is rolled three days prior to expiry to ensure that all contracts are rolled on the same day.

2.1.2 Currency Options

Options on the currency futures contracts also trade on the CME. These trade on a monthly cycle. I use option data on each of the four currencies. The data come from OptionWorks via Quandl.\textsuperscript{15} Option prices are sampled at the close of each trading day. The data start in June 2009 and end in December 2018. The data take the form of one month implied volatility curves.

Implied volatility is a function of the strike price. First, the option price is converted to an implied volatility, $\sigma$, via the Black Scholes model. This is done across the range of traded strike prices. Let $F$ be the futures price, $K$ be the strike price, $T$ be the time to maturity, $\sigma$ be the implied volatility, and $r$ be the interest rate. The call option price $C$ is given by:

\[
C = e^{-rT}[FN(d_1) - KN(d_2)]
\]

\[
d_1 \equiv \frac{\log(F/K) + (\sigma^2/2)T}{\sigma\sqrt{T}}
\]

\[
d_2 \equiv d_1 - \sigma\sqrt{T}
\]

Next, a polynomial of degree six is fitted to the data. This produces the implied volatility curve, where implied volatility is a function of the strike price. For convenience, the strike

\textsuperscript{15}Quandl is online data provider of financial and economic data. OptionWorks is one of the databases within Quandl that specializes in options on futures.
price $K$, is expressed as moneyness $M$, or the percentage deviation from the current futures price $F$.

\[ M \equiv \log(K/F) \]

\[ \sigma(K) = b_0 + b_1 M + b_2 M^2 + b_3 M^3 + b_4 M^4 + b_5 M^5 + b_6 M^6 \]  

(2)

The raw data consists of the closing futures price, the six model coefficients, the minimum and maximum moneyness, and the time to expiry. The minimum and maximum moneyness are upper and lower bounds. They reflect the fact that option prices only trade in a certain range of the current futures price. Typically, this includes the $5^{th}$ and $95^{th}$ quantile of the distribution.

Any strike and implied volatility pair can be converted to a call or put option price via the Black Scholes model. Using implied volatility curves does not require that Black Scholes assumptions hold. The implied volatility can be thought of as a normalized option price. It allows for a more intuitive comparison of option prices across strikes, time to maturity, or underlying currencies.

The curves are constructed for constant one month maturity. Options trade on a monthly cycle. One month contracts are created by interpolating across traded options with maturities less than and greater than one.\textsuperscript{16}

2.2 Central Bank Press Conferences

Central bank announcements consist of two parts. The first part is a policy action. Usually, this is an overnight interest rate that is either lowered, raised, or held constant. Policy actions include asset purchases. The second part is text. Examples of text include press conferences, interest rate decisions, meeting minutes, and economic outlook publications. The text contains useful information pertaining to the state of the economy and the future

\textsuperscript{16}This is a standard procedure. For example, this method is used to calculate the VIX, the one month implied volatility of the S&P500 index.
path of monetary policy. A press conference typically includes an introductory statement, followed by questions & answers. Press conferences tend to have the largest impact on asset prices. This is because they take place in real time and are partially unscripted.

I use press conference transcripts for five central banks: The Bank of England (BOE), the Bank of Canada (BOC), the European Central Bank (ECB), the Swiss National Bank (SNB), and the US Federal Reserve (FED). All the press conference data is publicly available on each central bank’s website. The Bank of England, Bank of Canada, and US Federal Reserve hold four press conferences per year. These coincide with alternate interest rate announcements that are made eight times per year. The European Central Bank holds eight press conferences per year, coinciding with each interest rate decision.¹⁷ The Swiss National Bank holds two press conferences per year. These coincide with alternate interest rate announcements that are made four times per year. The total sample consists of 224 press conferences. The data start in June 2009 for all central banks excluding the Fed. The Fed data start in April 2011, at the time it started holding press conferences. All the data end in December 2018.

3 Methodology

In this section, I present the methodology. First, I measure central bank tone, compute implied risk aversion, and compute variance risk premia. Then, I present an empirical example of a single observation. Finally, I use a regression to measure the impact of central bank tone on implied risk aversion and variance risk premia.

3.1 Central Bank Tone

Central bank tone is measured by the relative frequency of hawkish and dovish phrases. I use the method in Apel & Grimaldi (2014). Each phrase is a two word combination, consisting of an adjective followed by a noun. The nouns are common to both hawkish and dovish

¹⁷Through December 2014, the ECB held twelve press conferences per year.
phrases, while the adjective is used to identify whether the phrase is hawkish or dovish. Table 1 lists the adjectives and nouns. A hawkish phrase consists of a hawkish adjective and a noun. A dovish phrase consists of a dovish adjective and a noun. Any combination of adjective and noun is considered a phrase. For example, increased inflation is a hawkish phrase, while slower growth is a dovish phrase.

For each press conference, I count the number of hawkish phrases, \( #Hawk \), and dovish phrases, \( #Dove \). I define the net index, \( NI \), as the difference between the two.

\[
NI = #Hawk - #Dove
\]  

When the net index is greater than zero, tone is hawkish. When the net index is less than zero, tone is dovish. The magnitude of the net index indicates how hawkish or dovish the tone is. Figure 1 plots the net index for each central bank.

Apel & Grimaldi (2014) propose this method to analyze the text in Swedish central bank minutes. First, they select a set of phrases that are either hawkish or dovish. Second, they count the number of hawkish and dovish phrases contained in the text. Their measure of tone is based on the relative proportion of hawkish and dovish phrases contained in the text. They find that the tone of Swedish central bank minutes is useful in predicting future interest rate decisions, and conclude that the minutes contain useful information not captured by observable macroeconomic variables. Phrases associated with a stronger economy or higher inflation are hawkish, while phrases associated with a weaker economy or lower inflation are dovish.\(^{18}\)

The upside to this approach is that tone can be quantified and objectively calculated. It can later be used in a regression. The downside is that the full content of the announcement is not captured. Given that text is inherently subjective, there is an inevitable trade-off in objectively quantifying tone.

\(^{18}\)Hawkish tone implies that the central bank is likely to tighten monetary policy in the future, while dovish tone implies that the central bank is likely to ease monetary policy in the future.
Why is this best method to measure central bank tone? Loughran & McDonald (2016) document that most methods to measure tone or sentiment rely on the frequency of certain words or phrases in the text. The relevant words are selected based on what the researcher wishes to measure. The method I use in this paper, based on Apel & Grimaldi (2014), differs in two ways from other common methods. First, it uses the frequency of two word combinations rather a single word. This increases the precision of each phrase, at the expense of fewer phrases identified. Second, it uses two categories of phrases (hawkish and dovish), instead of one. Loughran & McDonald (2011) show that the negative words are better at measuring tone, relative to positive words, and so some studies use only one category of phrases. This is because positive words are more frequently negated, relative to negative words. This is more likely to be a problem when analyzing single words rather than two word combinations. The use of two word combinations makes it easier to accurately identify two categories of phrases.

Apel & Grimaldi (2014) apply their method to Swedish central bank minutes, which is published in Swedish. Is there a linguistic issue in applying this method to other central banks? Other than the Swiss National Bank, all the central banks analyzed in this paper publish in English (including the European Central Bank). The Swiss National Bank publishes English language versions of their statements; these are what I use. Even though this list of words is developed in the context of the Swedish central bank, all the words are commonly used in English, and are regularly used by economists and central bankers. There is no reason to believe that the list of words would be any different if the initial method was developed for an English medium central bank.

Note that Apel & Grimaldi (2014) calculate the net index differently. They take the difference between the number of phrases hawkish and dovish phrases, and divide by the total number of phrases. Their net index is the proportion of hawkish or dovish phrases, rather than raw value. I avoid this method so that the magnitude of the net index is more

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19 Alternatives include machine learning based approaches that are beyond the scope of this paper.
20 For example, Schmeling & Wagner (2019) analyze ECB press conferences using only negative words.
meaningful. Suppose, for example, that the central bank makes nine dovish phrases and one hawkish phrase. The regular net index is $-8$, while the proportional net index is $-0.8$. In the next period, suppose that the central bank makes two dovish statements and no hawkish statements. The regular net index is $-2$, while the proportional net index is $-1$. Which of the two statements is more dovish? We get different answers depending on which measure we use. The baseline results are reported using the regular net index. As a robustness check, results are reported using the proportional net index.

A potential downside to not using the proportional net index is that results are affected by the length of the press conference. For example, a longer press conference implies a higher frequency of phrases, but not necessarily a higher proportion of phrases. This is only a problem if there is considerable variation in the length of press conferences. Table 2 reports the average length (in words) of each central bank’s press conferences, and the corresponding coefficient of variation (standard deviation divided by average length). First, note that there is considerable variation in average length across central banks. But within central banks, this is generally not the case. Other than the Bank of England, the coefficient of variation is low for each central bank. The standard deviation of the net index for each central bank tends to vary in line with the average length of the press conference. Central banks with longer press conferences have a larger standard deviation of the net index. In the regression analysis, observations for each central bank are pooled together. I control for the difference in press conference length by dividing each central bank’s net index by its own standard deviation. This makes the net index value comparable between central banks, in addition to a more intuitive interpretation.

### 3.2 Implied Risk Aversion

Implied risk aversion is identified from the risk neutral and physical densities of returns, at a one month horizon. This approach follows the method of Jackwerth (2000). Consider a complete market economy with a representative investor. The investor maximizes expected
utility subject to a budget constraint. Let $S$ denote the state, $p(S)$ the physical density, $q(S)$
the risk neutral density, $W(S)$ the investor’s wealth, $U[W(S)]$ the investor’s utility function,
and $\lambda$ the Lagrange multiplier. The investor is endowed with one unit of wealth, and can
purchase state contingent securities. The investor maximizes expected utility subject to the
budget constraint.

$$\max \int p(S)U[W(S)] \, dS - \lambda \left( \int q(S)W(S) \, dS - 1 \right)$$ (4)

The investor chooses wealth in each state to equate the expected marginal utility of
wealth with its relative price. The optimal solution results in the following expressions for
$U'[W(S)]$ and $U''[W(S)]$.

$$U'[W(S)] = \lambda \frac{q(S)}{p(S)}$$

$$U''[W(S)] = \lambda \left( \frac{p(S)q'(S) - q(S)p'(S)}{[p(S)]^2} \right)$$

I combine these two equations to get an expression for the Arrow-Pratt coefficient of
absolute risk aversion, $ARA(S)$. The absolute risk aversion function is identified from the
risk neutral and physical densities, as the Lagrange multiplier is no longer in the expression.

$$ARA(S) = -\frac{U''[W(S)]}{U'[W(S)]} = \frac{p'(S)}{p(S)} - \frac{q'(S)}{q(S)}$$ (5)

Closely related to absolute risk aversion function is the pricing kernel, $m(S)$. This is
the ratio of the risk neutral density to the physical density. Intuitively, this is the price of
consumption in a given state, relative to the probability that the state occurs.

$$m(S) = \frac{q(S)}{p(S)}$$ (6)

The absolute risk aversion function is proportional to the derivative of the pricing kernel.
The slope of the pricing kernel tells us the sign of the absolute risk aversion function. When the pricing kernel is downward sloping, absolute risk aversion is positive. When the pricing kernel is upward sloping, absolute risk aversion is negative.

\[ ARA(S) = -\frac{m'(S)}{m(S)} \]  

(7)

To estimate the risk neutral density, I employ the method of Malz (2014). Recall from section 2 that each observation is an implied volatility curve, which is a function of the strike price. I convert implied volatilities into call option prices, via the Black-Scholes formula, given by equation 1.\(^{21}\)

The call option price can be calculated for any strike price, \( K \). Define this as the call valuation function, \( C(K) \). The risk neutral CDF is the derivative of the call price with respect to the strike price. The risk neutral PDF is the derivative of the CDF with respect to the strike price. The derivatives are approximated by numerical differencing. I calculate the call price across a fine grid of strike prices. This fills in the gaps between the prices of actual traded options. A discrete set of option prices becomes effectively continuous. This is necessary to compute a density function, that is also continuous. The step size of the grid is \( \Delta = 0.1\% \). The unit is log return, or the log difference between the strike price the and current futures price. The risk neutral CDF \( Q(K) \) and PDF \( q(K) \) are given by:

\[ Q(K) \approx 1 + e^{-rT} \frac{1}{\Delta} \left[ C\left(K + \frac{\Delta}{2}\right) - C\left(K - \frac{\Delta}{2}\right)\right] \]  

(8)

\[ q(K) \approx \frac{1}{\Delta} \left[ Q\left(K + \frac{\Delta}{2}\right) - Q\left(K - \frac{\Delta}{2}\right)\right] \]

This procedure is valid for strikes within the minimum and maximum moneyness. The density is constructed only as far as actual options are traded. Appending tails to the density requires an extrapolation of option prices, rather than interpolation between prices. There

\(^{21}\)Using implied volatility curves does not require that Black Scholes assumptions hold. The implied volatility can be thought of as a normalized option price. It allows for a more intuitive comparison of prices across contracts and over time.

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are numerous methods to append tails to the distribution. Usually, it requires assuming a particular distribution to fit the tails, such as lognormal or generalized extreme value. I do not append tails to the distribution. Instead, I define the density and compute implied risk aversion only in the range of traded strike prices. This typically includes the 5th and 95th quantile of the distribution. Incorporating tails into the distribution does not have a material impact on calculation of implied risk aversion, and the subsequent results. Further, the results are a function only of traded option prices, rather than how the tails are appended.

The physical density is estimated using the Realized GARCH model of Hansen et al. (2012), combined with filtered historical simulation. It is constructed using a historical time series. The Realized GARCH model incorporates measurements of volatility based on intraday high frequency data, and it allows for an asymmetric response of volatility to positive and negative shocks, i.e. leverage effects.\(^{22}\) Let \(y_t\) be the daily return on the futures contract, \(h_t\) be the latent volatility process, and \(x_t\) be the daily realized volatility constructed from five minute returns. \(\epsilon_t\) and \(v_t\) are mean zero i.i.d. innovations. The model consists of three equations: the return equation, the GARCH equation, and the measurement equation.

\[
\begin{align*}
    y_t &= \mu + \sqrt{h_t} \epsilon_t \\
    \log h_t &= \omega + \sum_{i=1}^{q} \alpha_i \log h_{t-i} + \sum_{i=1}^{p} \beta_i \log x_{t-i} \\
    \log x_t &= \zeta + \delta \log h_t + \eta_1 \epsilon_t + \eta_2 (\epsilon_t^2 - 1) + v_t
\end{align*}
\]

I set \(p = 1\) and \(q = 2\). This is the preferred specification of Hansen et al. (2012). I assume \(\epsilon_t\) is student t distributed with variance one, and \(v_t\) is normally distributed. For each density, the GARCH model is estimated using daily data. This includes daily values of realized volatility compute from five minute returns.\(^{23}\) For exposition, table 3 presents estimates for a single observation. All estimates are computed out of sample, meaning that models are estimated using only data available at the time.

\(^{22}\)Leverage effects are statistically significant for currencies, as per the results in table 3.
\(^{23}\)Estimation is by maximum likelihood using the rugarch package in R.
An alternative specification for the GARCH model is to include the net index as an explanatory variable in the GARCH equation. When doing so, the estimated coefficient on the net index is not statistically significant. One interpretation of this finding is that the impact of the net index is primarily captured through option prices and the risk neutral density, rather than the physical density. That said, an alternative explanation is that the sample size of press conference for each currency is too small, leading to limited statistical power.\(^{24}\)

The statistical power of the net index comes from pooling the central bank observations together. Further, since the GARCH models are estimated out of sample, including the net index would make it difficult to construct a density forecast for the first few press conferences.

Once the GARCH model is estimated, filtered historical simulation (FHS) is used to construct a density forecast one month ahead. This process is repeated for each date. The FHS procedure works as follows:

1. Sample \(D\) standardized residuals with replacement from the model, where \(D\) is the number of trading days in a month.

2. The residuals are fed iteratively through the GARCH model to construct a simulated monthly return.

3. Repeat this process 500,000 times to construct 500,000 simulated monthly returns.

4. Apply a kernel density estimator on the simulated returns to construct the density.

The bandwidth choice is based on the plug in method of Wand & Jones (1994).

Using the estimated risk neutral and physical densities, I compute risk aversion as a function of future states. The risk aversion function is proportional to the derivative of the pricing kernel, as per equation 7. One point to note is that the function is not smooth. This is because the physical density is estimated using a kernel smoother. The bandwidth is selected to ensure that the density is smooth, but does not ensure that the derivative of

\(^{24}\)The GARCH model is estimated separately for each currency.
the density is smooth. Calculating the risk aversion function requires the derivative of the physical density. To get around this problem, I fit the risk aversion function to a polynomial of degree two.

To see how this works, let $r$ be the return on the currency futures contract. When $r$ is positive, the foreign currency appreciates relative to the US dollar. When $r$ is negative, the foreign currency depreciates relative to the US dollar. The polynomial coefficients can be interpreted as the level, slope, and curvature of the risk aversion function. Typically, the three coefficients capture 99% of the variation in the risk aversion function. Thus, a quadratic polynomial is sufficient to capture the variation in the risk aversion function, without significant approximation errors.\(^{25}\)

$$ARA(r) = a + br + cr^2$$  \hspace{1cm} (10)

In the majority of cases, risk aversion is positive in states where the foreign currency depreciates ($r < 0$), and it is negative in states where the US dollar depreciates ($r > 0$). A positive sign indicates a premium to holding the foreign currency. A negative sign indicates a premium to holding the US dollar. The implication is that there is hedging on both sides of the contract. Investors pay a premium to hedge against declines in the foreign currency as well as declines in the US dollar. This is equivalent to a U-shaped pricing kernel.\(^{26}\)

I define implied risk aversion as the probability weighted sum of the distance between the risk aversion function and zero. The probabilities come from the physical density estimates. The absolute value of risk aversion tells us the degree of insurance or hedging demand. The sign of this number tells us the direction, i.e. demand for hedging the foreign or domestic currency. The best way to capture the total amount of risk aversion in single number is a weighted sum of the distance between the risk aversion function and zero. In the regression,\(^{25}\) Gagnon & Power (2016) apply a similar approach to measure changes in risk aversion in the crude oil market.

\(^{26}\)The hedging demand on both sides isn’t necessarily the same. Net hedging, or the difference between the positive and negative values of risk aversion, need not be zero.
I use the change in implied risk version over the course of the press conference. Suppose the press conference takes place during market hours on day $\tau$. Then I compute the change in implied risk aversion between the close of day $(\tau - 1)$ to the close of day $\tau$.

$$IRA = \sum_r p(r) |ARA(r)| \quad (11)$$

$$\Delta IRA^{\tau-1,\tau} = \log IRA^\tau - \log IRA^{\tau-1} \quad (12)$$

To the best of my knowledge, this definition is not present in the literature. Prior studies, such as Jackwerth (2000), assume that the return is a proxy for wealth. In that case, there is no reason to use the absolute value of implied risk aversion when aggregating across the distribution. This link between returns and wealth is a reasonable assumption when the underlying asset is a market index such as the S&P 500, rather than a currency futures contract. If the absolute value is not used, then positive and negative values of risk aversion cancel each other out. However, if positive and negative values of implied risk aversion actually represent hedging demand on both sides of the contract, it is the magnitude that matters. Then, the absolute value is the correct measure.

### 3.3 Variance Risk Premium

The variance risk premium is the difference between option implied and realized variance. It reflects the cost of insuring against an increase in variance. Suppose that variance is time varying and that investors dislike higher variance. Then, investors are willing to pay a premium to insure against an unexpected increase in variance. Currency variance risk premia have been found to predict future returns. Della Corte et al. (2016) find that low insurance-cost currencies outperform high insurance-cost currencies. Londono & Zhou (2017) find that currency variance risk premia predict future changes in exchange rates. Menkhoff et al. (2012) find a strong link between currency variance risk premia and returns from currency carry trades.
I use the method in Carr & Wu (2009) to quantify the variance risk premium. Their method constructs a variance swap using realized and option implied variance. They show that the variance swap rate is well approximated by a particular portfolio of options. A variance swap is a forward contract on the realized variance of an underlying asset. Suppose a swap is initiated at the close of day $\tau$, and matures at the close of day $(\tau + 30)$. Let $RV_{\tau,\tau+30}$ be the thirty day (one month) realized variance, defined as the sum of daily squared returns over the life of the swap. Let $VS_{\tau,\tau+30}$ be the variance swap rate, agreed at initiation of the contract. I define the variance risk premium, $VRP_{\tau,\tau+30}$, as the payoff to the holder of a short position in a variance swap.\footnote{Note that the literature sometimes defines the variance risk premium as the payoff to the long position in variance swap. The benefit to defining it as I have here is simpler intuition. An increase in the variance risk premium is an increase in the cost of insurance for investors. The literature also sometimes uses volatility (square root of variance) swaps instead of variance swaps. Variance swaps have the advantage that they can be replicated with a static option portfolio, unlike volatility swaps that require a dynamic option portfolio. As a result, in the financial markets, variance swaps are more commonly traded.}

$$VRP_{\tau,\tau+30} = VS_{\tau,\tau+30} - RV_{\tau,\tau+30}$$ \hfill (13)

The expected value of the variance swap is zero under the risk neutral measure $Q$. Thus, the variance swap rate is the risk neutral expectation of realized variance between time $\tau$ and $(\tau + 30)$.

$$VS_{\tau,\tau+30} = E^Q[RV_{\tau,\tau+30}]$$ \hfill (14)

### 3.4 Empirical Example

I now present an empirical example of the methodological procedure. This is a single observation in the dataset. On September 4, 2014, the ECB held a press conference. It lowered the deposit rate from -0.10% to -0.20%, and it announced the Bank’s intention to begin purchasing non-financial private sector assets. As part of the announcement, the Bank stressed that inflation remained well below its 2% target. A portion of the introductory statement of the ECB press conference is presented in appendix A. Relevant phrases for computing the
net index are highlighted for exposition. The net index value of this press conference was 
−6, or −1.3 standard deviations. The example demonstrates how the net index captures the 
underlying tone of this particular press conference.

The one month implied risk aversion decreased by 32.9%. The one month variance risk 
premium was 8.3%, relative to the average of 28.8%. These numbers reflect the main result 
of a decrease in implied risk aversion, and lower than average variance risk premia.

Figure 2 presents the various steps involved in computing the option implied risk aversion. 
The top left figure plots the risk neutral density before and after the press conference. The 
top right figure plots the physical density before and after the announcement. The bottom 
left figure plots the pricing kernel before and after the press conference. From this picture, 
the impact of the press conference is a flatter pricing kernel. The bottom right figure plots 
the absolute risk aversion function before and after the press conference. The flatter pricing 
kernel is reflected in the absolute risk aversion function that is now closer to zero following 
the press conference. The implied risk aversion is calculated as the probability weighted sum 
of the distance between the absolute risk aversion function and zero. This decreases as the 
absolute risk aversion function is closer to zero following the press conference.

3.5 Net Index Regressions

I run regressions to analyze the impact of the net index on the change in implied risk aversion 
and the variance risk premium. Let \( i t \) denote the press conference of central bank \( i \) on date 
\( t \), and suppose \( \tau \) is the day of the press conference. The dependent \( Y_{it} \) is either \( \Delta IRA_{it}^{\tau-1,\tau} \) 
or \( VRP_{it}^{\tau,\tau+30} \). The change in implied risk aversion, \( \Delta IRA_{it}^{\tau-1,\tau} \), is contemporaneous with 
respect to the press conference. The variance risk premium, \( VRP_{it}^{\tau,\tau+30} \), is measured after 
the press conference has occurred. An investor could enter into this short variance swap 
after observing the press conference. I estimate the following fixed effects regression:

\[
Y_{it} = \alpha_i + \beta NI_{it}^{\tau-1,\tau} + \gamma X_{it} + \epsilon_{it}
\]  

(15)
The central bank fixed effect is $\alpha_i$. The net index is $NI_{it}^{\tau-1,\tau}$. $X_{it}$ is a vector of control variables consisting of the lagged value of the net index $NI_{i(t-1)}^{\tau-1,\tau}$, the change in the central bank policy interest rate $\Delta IR_{it}^{\tau-1,\tau}$, the prior month variance risk premium $VRP_{it}^{\tau-31,\tau-1}$, the prior month change in implied variance $\Delta IV_{it}^{\tau-31,\tau-1}$, the daily return $R_{it}^{\tau-1,\tau}$, and the daily change in implied variance $\Delta IV_{it}^{\tau-1,\tau}$.

The first control variable is the lagged value of the net index. This captures any trends or persistence in the net index. The second control variable is the change in the central bank policy rate. Including this control means that the coefficient on the net index captures additional information about monetary policy not captured by the change in the policy rate. The third and fourth control variables are the prior month variance risk premium and the prior month change in implied variance. These are intended to capture persistence in the variance risk premium and implied variance. Both these variables are measured from the close of $(\tau - 31)$ until the close of $(\tau - 1)$. This is the one month period before the press conference takes place. The fifth and sixth control variables are the daily return and the daily change in implied variance. These capture the market impact of the press conference. If the market was surprised by the press conference, these two variables can account for that. Then, the coefficient on the net index measures the additional information from the press conference not captured by market movements.

Observations from all central banks are pooled together. Each central bank’s net index is divided by its own standard deviation. This makes the net index values across central banks directly comparable, and justifies pooling of observations. The pooling is critical to ensure sufficient power in hypothesis tests. The coefficient on the net index can be interpreted as the impact of a one standard deviation increase in hawkishness of a press conference.
4 Results

This section presents and discusses the results. I begin with summary statistics and variance swap portfolios. Following that is a discussion of the regression results and their economic significance.

4.1 Summary Statistics and Variance Swap Portfolios

Figure 3 is a scatter plot of the net index against four dependent variables: the change in implied risk aversion, one month variance risk premium, the daily return, and the change in the central bank policy rate. A line of best fit is drawn and the correlation coefficient is reported. The net index is positively correlated with the change in implied risk aversion, the variance risk premium, and the change in the central bank policy rate. The net index is uncorrelated with the daily return.

Table 2 reports summary statistics for each central bank. The sample period is from June 2009 to December 2018. The statistics include the annual frequency of press conferences, the sample size, the average length (number of words) of each press conference, the corresponding coefficient of variation (standard deviation divided by average length), and the mean and standard deviation of the net index. The mean values of the net index are all negative, indicating that central banks are dovish on average. This is not surprising, given that the majority of the sample period was characterized by unprecedented global monetary easing. The standard deviation also varies considerably by central bank. This is partially explained by variation in the average lengths of press conferences.

Table 4 presents summary statistics for variance swap portfolios. Patton & Timmermann (2010) propose a test for monotonicity in returns or other financial variables. For this test, observations are sorted by their net index value and split into three equal sized portfolios.\footnote{Observations with a net index value equal to zero are removed. This is to ensure that the net index is strictly decreasing across most observations} The null hypothesis is that the variance risk premium is not monotonically increasing in the
net index. The alternative is that the variance risk premium is monotonically increasing in the net index. I report the p-value of this test, which is 0.007, indicating that the variance risk premium is increasing in the net index. Next, I form short variance swap portfolios conditional on whether net index is positive or negative. I report the Sharpe Ratio corresponding to each case. The Sharpe Ratio is approximately one and a half times as large when the net index is positive, relative to when it is negative. These results are consistent with the theory. Namely, that when central banks are hawkish, risk premia are higher. And when central banks are dovish, risk premia are lower.

4.2 Regression Results

The regression specification is given by equation 15. Table 5 reports baseline regression results. Coefficients are reported with Newey West standard errors in parentheses below. One, two, and three stars indicate p-values below 0.10, 0.05, and 0.01, respectively. The sample period is June 2009 until December 2018. The first and second columns do not include the control variables. A one standard deviation increase in the hawkishness of a press conferences increases implied risk aversion by 2.1%, and the variance risk premium by 5.0%. The third and fourth columns include the control variables. This results in a modest decline in the magnitude of the coefficients on the net index. A one standard deviation increase in the hawkishness of a press conferences increases implied risk aversion by 1.4%, and the variance risk premium by 4.1%. Among the control variables, for the change in implied risk aversion regression, the coefficients on the lagged net index, the prior month variance risk premium, and the prior month change in implied variance are significant. For the variance risk premium regression, the coefficients on the prior month variance risk premium, the prior month change in implied variance, and the daily change in implied variance are significant. In all regressions, the coefficients on the net index are statistically and economically significant.

Table 6 reports regression results for separate portions of the press conference. The first

\[ \text{The Sharpe Ratio is the annualized mean return divided by the annualized standard deviation of returns from shorting a variance swap.} \]
and second columns report results for the net index values of the introductory statement. The third and fourth columns report results for the net index values of the questions & answers. The introductory statements are prepared beforehand, whereas the questions & answers are unscripted. The purpose of this exercise is to determine whether the market impact of the press conference is primarily coming from the introductory statements or the questions & answers. Note that the sample size for the questions & answers regression is smaller because the Swiss National Bank and the Bank of Canada do not publish transcripts of the questions & answers portion of the press conference, and so they are excluded from the sample. For the introductory statements, the coefficients on the net index are smaller and no longer statistically significant. For the questions & answers, the coefficients on the net index are statistically significant and similar in magnitude to the baseline results. This indicates that the market impact of the net index primarily comes from the questions & answers portion of the press conference, which is the unscripted portion.

Table 7 reports regression results for alternative measures of tone. The first and second columns report results using the proportional net index, proposed by Apel & Grimaldi (2014), which divides the net index value by the total number of phrases. The third and fourth columns report results using the proportion of negative words in the press conference, using the dictionary in Loughran & McDonald (2011), and following the method in Schmeling & Wagner (2019). For the proportional net index, the coefficients are positive but no longer statistically significant. As discussed in section 3.1, using the proportional net index can materially impact the relative magnitude across observations, and the results are sensitive to this. For the proportion of negative words, the coefficient on implied risk aversion is statistically insignificant, whereas the coefficient on the variance risk premium is statistically significant and similar in magnitude to the baseline results. The interpretation is that positive tone results in higher variance risk premia. This result is consistent with the baseline results, but is in contrast to Schmeling & Wagner (2019), who find that positive tone is associated with lower equity volatility risk premia. The asset classes and sample of central banks are
difference, and so the results need not be similar.

5 Conclusion

This paper asks how the tone of central bank press conferences impacts risk premia in the currency market. A hawkish press conference results in an increase in implied risk aversion and higher variance risk premia. A dovish press conference results in a decrease in implied risk aversion and lower variance risk premia. The results are economically and statistically significant, and robust to the inclusion of relevant control variables. Furthermore, the market impact of the press conference comes primarily from the questions & answers, or the unscripted portion of the press conference. The basic intuition of the result is as follows: The tone of a central bank press conference indicates to investors the likelihood of central bank intervention, conditional on the state of the economy. When a central bank is dovish, it is more likely to intervene in bad economic states, and investors pay less for insurance in those states. When a central bank is hawkish, it is less likely to intervene in bad economic states, and investors pay more for insurance in those states. Three broad themes emerge from this paper.

The first theme is that central banks have some ability to influence risk premia in markets. Central banks may have an incentive to choose their words in such a way as to generate a favorable market reaction. The second theme is that investors should incorporate central bank tone into their portfolio decisions. The best case for this is the difference in the Sharpe ratios of shorting a variance swap for different values of the net index. The Sharpe ratio following a hawkish press conference is approximately one and a half times that of a dovish press conference. An example of simple trading strategy is to short variance swaps only if a central bank is hawkish, and stay out of the market otherwise. The third theme is the value of text based information. An any point in time, an investor making a decision has access to qualitative and quantitative information. The qualitative information typically consists
of text, e.g. central bank press conferences, news articles, etc. Text based information poses the following challenge, relative to quantitative information. There are multiple methods to quantify text, and quantification involves some loss of information. This paper employs a binary classification scheme for text, i.e. treating phrases as hawkish or dovish. It is encouraging that even a simple method produces valuable insights.
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A ECB Press Conference

This is a portion of the introductory statement of the ECB press conference on September 4, 2014. It contained six dovish phrases and no hawkish phrases. One of the dovish phrases appears in this portion, and is highlighted in blue.

Ladies and gentlemen, the Vice-President and I are very pleased to welcome you to our press conference. We will now report on the outcome of today’s meeting of the Governing Council, which was also attended by the Commission Vice-President, Mr Katainen.

Based on our regular economic and monetary analyses, the Governing Council decided today to lower the interest rate on the main refinancing operations of the Eurosystem by 10 basis points to 0.05% and the rate on the marginal lending facility by 10 basis points to 0.30%. The rate on the deposit facility was lowered by 10 basis points to -0.20%. In addition, the Governing Council decided to start purchasing non-financial private sector assets. The Eurosystem will purchase a broad portfolio of simple and transparent asset-backed securities (ABSs) with underlying assets consisting of claims against the euro area non-financial private sector under an ABS purchase programme (ABSPP). This reflects the role of the ABS market in facilitating new credit flows to the economy and follows the intensification of preparatory work on this matter, as decided by the Governing Council in June. In parallel, the Eurosystem will also purchase a broad portfolio of euro-denominated covered bonds issued by MFIs domiciled in the euro area under a new covered bond purchase programme (CBPP3). Interventions under these programmes will start in October 2014. The detailed modalities of these programmes will be announced after the Governing Council meeting of 2 October 2014. The newly decided measures, together with the targeted longer-term refinancing operations which will be conducted in two weeks, will have a sizeable
impact on our balance sheet.

These decisions will add to the range of monetary policy measures taken over recent months. In particular, they will support our forward guidance on the key ECB interest rates and reflect the fact that there are significant and increasing differences in the monetary policy cycle between major advanced economies. They will further enhance the functioning of the monetary policy transmission mechanism and support the provision of credit to the broad economy. In our analysis, we took into account the overall subdued outlook for inflation, the weakening in the euro area growth momentum over the recent past and the continued subdued monetary and credit dynamics. Today’s decisions, together with the other measures in place, have been taken with a view to underpinning the firm anchoring of medium to long-term inflation expectations, in line with our aim of maintaining inflation rates below, but close to, 2%. As our measures work their way through to the economy they will contribute to a return of inflation rates to levels closer to 2%. Should it become necessary to further address risks of too prolonged a period of low inflation, the Governing Council is unanimous in its commitment to using additional unconventional instruments within its mandate.
Figure 1: Net Index by Central Bank

(a) Bank of England

(b) Bank of Canada

(c) European Central Bank

(d) Swiss National Bank

(e) US Federal Reserve

These figures plot the time series of the net index for each central bank. The net index is the difference between the number of hawkish and dovish phrases made during a press conference, i.e. $NI = \#Hawk - \#Dove$
These four plots illustrate the how the change in implied risk aversion is computed. The observation is the European Central Bank press conference on September 4, 2014. The net index value is -6, or -1.44 standard deviations. The top left figure plots the risk neutral density before and after the press conference. The top right figure plots the physical density before and after the announcement. The bottom left figure plots the pricing kernel before and after the press conference. From this picture, the impact of the press conference is a flatter pricing kernel. The bottom right figure plots the absolute risk aversion function before and after the press conference. The flatter pricing kernel is reflected in the absolute risk aversion function that is now closer to zero following the press conference. Implied risk aversion is calculated as the probability weighted sum of the distance between the absolute risk aversion function and zero.
Figure 3: Net Index Scatter Plots

(a) $NI_{it}^{\tau-1,\tau} \& \Delta IRA_{it}^{\tau-1,\tau}, \rho = 0.22$

(b) $NI_{it}^{\tau-1,\tau} \& VRP_{it}^{\tau,\tau+30}, \rho = 0.14$

(c) $NI_{it}^{\tau-1,\tau} \& R_{it}^{\tau-1,\tau}, \rho = -0.02$

(d) $NI_{it}^{\tau-1,\tau} \& \Delta IR_{it}^{\tau-1,\tau}, \rho = 0.22$

These figures plot the net index on the horizontal axis and the dependent variable on the vertical axis. Observations for all central banks are pooled together. Each central bank’s net index value is divided by its own standard deviation. The units for the net index is standard deviations, and the units for the dependent variable is percentage points. The four dependent variables are the change in implied risk aversion $\Delta IRA_{it}^{\tau-1,\tau}$ (top left), the one month variance risk premium $VRP_{it}^{\tau,\tau+30}$ (top right), the daily return $R_{it}^{\tau-1,\tau}$ (bottom left), and the change in the central bank policy interest rate $\Delta IR_{it}^{\tau-1,\tau}$ (bottom right). For each figure, a line of best fit is drawn, and the correlation coefficient $\rho$ is reported in the header.
Table 1: Adjectives and Nouns

<table>
<thead>
<tr>
<th>Hawkish Adjectives</th>
<th>Dovish Adjectives</th>
<th>Nouns</th>
</tr>
</thead>
<tbody>
<tr>
<td>increased/increasing</td>
<td>decreased/decreasing</td>
<td>inflation</td>
</tr>
<tr>
<td>fast/faster</td>
<td>slow/slower</td>
<td>cyclical position</td>
</tr>
<tr>
<td>strong/stronger</td>
<td>weak/weaker</td>
<td>growth</td>
</tr>
<tr>
<td>high/higher</td>
<td>low/lower</td>
<td>price</td>
</tr>
<tr>
<td></td>
<td></td>
<td>wages</td>
</tr>
<tr>
<td></td>
<td></td>
<td>oil price</td>
</tr>
<tr>
<td></td>
<td></td>
<td>development</td>
</tr>
</tbody>
</table>

This table presents the adjectives and nouns used to construct the net index. The net index is calculated as the difference between the number of hawkish and dovish phrases made during a press conference. A hawkish phrase consists of a hawkish adjective and a noun. A dovish phrase consists of a dovish adjective and a noun. Any combination of adjective and noun is considered a phrase. For example, higher growth is a hawkish phrase, while lower inflation is a dovish phrase.

Table 2: Central Bank Press Conference Summary Statistics

<table>
<thead>
<tr>
<th>Bank</th>
<th>PC/year</th>
<th>N</th>
<th>Avg Len</th>
<th>CV Len</th>
<th>Avg NI</th>
<th>Std Dev NI</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOE</td>
<td>4</td>
<td>38</td>
<td>10,487</td>
<td>0.468</td>
<td>−0.868</td>
<td>2.993</td>
</tr>
<tr>
<td>BOC</td>
<td>4</td>
<td>38</td>
<td>874</td>
<td>0.292</td>
<td>−0.526</td>
<td>1.069</td>
</tr>
<tr>
<td>ECB</td>
<td>8</td>
<td>97</td>
<td>6,564</td>
<td>0.122</td>
<td>−1.814</td>
<td>4.182</td>
</tr>
<tr>
<td>SNB</td>
<td>2</td>
<td>20</td>
<td>1,660</td>
<td>0.203</td>
<td>−0.350</td>
<td>1.152</td>
</tr>
<tr>
<td>FED</td>
<td>4</td>
<td>31</td>
<td>8,202</td>
<td>0.142</td>
<td>−1.097</td>
<td>2.319</td>
</tr>
</tbody>
</table>

This table reports summary statistics for central bank press conferences. The central banks are: Bank of England (BOE), Bank of Canada (BOC), European Central Bank (ECB), Swiss National Bank (SNB), US Federal Reserve (FED). The sample period is June 2009 until December 2018. The sample size is 224. The following statistics are reported for each central bank: the number of press conferences per year, the total sample size, the average length (number of words) of each press conference, the corresponding coefficient of variation (standard deviation divided by average length), the average value of the net index, and the corresponding standard deviation.
Table 3: Realized GARCH Parameter Estimates

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mu$</td>
<td>0.0069</td>
<td>0.0095</td>
</tr>
<tr>
<td>$\omega$</td>
<td>0.0311</td>
<td>0.0215</td>
</tr>
<tr>
<td>$\alpha_1$</td>
<td>0.3516***</td>
<td>0.0253</td>
</tr>
<tr>
<td>$\beta_1$</td>
<td>0.3012***</td>
<td>0.0605</td>
</tr>
<tr>
<td>$\beta_2$</td>
<td>0.3672***</td>
<td>0.0549</td>
</tr>
<tr>
<td>$\eta_1$</td>
<td>0.0036</td>
<td>0.0088</td>
</tr>
<tr>
<td>$\eta_2$</td>
<td>0.0947***</td>
<td>0.0059</td>
</tr>
<tr>
<td>$\delta$</td>
<td>0.9182***</td>
<td>0.0335</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>0.3706***</td>
<td>0.0056</td>
</tr>
<tr>
<td>$\nu$</td>
<td>12.3358***</td>
<td>3.0559</td>
</tr>
<tr>
<td>$\zeta$</td>
<td>-0.1212**</td>
<td>0.0535</td>
</tr>
</tbody>
</table>

This table reports parameter estimates and robust standard errors of the Realized GARCH model for a single observation, the euro futures contract on September 4, 2014. One, two, and three stars indicate p-values below 0.10, 0.05, and 0.01, respectively. Estimation is by maximum likelihood using the rugarch package in R. The Realized GARCH model incorporates measurements of volatility based on intraday high frequency data, and it allows for an asymmetric response of volatility to positive and negative shocks, i.e. leverage effects. Let $y_t$ be the daily return on the futures contract, $h_t$ be the latent volatility process, and $x_t$ be the daily realized volatility constructed from five minute returns. $\epsilon_t$ and $v_t$ are mean zero i.i.d. innovations. The model consists of three equations: the return equation: $y_t = \mu + \sqrt{h_t} \epsilon_t$, the GARCH equation: $\log h_t = \omega + \sum_{i=1}^{q} \alpha_i \log h_{t-i} + \sum_{i=1}^{p} \beta_i \log x_{t-i}$, and the measurement equation: $\log x_t = \zeta + \delta \log h_t + \eta_1 \epsilon_t + \eta_2 (\epsilon_t^2 - 1) + v_t$. I set $p = 1$ and $q = 2$. This is the preferred specification of Hansen et al. (2012). I assume $\epsilon_t$ is student t distributed with variance one and shape $\nu$, and $v_t$ is normally distributed with variance $\lambda$.

Table 4: Variance Swap Portfolios

<table>
<thead>
<tr>
<th>Monotonicity Test (p-value)</th>
<th>0.007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sharpe Ratio ($NI_{it}^{-1,\tau} &gt; 0$)</td>
<td>1.052</td>
</tr>
<tr>
<td>Sharpe Ratio ($NI_{it}^{-1,\tau} &lt; 0$)</td>
<td>0.656</td>
</tr>
</tbody>
</table>

The first row reports the p-value from the Patton & Timmermann (2010) test of monotonicity in the variance risk premium, or variance swap return. The null hypothesis is that the variance swap return is not monotonically increasing in the net index. The alternative is that the dependent variable is monotonically increasing in the net index. For this test, the observations are sorted by the net index value and split into three equal sized portfolios. Observations with a net index value equal to zero are removed. This is to ensure that the net index is strictly decreasing across most observations. The second and third row report the Sharpe ratio from variance swap portfolios conditional on positive and negative values of the net index, respectively.
Table 5: Baseline Regression Results

<table>
<thead>
<tr>
<th>Without Controls</th>
<th>With Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Y_{it}$</td>
<td>$\Delta IRA_{it}^{\tau-1,\tau}$</td>
</tr>
<tr>
<td>$NI_{it}^{\tau-1,\tau}$</td>
<td>2.098***</td>
</tr>
<tr>
<td></td>
<td>(0.774)</td>
</tr>
<tr>
<td>$NI_{i(t-1)}^{\tau-1,\tau}$</td>
<td>1.433**</td>
</tr>
<tr>
<td></td>
<td>(0.618)</td>
</tr>
<tr>
<td>$\Delta IR_{it}^{\tau-1,\tau}$</td>
<td>-0.674</td>
</tr>
<tr>
<td></td>
<td>(7.788)</td>
</tr>
<tr>
<td>$VRP_{it}^{\tau-31,\tau-1}$</td>
<td>0.068***</td>
</tr>
<tr>
<td></td>
<td>(0.017)</td>
</tr>
<tr>
<td>$\Delta IV_{it}^{\tau-31,\tau-1}$</td>
<td>0.034**</td>
</tr>
<tr>
<td></td>
<td>(0.017)</td>
</tr>
<tr>
<td>$R_{it}^{\tau-1,\tau}$</td>
<td>1.258</td>
</tr>
<tr>
<td></td>
<td>(1.028)</td>
</tr>
<tr>
<td>$\Delta IV_{it}^{\tau-1,\tau}$</td>
<td>0.073</td>
</tr>
<tr>
<td></td>
<td>(0.050)</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.048</td>
</tr>
<tr>
<td>Obs.</td>
<td>219</td>
</tr>
</tbody>
</table>

$Y_{it} = \alpha_i + \beta NI_{it}^{\tau-1,\tau} + \gamma X_{it} + \epsilon_{it}$

This table reports baseline regression results, without and with control variables. Each central bank’s net index is divided by its own standard deviation. Thus, the coefficient on the net index can be interpreted as the affect of a one standard deviation increase in hawkishness. The coefficients are reported with Newey West standard in parentheses below. One, two, and three stars indicate p-values below 0.10, 0.05, and 0.01, respectively. The sample period is June 2009 until December 2018. The dependent variable $Y_{it}$ is either the change in implied risk aversion $\Delta IRA_{it}^{\tau-1,\tau}$, or the one month variance risk premium $VRP_{it}^{\tau,\tau+30}$. The central bank fixed effect is $\alpha_i$. The net index is $NI_{it}^{\tau-1,\tau}$. $X_{it}$ is a vector of control variables consisting of the lagged value of the net index $NI_{i(t-1)}^{\tau-1,\tau}$, the change in the central bank policy interest rate $\Delta IR_{it}^{\tau-1,\tau}$, the prior month variance risk premium $VRP_{it}^{\tau-31,\tau-1}$, the prior month change in implied variance $\Delta IV_{it}^{\tau-31,\tau-1}$, the daily return $R_{it}^{\tau-1,\tau}$, and the daily change in implied variance $\Delta IV_{it}^{\tau-1,\tau}$.
Table 6: Introductory Statements and Questions & Answers

<table>
<thead>
<tr>
<th></th>
<th>Introductory Statements</th>
<th>Questions &amp; Answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Y_{it}$</td>
<td>$\Delta IRA_{it}^{\tau-1,\tau}$</td>
<td>$VRP_{it}^{\tau,\tau+30}$</td>
</tr>
<tr>
<td>$NI_{it}^{\tau-1,\tau}$</td>
<td>0.709 (0.799)</td>
<td>0.780 (2.088)</td>
</tr>
<tr>
<td>$NI_{it(t-1)}^{\tau-1,\tau}$</td>
<td>0.474 (0.670)</td>
<td>2.488 (2.313)</td>
</tr>
<tr>
<td>$\Delta IR_{it}^{\tau-1,\tau}$</td>
<td>3.890 (8.497)</td>
<td>-1.092 (17.148)</td>
</tr>
<tr>
<td>$VRP_{it}^{\tau-31,\tau-1}$</td>
<td>0.073*** (0.018)</td>
<td>(0.574)*** (0.083)</td>
</tr>
<tr>
<td>$\Delta IV_{it}^{\tau-31,\tau-1}$</td>
<td>0.034** (0.016)</td>
<td>0.435*** (0.089)</td>
</tr>
<tr>
<td>$R_{it}^{\tau-1,\tau}$</td>
<td>1.242 (1.016)</td>
<td>2.545 (2.642)</td>
</tr>
<tr>
<td>$\Delta IV_{it}^{\tau-1,\tau}$</td>
<td>0.081 (0.051)</td>
<td>0.471*** (0.111)</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.094 (0.051)</td>
<td>0.234 (0.111)</td>
</tr>
<tr>
<td>Obs.</td>
<td>219 (219)</td>
<td>163 (163)</td>
</tr>
</tbody>
</table>

$Y_{it} = \alpha_i + \beta NI_{it}^{\tau-1,\tau} + \gamma X_{it} + \epsilon_{it}$

This table reports regression results for each component of the press conference: the introductory statement and questions & answers. The sample size for the questions & answers regression is smaller because the Swiss National Bank and the Bank of Canada do not publish transcripts of the questions & answers portion of the press conference, and so they are excluded from the sample. Each central bank’s net index is divided by its own standard deviation. Thus, the coefficient on the net index can be interpreted as the affect of a one standard deviation increase in hawkishness. The coefficients are reported with Newey West standard in parentheses below. One, two, and three stars indicate p-values below 0.10, 0.05, and 0.01, respectively. The sample period is June 2009 until December 2018. The dependent variable $Y_{it}$ is either the change in implied risk aversion $\Delta IRA_{it}^{\tau-1,\tau}$, or the one month variance risk premium $VRP_{it}^{\tau,\tau+30}$. The central bank fixed effect is $\alpha_i$. The net index is $NI_{it}^{\tau-1,\tau}$. $X_{it}$ is a vector of control variables consisting of the lagged value of the net index $NI_{it(t-1)}^{\tau-1,\tau}$, the change in the central bank policy interest rate $\Delta IR_{it}^{\tau-1,\tau}$, the prior month variance risk premium $VRP_{it}^{\tau-31,\tau-1}$, the prior month change in implied variance $\Delta IV_{it}^{\tau-31,\tau-1}$, the daily return $R_{it}^{\tau-1,\tau}$, and the daily change in implied variance $\Delta IV_{it}^{\tau-1,\tau}$.
Table 7: Alternative Measures of Tone

<table>
<thead>
<tr>
<th></th>
<th>Proportional Net Index</th>
<th>Negative Words</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( \Delta IRA_{it}^{\tau-1,\tau} )</td>
<td>( VRP_{it}^{\tau,\tau+30} )</td>
</tr>
<tr>
<td>( NI_{it}^{\tau-1,\tau} )</td>
<td>0.689</td>
<td>3.148</td>
</tr>
<tr>
<td></td>
<td>(0.850)</td>
<td>(2.835)</td>
</tr>
<tr>
<td>( NI_{i(t-1)}^{\tau-1,\tau} )</td>
<td>1.385*</td>
<td>1.634</td>
</tr>
<tr>
<td></td>
<td>(0.785)</td>
<td>(2.713)</td>
</tr>
<tr>
<td>( \Delta IR_{it}^{\tau-1,\tau} )</td>
<td>3.731</td>
<td>-0.102</td>
</tr>
<tr>
<td>( VRP_{it}^{\tau-31,\tau-1} )</td>
<td>0.074***</td>
<td>(0.574)***</td>
</tr>
<tr>
<td></td>
<td>(0.018)</td>
<td>(0.086)</td>
</tr>
<tr>
<td>( \Delta IV_{it}^{\tau-31,\tau-1} )</td>
<td>0.032*</td>
<td>0.434***</td>
</tr>
<tr>
<td></td>
<td>(0.016)</td>
<td>(0.089)</td>
</tr>
<tr>
<td>( R_{it}^{\tau-1,\tau} )</td>
<td>1.141</td>
<td>2.430</td>
</tr>
<tr>
<td></td>
<td>(1.021)</td>
<td>(2.636)</td>
</tr>
<tr>
<td>( \Delta IV_{it}^{\tau-1,\tau} )</td>
<td>0.079</td>
<td>0.454***</td>
</tr>
<tr>
<td></td>
<td>(0.048)</td>
<td>(0.112)</td>
</tr>
<tr>
<td>( R^2 )</td>
<td>0.101</td>
<td>0.234</td>
</tr>
<tr>
<td>Obs.</td>
<td>219</td>
<td>219</td>
</tr>
</tbody>
</table>

\[ Y_{it} = \alpha_i + \beta NI_{it} + \gamma X_{it} + \epsilon_{it} \]

This table reports regression results for two alternative measures of tone. The first is the proportional net index, and the second is based on the proportion of negative words, following the method in Schmeling & Wagner (2019). Since their method uses the change in tone from one press conference to the next, the lagged value of the net index is not included in the set of control variables. The coefficients are reported with Newey West standard in parentheses below. One, two, and three stars indicate p-values below 0.10, 0.05, and 0.01, respectively. The sample period is June 2009 until December 2018. The dependent variable \( Y_{it} \) is either the change in implied risk aversion \( \Delta IRA_{it}^{\tau-1,\tau} \), or the one month variance risk premium \( VRP_{it}^{\tau,\tau+30} \). The central bank fixed effect is \( \alpha_i \). The net index is \( NI_{it}^{\tau-1,\tau} \). \( X_{it} \) is a vector of control variables consisting of the lagged value of the net index \( NI_{i(t-1)}^{\tau-1,\tau} \), the change in the central bank policy interest rate \( \Delta IR_{it}^{\tau-1,\tau} \), the prior month variance risk premium \( VRP_{it}^{\tau-31,\tau-1} \), the prior month change in implied variance \( \Delta IV_{it}^{\tau-31,\tau-1} \), the daily return \( R_{it}^{\tau-1,\tau} \), and the daily change in implied variance \( \Delta IV_{it}^{\tau-1,\tau} \).