Subjective Beliefs and Macro Announcement Premium*

Zhenzhen Fan† Xiaowen Lei‡

This version: August 14, 2023

Abstract

Stock market returns on macro announcement days are significantly higher than on non-announcement days. This paper argues that a large proportion of this premium can be attributed to the resolution of investor disagreement on macro announcement days. To quantify the heterogeneous beliefs, we introduce a novel approach employing option order imbalances. Specifically, we construct the market-perceived cumulative distribution function of the S&P 500 returns using signed index option trading volume on a daily basis. Our empirical finding indicates that variance of subjective beliefs (disagreement) decreases around macro announcement events and results in announcement-day premium. Moreover, disagreement resolution explains the heterogeneity of announcement-day premium across different macro variables. To explain these findings, we build a two-period Lucas tree model with heterogeneous beliefs. Our model-implied announcement premium counts a substantial 17% of the macro announcement day premium observed in the data. This finding suggests that belief heterogeneity is a non-negligible channel in understanding macro announcement day premiums.

JEL Classification: G11, G12
Keywords: macro announcement premium, options order imbalance, heterogeneous beliefs

*Zhenzhen Fan and Xiaowen Lei are from the University of Guelph, Department of Economics and Finance. We have benefited from useful comments from Kenneth Kasa, Xiaonhan Ma and Yiguo Sun. We would like to thank John Dowdall for his excellent research assistance work.

†Lang School of Business, University of Guelph. Email: zhenzhen.fan@uoguelph.ca
‡Lang School of Business, University of Guelph. Email: leix@uoguelph.ca

1 Introduction

In recent years, the macro-finance literature has been interested in the remarkably high equity returns on macro announcement days since the seminal paper by Savor and Wilson (2013). However, several new studies are skeptical about this abnormal announcement premium, arguing that they are due to potential statistical artifacts like small sample bias or selective sampling (Ernst, Gilbert, and Hrdlicka (2019), Ghaderi and Seo (2021)). While statisticians debate over the existence of macro announcement premiums, the subjective beliefs of investors around macro announcement days remain unexplored. This paper aims to infer investor beliefs using option trading data surrounding macro announcements, with a focus on unraveling the belief channel through which macro announcements influence financial markets.

To measure investor beliefs around the macro announcement events, we introduce a novel approach that infers the cumulative distribution function of investor beliefs from option order imbalances. Most studies on disagreement rely on survey-based investor disagreement. While such surveys are valuable for many purposes, those measures are rarely available on a daily basis, which makes event study impossible. In this paper, we use option delta-weighted buying and selling volume to gauge the subjective probability of a future prospect. To do this, we consider investors asking themselves the following question during an option transaction: what is the probability that the stock price will be higher than $x in the near future? To answer this question, we need the concept of odds commonly used in sports gambling. In sports betting, odds represent the probability of an event occurring. If x individuals place bets on Team A winning and y individuals bet on Team B winning, the odds can be determined by dividing the number of bets on Team A (x) by the total number of bets on both teams ($x+y$). This ratio, expressed as $A/(A+B)$, provides an estimate of the probability or likelihood of Team A winning, relative to Team B. Similarly, we can evaluate the probability that the stock price will be higher than

\$x by dividing the number of bets on a stock price lower than \$x, which is the total negative beliefs implied from call options sell contracts and call option buy contracts, by the total number of bets, which is the total volume of options. The availability of options across different strike prices then allows us to infer the entire probability distribution of subjective beliefs at the end of each trading day.

The advantages of using option signed volume to construct investor beliefs compared to survey-based measures are threefold. First, since index options are actively traded over a wide range of strike prices, we are able to construct subjective belief measures on almost the entire support of the asset prices. Unlike survey-based belief measures which are often limited to the expected mean return, our measure can potentially recover higher order moments if necessary. Second, unlike the survey-based belief measures which are usually sampled on a monthly basis or less, we are able to create a higher frequency data of investor beliefs using end-of-day option trading volume. Investor beliefs at daily frequency are then essential to understand the sentiment and disagreement dynamics around the macro announcements. Third, while survey-based measures are subject to reporting errors, our measure is trading-based. Thus, it reflects investor beliefs more accurately.

Although the option-implied measure of subjective beliefs can potentially allow us to study higher-order moments of beliefs, to start with, we focus on the first two moments of the belief distribution function. Using the S&P index option signed volume data from 2005 to 2020, we find that disagreement, measured as the cross-sectional variance of subjective beliefs, significantly reduces on pre-announcement days. This trend carries over to announcement days, resulting in considerably lower levels of disagreement during macro announcement days. Throughout the sample and across all macro variables, we find that disagreement reduces by 4.3% on pre-announcement days and 1.1% on announcement days on average. This suggests that investors might be able to acquire informative private signals before the announcement days, which reduces disagreement. Beliefs dispersion reduces further on the announcement days when upon public news release.

Next, we establish that the reduction in disagreement around the announcements is associated with the announcement premiums. We first employ a time series regression and show that throughout the sample, a larger reduction in disagreement is associated with higher returns on the next day as well as the current day. The effect is slightly more pronounced during macro announcement events.

Second, we show that the reduction in disagreement explains the cross-section heterogeneity of announcement premiums across different macro variables. Macro announcements which result in a larger disagreement resolution earn higher announcement day returns on average. For example, FOMC sees the largest disagreement resolution, with an average reduction of 3.5% in disagreement on pre-announcement days and 6.4% on announcement days. FOMC also has the largest announcement day returns across all macro variables, which is as high as 31 bps in our sample. On the other extreme, Fed Manufacturing Index sees the largest disagreement enhancement, with an average increase of 1.2% on pre-announcement days and 7.1% on announcement days. Announcement day returns of the Fed Manufacturing Index are also among the lowest of all macro variables, with an average announcement day return of -2.6 bps.

Third, in a panel regression analysis, we find that disagreement resolution explains announcement-day return after including time and variable fixed effects. Both pre-announcement day and announcement day disagreement reduction significantly affect announcement day returns. The regression results show that on average the disagreement reduction around the announcements increases announcement day returns by 3.64 bps. Moreover, we find that the pre-announcement disagreement level is positively related to the announcement day return. The finding is consistent with the heterogeneous beliefs model: information resolves uncertainty through disagreement reduction, which then leads to an increase in asset prices.

To capture these empirical findings, we build and solve a two-period Lucas tree model with heterogeneous beliefs *a la* (Abel 1989). Endowed with heterogeneous prior beliefs about future output, agents trade a riskless and risky asset in an otherwise complete market economy. On the pre macro announcement days, disagreement decreases when agents receive unbiased private signals about future output. On the macro announcement day, the release of public news coordinates agents' beliefs further, which triggers more unwinding in asset positions. We then solve for the changes in equilibrium asset prices on both pre-announcement as well as announcement days. While both changes in market sentiment and disagreement account for a significant part of the total premium, the disagreement channel is quantitatively more substantial. By calibrating the model to the asset price and beliefs data in the US from 2005.03 to 2022.12, we find that our heterogeneous beliefs model can account for 17% of macro announcement premium in the data during the same period. Our comparative statics analysis further examines how risk aversion, news relevance, prior market sentiment and disagreement level can attribute to the shifts in the macro announcement day premium.

The subsequent sections of this paper are structured as follows. Section 2 reviews relevant recent literature related to this paper. Section 3 presents the methods used to construct our subjective belief measures. We describe the data used in section 4, and shows our main empirical results in section 5. We highlight the theoretical framework in the section 6. Calibration and sensitivity analysis results are shown in section 7. Finally, we conclude and discuss future research direction in section 8. The appendix provides further information on data documentation, summary statistics and results on empirical analysis.

2 Literature review

This paper contributes to three key strands of literature in macro-finance. First, it addresses the emerging literature concerning the macro announcement premium and its rationale. Savor and Wilson (2013) documents that between 1958 and 2009, the average excess return on announcement days exceeded non-announcement days by 10.3 basis points, accounting for over 60% of the cumulative annual equity risk premium. In a subsequent study, Savor and Wilson (2014) demonstrated that stocks with higher beta exhibit significantly higher returns on announcement days, while such patterns do not persist on non-announcement days. These novel empirical findings have generated interest in understanding the contributing factors to the increased equity premium on announcement days.Ai and Bansal (2018) adopts generalized risk sensitivity to generate the macro announcement premium. Given that there is no significant risk reduction on announcement days compared to non-announcement days, Wachter and Zhu (2018) argues that information frictions related to disaster risk provide a more compelling explanation for the existence of the announcement premium. In comparison, Ghaderi and Seo (2021) uses a long-run risks model as a point of reference. Perhaps the study most closely related to our work is that of Ying (2018). Using high-frequency data on option open interests, Consistent with recent empirical evidence of the information effect of macro announcements (Nakamura and Steinsson (2018)), Ying documents a significant reduction in disagreement following announcements and then rationalizes the increase in trading volume and changes in the stochastic discount factor on announcement days using a heterogeneous beliefs model. However, Ying focuses solely on FOMC announcements, whereas our paper quantifies the belief dispersion channel by examining all macro announcements. Additionally, our paper quantifies the relationship between news relevance and the size of the announcement premium.

The second strand of related literature pertains to asset pricing under heterogeneous beliefs. Abel (1989) demonstrates that heterogeneous beliefs can provide a resolution to the equity premium puzzle. Subsequently, a substantial body of literature has focused on the development of asset pricing theory under the assumption of heterogeneous beliefs, with notable contributions from authors such as Basak (2000), Basak (2005), and Atmaz and Basak (2018), among others. This line of research has been reinforced by the utilization of survey data on analysts' forecasts as a proxy for disagreement (Anderson, Ghysels, and Juergens (2005)). Additionally, Buraschi and Jiltsov (2006) extends the implications of heterogeneous beliefs to the options market. In light of recent empirical evidence revealing a significant increase in trading volume upon announcement (Lucca and Moench (2015)), we leverage these frameworks to understand the implications of heterogeneous beliefs on macro announcement days.

Lastly, the paper is related to the literature on measuring heterogeneous beliefs in the financial market. Traditional measures of subjective beliefs in the financial markets mostly rely on survey data. Examples include the analysts' earnings forecasts from the Institutional Brokers Estimate System (I/B/E/S) (see Sadka and Scherbina (2007), Buraschi, Trojani, and Vedolin (2014), De La O and Myers (2021)), surveys on the perception of macro indicators (see Gao, Lu, Song, and Yan (2019), Li (2016)), surveys on stock market return expectations including UBS/Gallup, Yale/ICF, Michigan Survey of Consumers, Graham-Harvey CFO, Livingston (see Greenwood and Shleifer (2014), Adam and Nagel (2022), Adam, Matveev, and Nagel (2021), Nagel and Xu (2022), etc.), or other unique survey data from the private sector (see Carlin, Longstaff, and Matoba (2014), Giglio, Maggiori, Stroebel, and Utkus (2021), Da, Huang, and Jin (2021), etc). Our option-implied belief measure adds to this literature by constructing trading-inferred beliefs at daily frequency. Moreover, the paper speaks to the literature on recovery theorem. This literature is pioneered by the seminal work of Ross (2015) and extended by Carr and Yu (2012), Qin and Linetsky (2016), and Schneider and Trojani (2019). However, additional assumptions on investor preferences are necessary for these recovery theories and some of the assumptions are not realistic (see Borovička, Hansen, and Scheinkman (2016), Bakshi, Chabi-Yo, and Gao (2018)). We contribute to this literature by introducing a *model-free* option-implied subjective belief without assumptions on investor preferences or the consumption process.

3 Subjective belief construction

We assume that investors trade options according to their subjective beliefs about the future price. The total buy and sell volume of an option reveals how many investors believe the price will be higher and lower than the option strike price, respectively. Just as one would calculate implied probability from betting odds, we can calculate the market's subjective beliefs of a price distribution using buy and sell volumes of options across different strike prices.

Specifically, we define the implied positive, $O^+(t,T,K)$, and negative belief, $O^-(t,T,K)$, of any option O at time t with strike price K and expiry date T as the buy-sell volume imbalance:

$$\begin{aligned} O^+(t,T,K) &= |\Delta_o|(\text{buy volume} \times 1_{\{O=\text{Call}\}} + \text{sell volume} \times 1_{\{O=\text{Put}\}}), \\ O^-(t,T,K) &= |\Delta_o|(\text{buy volume} \times 1_{\{O=\text{Put}\}} + \text{sell volume} \times 1_{\{O=\text{Call}\}}), \end{aligned} \tag{1}$$

where $1_{\{O=\text{Call}\}}$ is an indicator that takes the value one if the option is a call option and zero otherwise. Here $|\Delta_o|$ is the Black-Sholes delta of option O. O^+ is the delta-adjusted number of bets that $S_T > K$ and O^- is the delta-adjusted number of bets that $S_T < K$. We use delta-adjusted volumes to account for the fact that call and put options have different sensitivities to the underlying stock price. For any $K_i < K$, if an investor believes $S_T < K_i$, she must agree that $S_T < K$. Conversely, for any $K_i > K$, if an investor believes $S_T > K_i$, she must agree that $S_T > K$. We define the aggregated bets of $S_T < K$ ($S_T > K$, respectively), denoted by $\mathrm{NEG}(t, T, K)$ ($\mathrm{POS}(t, T, K)$, respectively) as the option-delta weighted aggregation of negative (positive) beliefs implied by options with strike price lower (higher) than K.

$$\mathrm{NEG}(t, T, K) = \sum_{K_i < K} O^-(t, T, K), \qquad \mathrm{POS}(t, T, K) = \sum_{K_i > K} O^+(t, T, K). \tag{2}$$

We will use the positive and negative beliefs given by Equation (2) to calculate a subjective belief density function.

What is the probability that the stock price will be higher than \$x in the near future? Think about sport gambling. In sports betting, odds represent the probability of an event occurring. If x individuals place bets on Team A winning and y individuals bet on Team B winning, the odds can be determined by dividing the number of bets on Team A (x) by the total number of bets on both teams (x + y). This ratio, expressed as A/(A+B), provides a numerical representation of the probability or likelihood of Team A winning, relative to Team B. By the same token, we can evaluate the probability of stock price will be higher than \$x by dividing the number of bets on stock price lower than \$x, which is the total negative beliefs NEG, by the total number of bets, which is POS + NEG. That is,

$$F(x) \equiv \mathrm{Prob}(S_T \leq x) = \frac{\mathrm{NEG}(t, T, x)}{\mathrm{NEG}(t, T, x) + \mathrm{POS}(t, T, x)}. \tag{3}$$

Note that $F(x)$ is a monotonic increasing function by construction. Moreover, since options are traded over various strike prices, we can evaluate Equation (3) at a range of x. Thus Equation (3) can be regarded as the cumulative distribution function of the future price S_T that characterizes the subjective probability distribution of S_T given the information at time t.

Denote the traded option strike prices by $K_n,\ n = 1, \ldots, N$. We define the subjective price expectation as

$$P^E_{t,T} = \sum_{n=1}^{N-1} \frac{K_n + K_{n+1}}{2} \Big(F(K_{n+1}) - F(K_n) \Big). \tag{4}$$

We normalize the above quantity to achieve the next-year price expectation

$$P^E_t = P_t \exp\Big(\frac{1}{T-t} (\log S^E_{t,T} - \log S_t) \Big). \tag{5}$$

Equation (5) gives the next-year price expectation of the S&P 500, based on the option-implied belief at time t. Here, we suppress the second time subscript $T = t + 12$ for simplicity if the quantity is annualized. The dynamics of the price expectations reflect changes in investors' belief on future economic outlook.

To illustrate how it works, consider the hypothetical example in Table 2.

Insert Table 2 here.

The stock price at time t is 100. Call and put options are traded at four strike prices, 95, 100, 105, and 110. The buy and sell volume are reported for each option. At each strike price, we can calculate the option-implied positive and negative beliefs, O^+ and O^- as in Equation (1). After calculating O^+ and O^- for all available strike prices, we can aggregate them to calculate the aggregated positive and negative bets according to Equation (2), which in turn gives the cdf according to Equation (3). The cdf allows us to compute the subjective crash risk of For instance, we calculate the total bets of $S_T > 95$ and $S_T < 95$ in the market using

$$\mathrm{POS}(K = 95) = O^+(K = 110) + O^+(K = 105) + O^+(K = 100) + O^+(K = 95) = 295,$$

$$\mathrm{NEG}(K = 95) = O^-(K = 95) = 3,$$

which implies a market subjective belief of $\text{Prob}(P_T/P_t < -5\%) = \frac{3}{295+3} = 1.0\%$. We may interpret it as the market subjective probability of a -5% market crash in 10 days.

By repeating the above procedure for every option at each day, we can have a time series of option-implied subjective crash risk of different horizons updated at daily frequency.

3.1 Option-implied disagreement

In the rest of the paper, we focus on second moment of the belief distribution function. We define disagreement as the log change of the standard deviation of P_t^E

$$D_{t+1} = \log \sigma[P_{t+1}^E] - \log \sigma[P_t^E] \tag{6}$$

A positive (negative) realization of D_{t+1} suggests that investors disagreement to a larger (smaller) extent at time $t+1$ than they are at time t.

4 Data

In this section, we describe the data used in the empirical analysis.

4.1 Data on option signed volume

The signed option trading volume are the end-of-day Open-Close CBOE C1 exchange volume summary data from the Chicago Board of Exchange (CBOE). On each trading day, the data distinguish between trades based on "buy" and "sell" orders and between trades based on orders to "open" new positions and orders to "close" existing positions. In total, we have four different types of volume for each call and put contract: "Open Buy", "Close Buy", "Open Sell", and "Close Sell." These option volumes are reported separately for different market participants—customer, professional customer, broker-dealer, and market maker. Data before 2010 only include option trading volumes for firms and customers. We aggregate the trading volume for customers (as well as professional customers after 2010) and exclude those for firms, market makers, and broker-dealers, who are primarily liquidity providers and do not necessarily reflect their beliefs through option trading.

For data before 2011, the Open-Close data do not report option price at which the trades take place. We merge the Open-Close volume data with OptionMetrics. We use the mid-point of the highest bid and lowest ask at the end of the day obtained from OptionMetrics to fill the missing price data. Following Golez and Goyenko (2022), we delete options with fewer than 10 days to maturity. We also discard options with missing implied volatility and an absolute value of the option delta greater than 0.98 or smaller than 0.02.

We collect historical prices of the S&P 500 index, dividends, and risk-free interest rate data (one-month treasury bill rates) from the Center for Research in Security Prices (CRSP).

4.2 Data on macro announcements

We collect data on 30 US macroeconomic series from Bloomberg, covering a broad set of real activity, prices, consumption, and investment activities. For each macro variable, we obtain pre-scheduled announcement dates, median of economists' expectations, and actual values. Table 8 provides details of the macroeconomic series and their definitions.

Insert Table 8 here.

Insert Table 8 here.

5 Empirical Results

5.1 Asset price response to announcement surprises

We first investigate the role of announcement surprises. Following the literature, we define the surprise component of a macroeconomic announcement as the difference between its actual realization and its market expectation, normalized by the historical standard deviation. The realization id the value of the macroeconomic variable n of period p released at time t. Market expectations are measured as the mean expectation across the Bloomberg economists' forecasts. We normalize the differences by dividing each of them by their sample standard deviation. The standardized announcement surprise is calculated as

$$\text{Surp}_{i,t} = \frac{a_{i,t} - \mu_{i,t}}{\sigma_i}. \tag{7}$$

We estimate the effect of a given macroeconomic announcement surprise on the market excess return using the following regression for every marco variable i:

$$R_t^e = \alpha_i + \beta_i \text{Surp}_{i,t} + \varepsilon_{i,t} \tag{8}$$

where R_t^e is the market excess return on the announcement day t, α_i is a time-invariant but variable-specific announcement return, β_i is the coefficient on the announcement surprises. Intuitively, we expect β_i to be significantly positive across all macro variable i, such that a positive surprise, i.e., good news, results in larger market returns on the announcement day.

Insert Table 8 here.

Table 8 reports the regression results for each of the 30 macroeconomic variables from 2005 to the end of 2022. Consistent with the existing literature, we find large differences in the β coefficients on surprises and R^2's across macro variables. Notice that not only the magnitude of the surprise coefficients vary greatly across the macro variables, but also the direction varies from significantly positive to significantly negative. In particular, announcement surprises of Unemployment rates, Advance retail sales, Nonfarm payroll, and Government budget deficit have significantly positive impact on announcement day returns, whereas Fed manufacturing index, and initial jobless claims have significantly negative impact. Announcement surprises of the rest of the macro variables have an impact on the announcement day return not significantly different from zero.

Table 8 shows that announcement-day returns do not respond to announcement surprises as one may expect. In the remaining of this section, we explore the potential explanation of announcement premium in the behavioral channel.

5.2 Overview of macro announcement premium and investor beliefs

Using options data from March 2005 to December 2022, we construct investor beliefs as outlined in Section 3. Table 7 reports the full sample summary statistics.

Insert Table 7 here.

Table 7 reports the sample moments and quartiles of the market excess returns, subjective return, disagreement, VIX, daily change in subjective return, daily percentage change in disagreement, and daily percentage change in VIX. The average daily excess return of the market in our sample 3.7 bps and is statistically significant at 95% level. Daily disagreement is 0.05%. None of the daily changes in subjective return, disagreement, or VIX are significantly different from zero in the sample.

We are interested to see whether beliefs are generally similar in the events of announcements. To give an overview of how investor belief changes during the announcement events, we create subsamples of announcement days, which are days where there is one or more macro announcements, pre-announcement days, which are days where there is one or more macro announcements on the following day, and non-announcement days, which are days where there is no macro announcements. Note that pre-announcement days may also be announcement days and non-announcement days. We report the summary statistics of the three subsamples in Table 8. Panel A reports the summary statistics for the pre-announcement days, Panel B for pre-announcement days, and Panel C for non-announcement days.

Insert Table 8 here.

To our surprise, from 2005 to the end of 2022, across all the macro announcements considered in our paper, investors earn highest returns on pre-announcement days—a highly significant daily excess return of 6 bps, almost 2 bps higher than announcement days and over 3 bps higher than non-announcement days. We confirm with the existing literature that most of the market returns are earned during macro announcement events. Disagreement and uncertainty are both lower on pre- and announcement days compared to non-announcement days. While disagreement and uncertainty drop on both pre- and announcement days, pre-announcement days see a more substantial reduction in disagreement while announcement-days see a more noticeable decline in uncertainty. This interesting difference highlights the different mechanism that drives disagreement and uncertainty: Disagreement reduces when investors start acquiring private information before the macro news are announced and uncertainty resolves only after macro variables are publically announced.

Since pre-announcement days overlap with announcement-days since macro variables may be scheduled to announce in a row, to distinguish pre-announcement day effect from the announcement day effect, we construct the announcement day dummy variable and pre-announcement day dummy variable, respectively. In particular, we define

$$D_m(t) = \begin{cases} 1 & \text{if there is an announcement on date } t \\ 0 & \text{otherwise} \end{cases} \tag{9}$$

$$D_{\text{pre}}(t) = \begin{cases} 1 & \text{if there is an announcement on date } t+1 \\ 0 & \text{otherwise} \end{cases} \tag{10}$$

We run the following linear regression of returns or beliefs on the dummy variables.

$$y_t = \alpha + \beta_m D_m(t) + \beta_{\text{pre}} D_{\text{pre}}(t) + \varepsilon_t \tag{11}$$

Here, we consider the daily excess return R^e, disagreement level, VIX, percentage change in disagreement, and percentage change in VIX as the left-hand-side variable y_t. β_{ann} and β_{pre} measure the announcement and pre-announcement day effect, respectively. Using the full sample data, Table 9 reports the regression results.

Insert Table 9 here.

We observe that both announcement day and pre-annoucement day have positive effect on excess returns. Returns are 6.2 bps higher on pre-announcement days and the effect is significant at 90% level. However, announcement days only increase returns by 1.4 bps and the coefficient is not significant at any level. Disagreement levels are significantly lower on pre- and announcement days, with announcement day effect more pronounced statistically. The majority of the disagreement reduction is achieved on pre-announcement days, as suggested by the highly significant coefficient on the pre-announcement dummy in the 'R^D' column, -4.3%. Disagreement continues to drop on announcement days, with an average of 1.1% reduction on announcement days. The level of VIX does not change significantly on pre- or announcement days. There is a significant reduction in VIX on announcement days but not on pre-announcement days.

The results from the regressions are consistent with the summary statistics in Table 8. Disagreement experiences a significant reduction on pre-announcement days. This trend gains momentum and carries over to the announcement day, resulting in considerably lower levels of disagreement during macro announcement days.

Next, we investigate whether a reduction in disagreement is associated with high excess returns. We regress daily excess returns on contemporaneous and lagged disagreement variables and VIX-related variables that capture uncertainty.

$$R_t^e = \alpha + \beta_1 \Delta\% DG_t + \beta_2 \Delta\% DG_{t-1} + \text{control} + \varepsilon_t. \tag{12}$$

We are primarily interested in the coefficients on disagreement variables, β_1 and β_2. We consider the lagged return, contemporaneous and lagged change in Economic Policy Uncertainty as control variables. Table 10 reports the regression results.

Insert Table 10 here.

Both coefficients on contemporaneous and past disagreement changes are highly significantly negative. The coefficients suggest that a larger reduction in disagreement is associated with a larger same-day excess return and a larger next-day excess return. According to table 10, one could expect a 0.8 bps increase in excess return from any 1% reduction in disagreement on the current day, and another 0.4 bps increase in excess return from any 1% reduction in disagreement on the previous day. From Table 9, the average reduction in disagreement is 1.1% on announcement days and 4.3% on pre-announcement days, which contribute to 2.6 bps in announcement premium altogether. We conclude from Table 10 that the stylized facts in disagreement dynamics around the macro announcement events are consistent with the conjecture that announcement premium could be a result of belief convergence.

5.3 Macro variable heterogeneity

In this section, we zoom in on the heterogeneity of macro announcements. To give a first look on the heterogeneity among macro announcements, we calculate the average excess return $\bar{R}_i^e$ and average return in disagreement $\bar{R}_i^D$ on the announcement days for each macro variable i. Figure 1 shows a scatter plot of $\bar{R}_i^e$ and $\bar{R}_i^D$ for all macro variables. We see that there is a negative relation between announcement-day returns and announcement-day disagreement reductions across macro variables. Indeed, when we regress $\bar{R}_i^e$ on $\bar{R}_i^D$ with a constant, the coefficient is -171.24 with a t-statistics of -2.55. It suggests that disagreement not only explains announcement-day premium for all macro announcements in general, but also explains why some macro variables have a larger announcement-day premium than others.

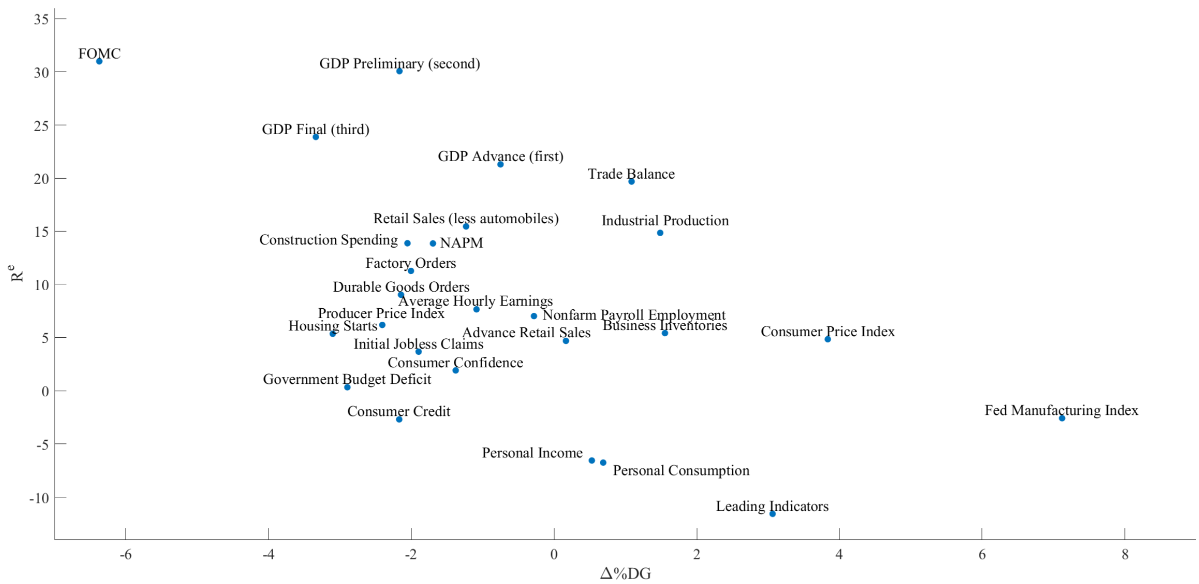


Figure 1: Announcement-day excess returns and return on disagreement

Next, to confirm the time-series and cross-section effect of disagreement on announcement-day returns, we run a panel regression of R_i^e on R_i^D with both macro-variable fixed effect and month fixed effect. Table 11 reports both the panel regression with only disagreement variables and those with other control variables. In all of the regressions, coefficients on disagreement reduction are highly significantly negative.

Insert Table 11 here.

In Table 11, regression (1) include only the contemporaneous and lagged change in disagreement. Both are highly significantly negative, suggesting that larger reduction in disagreement on the pre- and announcement day are associated with larger announcement day returns. In regression (2), we include the disagreement level at the end of the pre-announcement day. The coefficient is significantly positive, suggesting that the larger disagreement there is among the investors before the release of macro variables, the larger the return at the end of the announcement day. This is intuitive. If investors update their beliefs according to Bayes rule, the same amount of information would lead to larger belief revision when prior beliefs are more diverged. Consequently, macro announcement would have a larger impact on asset prices. In regression (3), we include the sign of the announcement surprises. Sgn_{surp} takes the value of one if the announcement surprise defined in Equation (7) is positive and zero otherwise. As expected, good news, i.e., positive surprises, increase the announcement returns. The last regression (4) includes the change in EPU as a control variable. All coefficients and their significance remain intact after controlling for the change in uncertainty in the economy. We include both macro-variable and month fixed-effect in all regressions.

How much does disagreement impact announcement day returns? Using the regression (4) in the last column of Table 11 as an example, a 1% reduction in disagreement on the announcement (pre-announcement) day raises the announcement day return by

0.74 (0.42) bps. According to Table 9, disagreement on average reduces by 4.3% on pre-announcement days and 1.1% on announcement days, which would increase the announcement day return by 3.64 bps ($4.3 \times 0.74 + 1.1 * 0.42 = 3.64$).

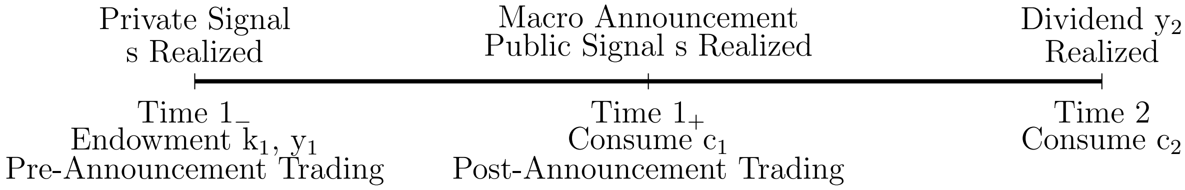
6 Model

The model incorporates learning in the seminal paper by Abel (1989). Abel (1989) shows that heterogeneous beliefs help to address the equity premium puzzle. We build on this intuition by allowing agents to engage in a dual information acquisition process, where the public signal is obtained through the macro announcement. This then allows us to study the role of the macro announcement on announcement premiums under heterogeneous beliefs.

6.1 The setup

The economy consists of a measure 1 continuum of agents that lives for two periods. Period 1 is further split into Period 1_- and 1_+, which indicates the pre-announcement vs. post-announcement period. At the beginning of Period 1_-, each agent is endowed with the same initial capital k_1 and same initial non-durable endowment y_1. Thus, the aggregate capital becomes $K = \int k_1 dk_1 = k_1$, which represents the aggregate quantity of the "Lucas tree" in the economy. The tree only yields a stochastic dividend y_2 in Period 2. Two signals can give the agent unbiased signals about this dividend, one private signal realized at the beginning of Period 1_+, and one public signal (i.e.; macro announcement) at the beginning of Period 1_+. At the beginning of Period 2, the dividend y_2 is realized. Agents can trade shares of the Lucas tree as well as a bond that is in zero net supply, with the objective of maximizing their utility from consumption in these two periods. Figure 2 illustrates the timing of the model.

Figure 2: Model Timeline



6.2 Bayesian updating

The dividend y_2 follows the Gaussian distribution

$$y_2 \sim N(\mu, \sigma^2) \tag{13}$$

For simplicity, we assume that each agent i is born with a prior with $y_2 \sim N(\mu_0^i, \sigma_0^2)$. That is, prior beliefs differ in the mean estimate. At the beginning of period 1_-, a private signal $s^i = y_2 + \epsilon^i$ where $\epsilon^i \sim N(0, \sigma_\epsilon^2)$ is realized, and agents update their beliefs of y_2 using the Bayes rule. This assumption can be micro-founded by allowing information acquisition where agents attempt to obtain information about the dividend through various news sources. Hence, at the end of Period 1_- (pre-announcement), the agent i posterior belief becomes

$$y_2 \sim N\left(\frac{\mu_0^i/\sigma_0^2 + s^i/\sigma_\epsilon^2}{1/\sigma_0^2 + 1/\sigma_\epsilon^2}, \frac{1}{1/\sigma_0^2 + 1/\sigma_\epsilon^2}\right) \tag{14}$$

At the beginning of Period 1_+, a macro announcement public signal S is released (e.g.: news about GDP, inflation, federal fund rate, etc.) which again serves as an unbiased signal of the dividend, i.e.: $S = \rho y_2 + \epsilon_S$ where $\epsilon_S \sim N(0, \sigma_S^2)$ and that $\rho \in [-1, 1]$. Thus, at the end of Period 1_+, the posterior beliefs becomes

$$y_2 \sim N\left(\frac{\mu_0^i/\sigma_0^2 + s^i/\sigma_\epsilon^2 + \rho S/\sigma_s^2}{1/\sigma_0^2 + 1/\sigma_\epsilon^2 + \rho^2/\sigma_S^2}, \frac{1}{1/\sigma_0^2 + 1/\sigma_\epsilon^2 + \rho^2/\sigma_S^2}\right) \tag{15}$$

As one shall see, both the private and the public signals reduce the estimation variance and disagreement.

6.3 Individual problem

Let p_+ and R_+ be the asset prices and bond interest rate at the beginning of 1_+ (post announcement), and correspondingly, p_- and R_- the asset prices and bond interest rate at the beginning of 1_- (pre-announcement). Given those prices and the above beliefs, agents make consumption and asset allocation decisions at the beginning of Period 1_+ to maximize their expected utility, i.e.:

$$\max_{c_1, c_2, b_+, k_+} u(c_1) + \beta \mathbb{E}_+(u(c_2)) \tag{16}$$

s.t.:

$$k_- p_+ + R_- b_- = p_+ k_+ + c_1 + b_+ \tag{17}$$

$$c_2 = y_2 k_+ + R_+ b_+ \tag{18}$$

where c_1, c_2 are the consumption in period 1 and 2, and that k_-, k_+, b_-, b_+ are the capital and bond allocation pre and post-announcement, respectively.

The first condition of optimal consumption and asset allocation gives us

$$u'(c_1) = \beta R \mathbb{E}_+(u'(c_2)) \tag{19}$$

$$u'(c_1)/p_+ = \beta \mathbb{E}_+(u'(c_2) y_2) \tag{20}$$

where $\mathbb{E}_+(.)$ denotes the post announcement expectations.

Combine the above, we have

$$p_+ R_+ = \frac{\mathbb{E}_+(y_2 u'(c_2))}{\mathbb{E}_+(u'(c_2))} \tag{21}$$

For simplicity, we assume that the preference is given by

$$u(c) = -\frac{1}{\gamma} e^{-\gamma c} \tag{22}$$

where γ is the coefficient of risk aversion. Substituting the post-announcement posterior beliefs into the above, we will get

$$\mathbb{E}_+(u'(c_2)) = e^{-\gamma R_+ b_+ - \gamma k_+ m_+ + \gamma^2 k_+^2 \hat{\sigma}_+^2/2} \tag{23}$$

$$\mathbb{E}_+(y_2 u'(c_2)) = (m_+ - \gamma k_+ \hat{\sigma}_+^2) e^{-\gamma R_+ b_+ - \gamma k_+ m_+ + \gamma^2 k_+^2 \hat{\sigma}_+^2/2} \tag{24}$$

Here, $\hat{\sigma}_+^2$ is the post-announcement posterior estimation variance, and m_+ is the post-announcement posterior mean estimate. Therefore, we have

$$p_+ R_+ = m_+ - \gamma k_+ \hat{\sigma}_+^2 \tag{25}$$

We can use this to back out the individual capital demand, i.e.:

$$k_+ = \frac{m_+ - p_+ R_+}{\gamma \hat{\sigma}_+^2} \tag{26}$$

6.4 Market clearing

To compute equilibrium prices, we can use the aggregate capital market clearing condition

$$K = \int k_+ dk_+ = \frac{\bar{m}_+ - p_+ R_+}{\gamma \hat{\sigma}_+^2} \tag{27}$$

where $\bar{m}_+$ denotes the post-announcement market average belief (referred to as "sentiment" later). By averaging out eqn. 25, we get

$$p_+ R_+ = \bar{m}_+ - \gamma \hat{\sigma}_+^2 K \tag{28}$$

Substitute back into 26, we have

$$k_+ = \frac{m_+ - \bar{m}}{\gamma \hat{\sigma}_+^2} + K \tag{29}$$

Intuitively, agents that are more optimistic/pessimistic about the dividend yield than the market average holds more/less stocks in equilibrium. Next, we use the solution of in eqn. 23 and 24 to compute c_1 using the Euler equation,

$$c_1 = -\frac{1}{\gamma} \ln \beta R_+ + R_+ b_+ + k_+ m_+ - \gamma k_+^2 \hat{\sigma}_+^2 / 2 \tag{30}$$

Impose the bond market clearing condition $\int b_+ db_+ = 0$, we can then compute the aggregate consumption

$$C_1 = -\frac{1}{\gamma} \ln \beta R_+ + \mathbb{E}_+{}^p (k_+ m_+) - \gamma \mathbb{E}_+{}^p (\frac{k_+^2 \hat{\sigma}_+^2}{2}) \tag{31}$$

where $\mathbb{E}_+{}^p$ is cross-sectional average in Period 1_+. Using the expression of k_+, we have

$$\mathbb{E}_+{}^p (k_+ m) = \frac{1}{\gamma \hat{\sigma}_+^2} var(m_+) + \frac{\bar{m}_+ K}{\gamma \hat{\sigma}_+^2} \tag{32}$$

and

$$\gamma \mathbb{E}_+{}^p (k_+^2 \hat{\sigma}_+^2 / 2) = \frac{\gamma \hat{\sigma}_+^2}{2} (K - var(\frac{m_+}{\gamma \hat{\sigma}_+^2})) \tag{33}$$

Substituting the above into the aggregate consumption C_1, and combining the definition

$$C_1 = y_1 K \tag{34}$$

we can then back out equilibrium interest rate

$$R = \frac{1}{\beta} e^{(\bar{m}_+ - y_1)\gamma K - \frac{\gamma \hat{\sigma}_+^2 K^2}{2} + \frac{var(m_+)}{2\hat{\sigma}_+^2}} \tag{35}$$

Finally, combine the above with eqn. 28, we can compute equity price

$$p_+ = \beta(\bar{m}_+ - \gamma \hat{\sigma}_+^2 K) e^{-\frac{var(m_+)}{2\hat{\sigma}_+^2} - (\bar{m}_+ - y_1)\gamma K + \frac{\gamma \hat{\sigma}_+^2 K^2}{2}} \tag{36}$$

6.5 The effect of disagreement

Before we dive into the macro announcement date, let us first examine the effect of disagreement on equity premiums. Let p_+^* denote the post-announcement equity price under homogeneous beliefs (i.e.: when $var(m_+) = 0$), we have

$$p_+^* = \beta(\bar{m}_+ - \gamma \hat{\sigma}_+^2 K) e^{-(\bar{m}_+ - y_1)\gamma K + \frac{\gamma \hat{\sigma}_+^2 K^2}{2}} \tag{37}$$

That is,

$$\frac{p}{p_+^*} = e^{-\frac{var(m_+)}{2\hat{\sigma}_+^2}} \tag{38}$$

Intuitively, an increase in disagreement suppresses asset prices. Define

$$q_+ = \frac{m_+}{p_+} - R_+ \tag{39}$$

the individual subjective equity premium. Then the market subjective equity premium becomes

$$Q_+ = \frac{\bar{m}_+}{p_+} - R_+ \tag{40}$$

Since $R_+ = \frac{\bar{m}_+}{p_+} - \frac{\gamma\hat{\sigma}_+^2}{Kp_+}$, we have

$$Q_+ = \frac{\gamma\hat{\sigma}_+^2}{Kp_+} \tag{41}$$

From here, using the solution of p_+, we can compute the market equity premium

$$Q_+ = \frac{\gamma\hat{\sigma}_+^2 e^{\frac{var(m_+)}{2\hat{\sigma}_+^2} + (\bar{m}_+ - y_1)\gamma K - \frac{\gamma\hat{\sigma}_+^2 K^2}{2}}}{K\beta(\bar{m}_+ - \gamma\hat{\sigma}_+^2 K)} \tag{42}$$

Again, define Q_+^* as the equity premium under homogeneous beliefs, we have

$$\frac{Q_+}{Q_+^*} = e^{var(m_+)/(2\hat{\sigma}_+^2)} \tag{43}$$

This is best illustrated in Figure 3. As one can see, the equity premium increases exponentially with disagreement.

6.6 Pre vs. Post announcement

We are interested in changes in equity prices before and after the macro announcement. To see this, first notice that

$$var(m_-) = var(\frac{\mu_0/\sigma_0^2 + s/\sigma_\epsilon^2}{1/\sigma_0^2 + 1/\sigma_\epsilon^2}) = \frac{1/\sigma_\epsilon^4}{(1/\sigma_0^2 + 1/\sigma_\epsilon^2)^2} > 0 \tag{44}$$

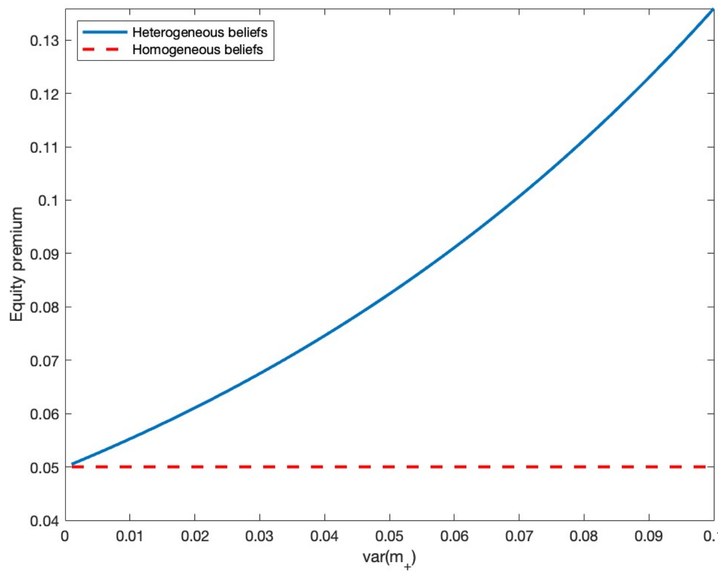


Figure 3: Equity premium vs. Disagreement

Since agents have common prior, by construction, the pre-announcement disagreement increases after private signals are realized. [1] Further, we have

$$var(m_+) = var\left(\frac{\mu_0/\sigma_0^2 + s/\sigma_\epsilon^2 + \rho S/\sigma_S^2}{1/\sigma_0^2 + 1/\sigma_\epsilon^2 + \rho^2/\sigma_s^2}\right) = \frac{1/\sigma_\epsilon^4}{(1/\sigma_0^2 + 1/\sigma_\epsilon^2 + \rho^2/\sigma_S^2)^2} < var(m_-) \quad (45)$$

Notice that we used the fact that the cross-sectional variance of signal S is zero, due to the fact that this is a public signal. That is, post-announcement disagreement decreases. Intuitively, this is simply because public information reduces cross-sectional belief heterogeneity. Next, we can compute the announcement premium:

$$\frac{p_+}{p^-} = \underbrace{\left(\frac{\bar{m}_+ - \gamma\hat{\sigma}_+^2 K}{\bar{m}_+ - \gamma\hat{\sigma}_-^2 K}\right)}_{disagreement} \underbrace{\left[\frac{1}{\exp\left((\bar{m}_+ - \bar{m}_-)\gamma K\right)}\right]\left(\frac{\bar{m}_+ - \gamma\hat{\sigma}_-^2 K}{\bar{m}_- - \gamma\hat{\sigma}_-^2 K}\right)}_{sentiment} \quad (46)$$

That is, the macro announcement premium can be decomposed into a component

[1] In a dynamic model, this can be achieved if agents get biased private signals, or is overconfident about their own private signal.

stemming from disagreement change and a component stemming from sentiment changes. Their quantitative significance is discussed in detail in the calibration section.

6.7 Non vs. Pre announcement

In a similar fashion, we can compute the pre-announcement day premium. Since we know that

$$var(m_-) = \frac{1/\sigma_\epsilon^2}{(1/\sigma_0^2 + 1/\sigma_\epsilon^2)^2} = \sigma_0^2 < var(m_0) \tag{47}$$

Therefore, the pre-announcement premium becomes

$$\frac{p_-}{p_0} = \underbrace{\left(\frac{\bar{m}_- - \gamma\hat{\sigma}_-^2 K}{\bar{m}_- - \gamma\hat{\sigma}_0^2 K}\right)}_{disagreement} \underbrace{\left[\frac{1}{\exp\left((\bar{m}_- - \bar{m}_0)\gamma K\right)}\right]\left(\frac{\bar{m}_- - \gamma\hat{\sigma}_0^2 K}{\bar{m}_0 - \gamma\hat{\sigma}_0^2 K}\right)}_{sentiment} \tag{48}$$

That is, the mechanism that generates a pre-announcement premium is the same as the announcement premium, except that the changes in beliefs come from private information acquisition.

7 Calibration

In this section, we calibrate the model above to the US S&P 500 index data. We aim to quantify how much empirically plausible changes in disagreement affect pre-announcement days and announcement days premiums.

7.1 Benchmark parameters

Table 1 reports the parameters used for this exercise. First, we normalize aggregate capital supply to one, which then implies that $k_0 = K = 1$. The risk aversion coefficient γ is chosen to be 3 so as to satisfy the parameter constraint, i.e.: $\gamma < 5$ is needed in order to ensure positive asset prices. However, we will conduct sensitivity analysis on the announcement premium using different values of γ in the robustness check. The news relevance parameter ρ is bounded between 0 and 1. We use $\rho = 0.5$ as the medium news relevance of a set of macro announcement variables in (Gilbert, Scotti, Strasser, and Vega 2017) as the benchmark case. We then calibrate prior disagreement at the beginning of period 0, measured by the cross-sectional variance of m_0, to match the annualized average disagreement on non-announcement days using the option order imbalance data. Hence, the initial estimation variance σ_0 is set to the same value too. Since signal standard deviation σ_ϵ and σ_S are both unobservable, we use the information of average reduction of disagreement on pre-announcement days (-4.3%) and on announcement days (-1.1%) to get private and public signal standard deviations respectively. This implies that $\sigma_\epsilon = 0.2411$ and that $\sigma_S = 0.9894$. The last set of parameters are estimated using the asset market data. The average annual return on equity μ and annual volatility σ are calibrated to the S&P 500 average yearly return and yearly volatility respectively. We then assume that the average market prior to any private signal realization equals the true average annual return μ. [2]Time discount rate β is calibrated to match the risk-free rate from CRSP.

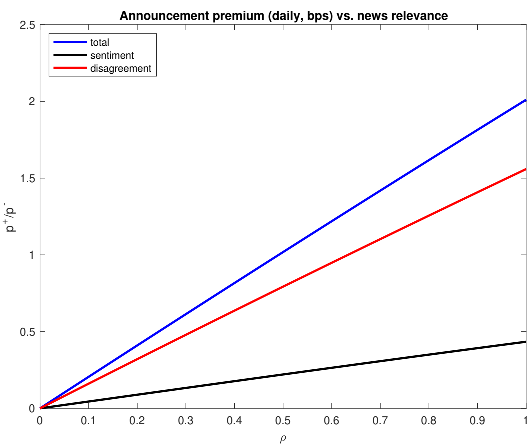
Figure 7.1 and 7.1 plots the model-implied announcement day premium as a function of news relevance ρ, where the total premium (blue line) itself is further decomposed into the components stemming from sentiment (black line) and stemming from disagreement (red line). The left panel assumes good announcement news ($\epsilon = 0.02$), and the right panel assumes bad announcement news ($\epsilon = -0.02$). There are several interesting observations from the figures. First, regardless of direction of the news, the announcement premium generated through disagreement is positive, and increases with news relevance. This is intuitive, because the more relevant a piece of public announcement is to the

[2]In later sections, we conduct sensitivity analysis to examine the role of prior on the size of the premium.

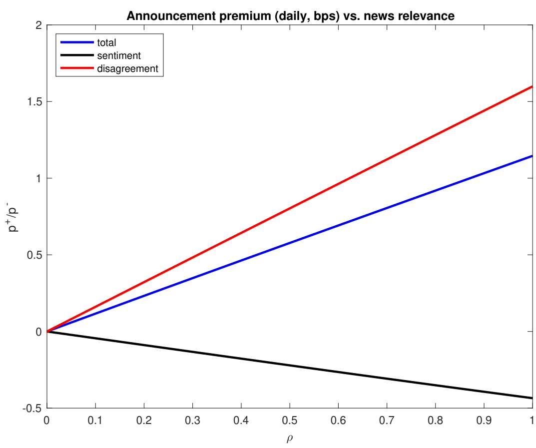
Table 1: Benchmark Parameter Values

Parameters	Value	Data Source
K	1	Aggregate capital supply normalized to 1
γ	3	Benchmark level of risk aversion
ρ	0.5	Benchmark level of news relevance
$\mathrm{var}(m_0)$	0.1459	Annualized average disagreement on non-M days
σ_0	0.1459	Same as $\mathrm{var}(m_0)$
σ_ϵ	0.2411	Match average disagreement change on pre-M days
σ_S	0.9894	Match average disagreement change on M days
μ	0.0996	Average annual S&P 500 return (2005.03-2022.12)
$\bar{m}_0$	0.0996	Market average prior assumed to be the true μ
σ	0.1862	Std. of annual S&P 500 return (2005.03-2022.12)
β	0.984	Match annual risk-free rate (2005.03-2022.12)

dividend, the more valuable this piece of information is in reducing disagreement on the announcement day, hence higher premium. Second, good news increases the premium while bad news reduces it through the sentiment component. Intuitively, investment demand increases/decreases in response to the direction of the news, which then bid up/down the asset prices. Again, the magnitude of this change of premium increases with news relevance.



Good news



Bad news

Using these benchmark parameters, we find that the model generates an M-day announcement premium of 0.80 bps at a daily frequency. Since the average daily M-day premium amounts to 4.73 bps, our model of heterogeneous beliefs is able to explain around 17% of the variation of M-day premium.

We then perform sensitivity analysis to examine how different parameter values affect the announcement premium. The results are shown in Table 8. We conduct this numerical experiment for positive, negative as well as neutral news content. For each set of analyses, we fix all other parameter values at their benchmark level and test how changes in the value of one parameter affect the premium $p+/p-$. We then further decompose it into the premium generated from disagreement and sentiment. All units are calculated in basis points at a daily frequency. To summarize, we have the following observations.

Observation 1) Increases in risk aversion γ amplifies the M-day announcement premium generated from both disagreement and sentiment changes.

Given the same information content, risk-averse investors tend to feel more "relief" with the same changes in beliefs. This is consistent with the standard result where equity premium increase with risk aversion. When the news content is neutral, they experience higher premiums solely through disagreement reduction. However, more risk-averse agents are more sensitive to both positive and negative news. Given good news, risk aversion amplifies both disagreement and sentiment components in the same direction, while with bad news, they work in the opposite direction.

Observation 2) Higher news relevance ρ also amplifies the M-day announcement premium generated from both disagreement and sentiment changes.

This is because increases in ρ increase the information content of the news, which draws more attention from the investors. Again, the decomposition result shows that the amplification effect works in the same direction in the case of good news, and in the opposite direction in the case of bad news.

Observation 3) Increase in the market average prior beliefs $\bar{m}_0$ reduces the M-day *premium generated from disagreement reduction. Good news increases the premium in a pessimistic market, while bad news increases the premium in an optimistic market.*

The macro announcement generates the most return through disagreement reduction when the market prior is the most pessimistic. This is consistent across positive, negative, and neutral news. The premium generated through the sentiment channel differs though, depending on the direction of the news. Not surprisingly, the same amount of good news implies more positive surprises for an initially bearish market, and the same amount of bad news implies more negative surprises for an initially bullish market. Similarly, the market exhibits a self-confirming bias with good (bad) news in an already bullish (bearish) market. [3]

Observation 4) The M-day premium stemming from both disagreement and sentiment channel is higher when the initial belief heterogeneity $var(m_0)$ is higher.

Intuitively, the same amount of information encourages more belief revision when investors have a higher prior disagreement. This follows straight from the Bayes rule where the learning gain is the highest when agents are more uncertain.

8 Conclusion

This paper studies investor disagreement and macro announcement premium. Using daily order imbalances on S&P index options, we construct investor disagreement as variance implied from the cumulative distribution functions of investor beliefs on future market returns. We find that investor disagreement reduces substantially on pre-announcement days, suggesting that investors are able to acquire private information on the macro

[3] It might appear strange at a glance that the premium from the sentiment component is not entirely zero in the neutral news case. However, since we set the realization of dividend y_2 to be the same as the true mean $\mu_0 = 0.0996$, the and that neutral news is defined as zero surprise in relation to the actual realization, therefore effectively those with a market with a prior of 0.07 experiences a positive surprise, and a market with a prior of 0.10 effectively experiences a negative surprise. That's why the premium stemming from the sentiment component in the neutral news case decreases with the prior.

variables before they are announced. Disagreement continues to resolve on announcement days when the actual realization is released to the general public.

We show that the resolution of disagreement significantly affects announcement day returns. On the time series, market excess returns are significantly negatively related to lagged and contemporaneous changes in disagreement. This effect is present in the full sample and is more pronounced during macro announcement events. On the cross-section, macro variables whose announcements resolve more disagreement earn higher announcement day return on average. Taken together, we find that a larger reduction in pre- and announcement days results in larger announcement returns after controlling for macro variable and time fixed-effects. In particular, disagreement resolution generates an average of 3.64 bps return on announcement days.

To understand these findings, we build a two-period asset pricing model with heterogeneous beliefs. The release of private as well as public information reduces disagreement on pre-announcement as well as announcement day, which then contribute to the premiums. We then calibrate the model to the US data and find that an empirically plausible reduction in disagreement around macro announcement days can account for 17% of the S&P 500 index announcement day premium from 2005 to 2022.

References

Abel, A. B. (1989): *Asset prices under heterogeneous beliefs: implications for the equity premium*. Rodney L. White Center for Financial Research Philadelphia.

Adam, K., D. Matveev, and S. Nagel (2021): "Do survey expectations of stock returns reflect risk adjustments?," *Journal of Monetary Economics*, 117, 723–740.

Adam, K., and S. Nagel (2022): "Expectations Data in Asset Pricing," Discussion paper, National Bureau of Economic Research.

Ai, H., and R. Bansal (2018): "Risk preferences and the macroeconomic announcement premium," *Econometrica*, 86(4), 1383–1430.

Anderson, E. W., E. Ghysels, and J. L. Juergens (2005): "Do heterogeneous beliefs matter for asset pricing?," *The Review of Financial Studies*, 18(3), 875–924.

Atmaz, A., and S. Basak (2018): "Belief dispersion in the stock market," *The Journal of Finance*, 73(3), 1225–1279.

Baker, S. R., N. Bloom, and S. J. Davis (2016): "Measuring economic policy uncertainty," *The quarterly journal of economics*, 131(4), 1593–1636.

Bakshi, G., F. Chabi-Yo, and X. Gao (2018): "A recovery that we can trust? Deducing and testing the restrictions of the recovery theorem," *The Review of Financial Studies*, 31(2), 532–555.

Basak, S. (2000): "A model of dynamic equilibrium asset pricing with heterogeneous beliefs and extraneous risk," *Journal of Economic Dynamics and Control*, 24(1), 63–95.

——— (2005): "Asset pricing with heterogeneous beliefs," *Journal of Banking & Finance*, 29(11), 2849–2881.

Borovička, J., L. P. Hansen, and J. A. Scheinkman (2016): "Misspecified recovery," *The Journal of Finance*, 71(6), 2493–2544.

Buraschi, A., and A. Jiltsov (2006): "Model uncertainty and option markets with heterogeneous beliefs," *The Journal of Finance*, 61(6), 2841–2897.

Buraschi, A., F. Trojani, and A. Vedolin (2014): "Economic uncertainty, disagreement, and credit markets," *Management Science*, 60(5), 1281–1296.

Carlin, B. I., F. A. Longstaff, and K. Matoba (2014): "Disagreement and asset prices," *Journal of Financial Economics*, 114(2), 226–238.

Carr, P., and J. Yu (2012): "Risk, return, and Ross recovery," *The Journal of Derivatives*, 20(1), 38–59.

Da, Z., X. Huang, and L. J. Jin (2021): "Extrapolative beliefs in the cross-section: What can we learn from the crowds?," *Journal of Financial Economics*, 140(1), 175–196.

De La O, R., and S. Myers (2021): "Subjective cash flow and discount rate expectations," *The Journal of Finance*, 76(3), 1339–1387.

Ernst, R., T. Gilbert, and C. M. Hrdlicka (2019): "More than 100% of the equity premium: How much is really earned on macroeconomic announcement days?," *Available at SSRN 3469703*.

Gao, G. P., X. Lu, Z. Song, and H. Yan (2019): "Disagreement beta," *Journal of Monetary Economics*, 107, 96–113.

Ghaderi, M., and S. B. Seo (2021): "Is There a Macro-Announcement Premium?," *Available at SSRN 3676120*.

GIGLIO, S., M. MAGGIORI, J. STROEBEL, AND S. UTKUS (2021): "Five facts about beliefs and portfolios," *American Economic Review*, 111(5), 1481–1522.

GILBERT, T., C. SCOTTI, G. STRASSER, AND C. VEGA (2017): "Is the intrinsic value of a macroeconomic news announcement related to its asset price impact?," *Journal of Monetary Economics*, 92, 78–95.

GOLEZ, B., AND R. GOYENKO (2022): "Disagreement in the equity options market and stock returns," *The Review of Financial Studies*, 35(3), 1443–1479.

GREENWOOD, R., AND A. SHLEIFER (2014): "Expectations of returns and expected returns," *The Review of Financial Studies*, 27(3), 714–746.

LI, F. W. (2016): "Macro disagreement and the cross-section of stock returns," *The Review of Asset Pricing Studies*, 6(1), 1–45.

LUCCA, D. O., AND E. MOENCH (2015): "The pre-FOMC announcement drift," *The Journal of finance*, 70(1), 329–371.

NAGEL, S., AND Z. XU (2022): "Dynamics of subjective risk premia," Discussion paper, National Bureau of Economic Research.

NAKAMURA, E., AND J. STEINSSON (2018): "High-frequency identification of monetary non-neutrality: the information effect," *The Quarterly Journal of Economics*, 133(3), 1283–1330.

QIN, L., AND V. LINETSKY (2016): "Positive eigenfunctions of Markovian pricing operators: Hansen-Scheinkman factorization, Ross recovery, and long-term pricing," *Operations Research*, 64(1), 99–117.

ROSS, S. (2015): "The recovery theorem," *The Journal of Finance*, 70(2), 615–648.

Sadka, R., and A. Scherbina (2007): "Analyst disagreement, mispricing, and liquidity," *The Journal of Finance*, 62(5), 2367–2403.

Savor, P., and M. Wilson (2013): "How much do investors care about macroeconomic risk? Evidence from scheduled economic announcements," *Journal of Financial and Quantitative Analysis*, 48(2), 343–375.

——— (2014): "Asset pricing: A tale of two days," *Journal of Financial Economics*, 113(2), 171–201.

Schneider, P., and F. Trojani (2019): "(Almost) model-free recovery," *The Journal of Finance*, 74(1), 323–370.

Wachter, J. A., and Y. Zhu (2018): "The macroeconomic announcement premium," Discussion paper, National Bureau of Economic Research.

Ying, C. (2018): "Heterogeneous Beliefs and FOMC Announcements," *Available at SSRN 3286682*.

Table 2: A hypothetical example of calculating option-implied subjective beliefs

Current stock price: $S_t = 100$, maturity = 30 days

Strike	type	delta	buy	sell	O^+	O^-	POS	NEG	$F(K)$
95	C	0.81	20	3	16	2.4	145.15	2.4	1.6%
	P	-0.21	0	30	6.3	0			
100	C	0.5	60	140	30	70	122.85	132.4	51.9%
	P	-0.5	120	90	45	60			
105	C	0.19	40	60	7.6	11.4	47.85	223.8	82.4%
	P	-0.80	100	50	40	80			
110	C	0.05	5	10	0.25	8.1	0.25	231.9	99.9%
	P	-0.95	8	0	0	7.6			

The table gives an example of constructing option-implied belief using option signed volume.

Table 3: Macro Announcement Documentation

Announcement	Frequency	Observations	Start Date	End Date
Construction Spending	monthly	213	2005-03-01	2022-12-01
FOMC	intraday	143	2005-03-22	2022-12-14
NAPM	monthly	214	2005-03-01	2022-12-01
Consumer Confidence	monthly	214	2005-03-04	2022-12-23
Housing Starts	monthly	209	2005-03-16	2022-12-20
Unemployment Rate	monthly	106	2005-03-04	2022-12-02
Advance Retail Sales	monthly	198	2005-03-15	2022-12-15
Durable Goods Orders	monthly	209	2005-03-24	2022-12-05
Personal Consumption	monthly	212	2005-03-31	2022-12-23
Capacity Utilization	monthly	180	2005-03-16	2022-12-15
Factory Orders	monthly	212	2005-03-24	2022-12-05
CPI	monthly	214	2005-03-23	2022-12-13
Trade Balance	monthly	212	2005-03-11	2022-12-06
Business Inventories	monthly	214	2005-03-15	2022-12-15
Leading Indicators	monthly	212	2005-03-17	2022-12-22
Monthly Budget Statement	monthly	212	2005-03-10	2022-12-12
Consumer Credit	monthly	212	2005-03-07	2022-12-07
GDP Advance	quarterly	71	2005-04-28	2022-10-27
GDP Preliminary	quarterly	70	2005-05-26	2022-11-30
GDP Final	quarterly	71	2005-03-30	2022-12-22
Non-farm Payroll Employment	monthly	209	2005-03-04	2022-12-02
Retail Sales (less auto)	monthly	160	2009-08-13	2022-12-15
Industrial Production	monthly	212	2005-03-16	2022-12-15
Personal Income	monthly	211	2005-03-31	2022-12-23
Government Budget Deficit	monthly	212	2005-03-10	2022-12-12
Average Hourly Earnings	monthly	150	2010-03-05	2022-12-02
Core PPI	monthly	106	2005-03-22	2014-01-15
Fed Manufacturing Index	monthly	166	2009-02-23	2022-12-27
Initial Jobless Claims	weekly	931	2005-03-03	2022-12-29

The table lists all macro series considered in the paper. “Frequency” is the announcement frequency; “Observations” is the total number of announcements in the sample; “Start Date” and “End Date” are the first and last announcements of the macro series in the sample, respectively.

Table 4: Macro Announcement Documentation

Announcement	Source	Definition
Construction Spend.	U.S. Census Bureau	Value of new construction activity
FOMC	Federal Reserve	Short term target interest rate
NAPM	ISM	Composite Index equally weighs new orders, production, employment, supplier deliveries, and inventories.
Consumer Conf.	University Of Michigan	Telephone survey of consumer sentiment.
Housing Starts	U.S. Census Bureau	New privately-owned housing units started, recorded when excavation of foundation begins.
Unemployment Rate	Bureau Of Labour Statistics	Number of unemployed persons as a percentage of the labour force (survey).
PPI	Bureau of Labour Statistics	The average change in the prices domestic producers receive for their output.
Advance Retail Sales	U.S. Census Bureau	Resale of new and used goods to the public, used for personal consumption. Month-over-month percentage change.
Durable Goods Orders	U.S. Census Bureau	New orders placed with domestic manufacturers for delivery of durable goods
Personal Consumption	Bureau of Economic Analysis	A measure of the prices that people living in the United States, or those buying on their behalf, pay for goods and services.
Capacity Utilization	Federal Reserve	An estimated ratio of actual output to potential output. Captured across 89 detailed industries (71 in manufacturing, 16 in mining, and 2 in utilities).

Table 5: Macro Announcement Documentation Extended

Announcement	Source	Definition
Factory Orders	U.S. Census Bureau	Dollar value for the durable goods from factories, including new orders, unfilled orders, shipments, and inventories.
CPI	Bureau of Labour Statistics	Overview of overall changes in prices faced by consumers based on a representative basket of goods and services over time.
Trade Balance	U.S. Census Bureau	Net sum of exports and imports of goods
Business Inventories	U.S. Census Bureau	A metric that tracks the dollar amount of inventories held by wholesalers, retailers, and manufacturers.
Leading Indicators	Conference Board	Tracking 3 major financial and 7 non-financial components to index a general leading indicator.
Consumer Credit	Federal Reserve	Seasonally adjusted personal debt taken by consumers.
GDP Advance	Bureau of Economic Analysis	The first estimate of the total market value of the goods and services produced in a year.
GDP Preliminary	Bureau of Economic Analysis	The second estimate of the total market value of the goods and services produced in a year.
GDP Final	Bureau of Economic Analysis	The total market value of the goods and services produced in a year.

Table 6: Macro Announcement Documentation Extended

Announcement	Source	Definition
Non-farm Payroll Employment	Bureau of Labour Statistics	Employees on non-farm payroll month over month net change.
Retail Sales (less auto)	U.S. Census Bureau	Retail trade excluding motor vehicles and parts dealers.
Industrial Production	Federal Reserve	Real production output of manufacturing, mining, and utilities.
Personal Income	Bureau of Economic Analysis	Income that people get from wages and salaries, Social Security and other government benefits, dividends and interest, business ownership, and other sources.
Government Budget Deficit	U.S. Treasury	Tracks monthly budget statement deficits.
Average Hourly Earnings	Bureau of Labour Statistics	The average dollar that private employees make - month over month change.
Core PPI	Bureau of Labour Statistics	Overview of overall changes in prices faced by consumers based on a more select representative basket of goods and services over time.
Fed Manufacturing Index	Federal Reserve Bank of Dallas	Measures the performance of the manufacturing sector in the state of Texas - derived from a survey of around 100 business executives and tracks variables such as output, employment, orders, and prices.
Initial Jobless Claims	Department of Labour	New claimants for unemployment insurance.

This table lists the macro variables whose announcements are considered in our paper.

Table 7: Summary statistics: Full sample

	R^e	DG	Δ%DG	EPU	Δ%EPU
# obs	4492	4490	4487	4492	4491
Mean	3.75	0.05	0.01	114.11	0.04
	(1.99)	(133.63)	(0.03)	(92.53)	(0.05)
Std	126.11	0.03	0.32	82.66	52.54
Min	-1200.00	0.01	-216.23	3.32	-314.83
25 percentile	-44.00	0.04	-18.71	61.03	-31.61
Median	7.00	0.05	0.02	92.56	-0.64
75 percentile	59.25	0.06	18.47	142.05	31.68
Max	1135.00	0.44	190.27	807.66	321.56

This table reports the full-sample summary statistics. We report the total number of daily observations (# obs), sample mean, t-statistics in brackets, standard deviation (Std) and quartile values of the market excess return (in basis points), disagreement level (DG), percentage change in disagreement (Δ%DG), economic policy uncertainty (EPU), and percentage change in EPU. Data is daily from March 2005 to December 2022.

Table 8: Summary statistics: Subsamples

	R^e	DG	Δ%DG	EPU	Δ%EPU
Panel A: Pre-announcement days					
# obs	2793	2793	2792	2792	2791
Mean	6.10	0.05	-1.62	111.72	-2.70
	(2.60)	(111.46)	(-2.61)	(72.91)	(-2.77)
Std	123.99	0.02	0.33	80.98	51.44
Min	-1200.00	0.01	-216.23	7.40	-314.83
25 percentile	-41.00	0.04	-20.99	60.07	-33.61
Median	8.00	0.05	-1.14	90.46	-2.36
75 percentile	61.00	0.06	17.01	137.52	28.28
Max	1135.00	0.24	189.11	738.02	198.10
Panel B: Announcement days					
# obs	2794	2793	2792	2792	2790
Mean	4.28	0.05	-0.42	112.13	0.11

Continued on next page

Table 8 – continued from previous page

	R^e	DG	Δ%DG	EPU	Δ%EPU
	(1.83)	(109.27)	(-0.69)	(73.05)	(0.11)
Std	123.56	0.03	0.32	81.14	51.46
Min	-963.00	0.01	-171.92	3.32	-199.40
25 percentile	-43.00	0.04	-19.78	59.73	-31.22
Median	8.00	0.05	-0.37	91.23	-0.32
75 percentile	63.75	0.06	18.32	139.23	31.56
Max	679.00	0.36	190.27	807.66	230.38
Panel C: Non-announcement days					
# obs	1698	1697	1695	1697	1695
Mean	2.86	0.05	0.73	117.38	-0.08
	(0.91)	(78.33)	(0.95)	(56.89)	(-0.06)
Std	130.23	0.03	0.32	85.01	54.29
Min	-1200.00	0.01	-216.23	7.40	-314.83
25 percentile	-46.00	0.04	-17.32	62.81	-32.21
Median	5.50	0.05	0.21	94.68	-1.07

Continued on next page

Table 8 – continued from previous page

	R^e	DG	Δ%DG	EPU	Δ%EPU
75 percentile	54.00	0.06	18.57	146.13	32.34
Max	1135.00	0.44	189.18	638.81	321.56

This table reports the summary statistics of the market excess return (in basis points), disagreement level (DG), percentage change in disagreement (Δ%DG), economic policy uncertainty (EPU), and percentage change in EPU on pre-announcement days in Panel A, announcement days in Panel B, and non-announcement days in Panel C. A day is defined as a pre-announcement day if there is any macro variable scheduled to be announced on the following day. A day is defined as an announcement day if there is any macro variable scheduled to be announced on this day. A day is defined as a non-announcement day if there is no macro variable scheduled to be announced on this day. Pre-announcement, announcement, and non-announcement days can be overlapping. We report the total number of daily observations (# obs), sample mean, t-statistics in brackets, standard deviation (Std) and quartile values of the market excess return (in basis points), disagreement level (DG), percentage change in disagreement (Δ%DG), economic policy uncertainty (EPU), and percentage change in EPU. Data is daily from March 2005 to December 2022.

Table 9: Regression on pre- and announcement day dummy

	R^e	DG	Δ%DG	EPU	Δ%EPU
Const	-1.00	0.06	3.42	121.30	4.41
	(-0.26)	(67.87)	(3.45)	(47.57)	(2.73)
$1_{\{\text{Pre-M}\}}$	6.22	0.00	-4.33	-5.24	0.20
	(1.60)	(-2.35)	(-4.39)	(-2.06)	(0.13)
$1_{\{\text{M}\}}$	1.41	0.00	-1.15	-6.32	-7.24
	(0.36)	(-2.89)	(-1.16)	(-2.49)	(-4.49)
R^2 (%)	0.06	0.31	0.46	0.23	0.45

This table reports the time series regression of the market excess return R^e (in bps), disagreement DG, percentage change in disagreement Δ%DG, EPU, and percentage change in EPU Δ%EPU on pre-announcement day dummy variable $1_{\{\text{Pre-M}\}}$ and announcement day dummy variable $1_{\{\text{M}\}}$. A day is defined as a pre-announcement day if there is any macro variable scheduled to be announced on the following day. A day is defined as an announcement day if there is any macro variable scheduled to be announced on this day. t-statistics are reported in brackets. Data is daily from March 2005 to December 2022.

Table 10: Time series Regression of market excess return on contemporaneous and past change in disagreement

	Full sample	M days	Non-M days
Const	3.69	3.29	4.25
	(1.99)	(1.42)	(1.35)
$\Delta\%\mathrm{DG}_t$	-0.76	-0.77	-0.76
	(-11.80)	(-9.60)	(-6.89)
$\Delta\%\mathrm{DG}_{t-1}$	-0.32	-0.34	-0.30
	(-5.02)	(-4.37)	(-2.59)
$\Delta\mathrm{EPU}_t$	0.04	0.07	-0.01
	(0.94)	(1.42)	(-0.22)
$\Delta\mathrm{EPU}_{t-1}$	-0.01	-0.01	-0.02
	(-0.29)	(-0.16)	(-0.29)
R^2 (%)	3.04	3.26	2.78

This table reports the time series regression of the market excess return (in bps) on contemporaneous and past change in disagreement with control variables. $\Delta\%\mathrm{DG}_t$ ($\Delta\%\mathrm{DG}_{t-1}$) is the contemporaneous (past-day) change in disagreement, R^e_{t-1} is the past-day market excess return, $\Delta\%\mathrm{EPU}_t$ ($\Delta\%\mathrm{EPU}_{t-1}$) is the contemporaneous (past-day) change in the daily Economic Policy Uncertainty index from Baker, Bloom, and Davis (2016). t-statistics are reported in brackets. Data is daily from March 2005 to December 2022.

Table 11: Panel regressions of announcement-day returns

	(1)	(2)	(3)	(4)
Const	5.60	-19.95	-23.51	-23.41
	(44.04)	(-1.67)	(-1.93)	(-1.92)
$\Delta\%DG_t$	-0.82	-0.73	-0.73	-0.74
	(-11.48)	(-8.86)	(-8.96)	(-9.11)
$\Delta\%DG_{t-1}$	-0.33	-0.42	-0.42	-0.42
	(-7.33)	(-8.25)	(-8.40)	(-8.40)
DG_{t-1}		30.05	29.70	29.41
		(2.13)	(2.11)	(2.09)
$\mathrm{Sgn}_{\mathrm{surp}}$			8.94	9.08
			(2.92)	(2.93)
Δ%EPU				0.08
				(3.01)
R^2 (%)	3.59	3.80	3.93	4.04
Macro-variable FE	X	X	X	X
Month FE	X	X	X	X

This table reports the panel regression of the market excess return (in bps) on contemporaneous and past change in disagreement with control variables. $\Delta\%\mathrm{DG}_t$ ($\Delta\%\mathrm{DG}_{t-1}$) is the contemporaneous (past-day) change in disagreement, $\mathrm{Sgn}_{\mathrm{surp}}$ is the sign of the announcement surprises which takes the value of 1 if the surprise is positive (i.e., good news) and zero otherwise. Δ%EPU is the percentage change in the daily Economic Policy Uncertainty index from Baker, Bloom, and Davis (2016). t-statistics are reported in brackets. Data is daily from March 2005 to December 2022.

Table 12: Regression on announcement surprises

	Const		Surp		R^2 (%)
Construction Spending	15.029	(1.56)	7.521	(0.79)	0.292
FOMC	30.475	(2.74)	-8.389	(-0.75)	0.400
NAPM	12.240	(1.27)	13.730	(1.43)	0.955
Consumer Confidence	2.511	(0.31)	-2.925	(-0.37)	0.065
Housing Starts	5.672	(0.65)	7.767	(0.89)	0.378
Unemployment Rate	4.093	(0.52)	-17.364	(-2.22)	2.317
Producer Price Index	6.497	(0.49)	-5.274	(-0.40)	0.153
Advance Retail Sales	4.312	(0.50)	17.844	(2.08)	2.001
Durable Goods Orders	9.077	(1.15)	8.907	(1.13)	0.644
Personal Consumption	-6.740	(-0.73)	-5.881	(-0.63)	0.193
Capacity Utilization	13.966	(1.81)	-5.479	(-0.72)	0.245
Factory Orders	12.270	(1.43)	7.239	(0.85)	0.404
Consumer Price Index	5.596	(0.61)	-7.898	(-0.87)	0.358
Trade Balance	19.482	(2.43)	6.412	(0.80)	0.300
Business Inventories	5.476	(0.63)	5.722	(0.66)	0.207
Leading Indicators	-12.996	(-1.55)	11.509	(1.38)	0.885
Consumer Credit	-2.061	(-0.26)	-10.573	(-1.36)	0.867
GDP Advance (first)	18.267	(1.29)	-23.408	(-1.66)	3.844
GDP Preliminary (second)	29.779	(2.07)	5.537	(0.38)	0.216
GDP Final (third)	23.771	(1.70)	-3.645	(-0.26)	0.097

Continued on next page

	const		Surp		R^2 (%)
Nonfarm Payroll Employment	5.480	(0.70)	21.004	(2.69)	3.390
Retail Sales (less automobiles)	15.444	(1.91)	1.106	(0.14)	0.012
Industrial Production	13.928	(1.81)	-6.113	(-0.80)	0.305
Personal Income	-6.767	(-0.73)	2.140	(0.23)	0.026
Government Budget Deficit	3.515	(0.40)	-21.914	(-2.53)	2.956
Average Hourly Earnings	7.148	(0.81)	8.128	(0.91)	0.562
Core PPI	5.523	(0.42)	9.174	(0.70)	0.464
Fed Manufacturing Index	-6.523	(-0.76)	-25.077	(-2.96)	5.074
Manufacturing PMI	12.240	(1.27)	13.730	(1.43)	0.955
Initial Jobless Claims	2.720	(0.65)	14.857	(3.54)	1.333

Good News + 0.02

Variable	p+/p-	p+/p-(disagreement)	p+/p-(sentiment)
$\gamma = 1/2$	0.14	0.05	0.09
$\gamma = 2$	0.46	0.33	0.13
$\gamma = 3$	1.02	0.79	0.22
$\gamma = 4$	3.51	2.83	0.63
$\rho = 0.3$	0.61	0.48	0.13
$\rho = 0.5$	1.02	0.79	0.22
$\rho = 0.7$	1.42	1.10	0.31
$\rho = 0.9$	1.81	1.41	0.39
$\bar{m}_0 = 0.07$	8.66	5.25	3.00
$\bar{m}_0 = 0.08$	2.66	1.81	0.81
$\bar{m}_0 = 0.09$	1.50	1.09	0.39
$\bar{m}_0 = 0.10$	1.00	0.78	0.22
$var(m_0) = 0.13$	0.24	0.17	0.07
$var(m_0) = 0.14$	0.31	0.23	0.08
$var(m_0) = 0.15$	0.41	0.30	0.10
$var(m_0) = 0.16$	0.53	0.40	0.13

Bad News - 0.02

Variable	p+/p-	p+/p-(disagreement)	p+/p-(sentiment)
$\gamma = 1/2$	-0.04	0.05	-0.09
$\gamma = 2$	0.19	0.33	-0.13
$\gamma = 3$	0.58	0.80	-0.22
$\gamma = 4$	2.25	2.93	-0.63

Neutral News - 0.00			
Variable	p+/p-	p+/p-(disagreement)	p+/p-(sentiment)
$\gamma = 1/2$	0.05	0.05	0.00
$\gamma = 2$	0.33	0.33	0.00
$\gamma = 3$	0.80	0.80	0.00
$\gamma = 4$	2.88	2.88	0.00
$\rho = 0.3$	0.48	0.48	0.00
$\rho = 0.5$	0.80	0.80	0.00
$\rho = 0.7$	1.11	1.11	0.00
$\rho = 0.9$	1.42	1.42	0.00
$\bar{m}_0$= 0.07	6.94	5.49	1.28
$\bar{m}_0$ = 0.08	2.12	1.84	0.27
$\bar{m}_0$ = 0.09	1.18	1.10	0.076
$\bar{m}_0$ = 0.10	0.79	0.79	-0.002
$var(m_0) = 0.13$	0.17	0.17	0.00
$var(m_0) = 0.14$	0.23	0.23	0.00
$var(m_0) = 0.15$	0.30	0.30	0.00
$var(m_0) = 0.16$	0.40	0.40	0.00