Identifying preference for early resolution from asset prices

Hengjie Ai, Ravi Bansal, Hongye Guo, and Amir Yaron*

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This paper develops a revealed preference theory for preference for the timing of resolution of uncertainty based on asset pricing data and present corresponding empirical evidence. Our main theorem provides a characterization of the representative agent's preference for early resolution of uncertainty in terms of the risk premium of assets realized during the period of resolution of informativeness of macroeconomic announcements. Empirically, we show how data on the dynamics of the S&P 500 index options prices around FOMC announcements can be used to identify investors' preference for the timing of resolution of uncertainty.

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Key words: preference for early resolution of uncertainty, generalized risk sensitivity, macroeconomic announcements, volatility

*Hengjie Ai (hengjie@umn.edu) is affiliated with the Carlson School of Management, University of Minnesota, Ravi Bansal (ravi.bansal@duke.edu) is at the Fuqua School of Business, Duke University and NBER, Hongye Guo (hoguo@wharton.upenn.edu) is at the Wharton School, University of Pennsylvania, and Amir Yaron (yaron@wharton.upenn.edu) is affiliated with Bank of Israel and the The Wharton School, University of Pennsylvania.

1 Introduction

In this paper, we develop a revealed preference theory that allows us to use asset market based evidence to detect investors' preference for the timing of resolution of uncertainty. Our main theorem states that the representative agent prefers early (late) resolution of uncertainty if and only if claims to market volatility, which can be constructed from index options, require a *positive* (negative) premium during the period where the informativeness of macroeconomic announcements is resolved. Empirically, using evidence on the implied volatility of S&P 500 index options around FOMC announcements, we find supportive evidence for investors' preference for *early* resolution of uncertainty.

The notion of preference for the timing of resolution of uncertainty is formally developed in Kreps and Porteus [28]. Models with preference for early resolution (PER) of uncertainty, in particular, the recursive preference with constant elasticity, has been widely applied in the asset pricing literature, for example, Epstein and Zin [13, 15], Weil [40], Bansal and Yaron [4], and Hansen, Heaton, and Li [19], among others. However, in the constant elasticity recursive utility model, and in most applied asset pricing models, PER is typically intertwined with other aspects of preferences, such as risk aversion and intertemporal elasticity of substitution. As a result, the exactly role for PER in asset pricing is not well understood. In addition, the asset pricing implications of models with PER are typically similar to a broad class of preferences that satisfy generalized risk sensitivity (Ai and Bansal [2]). The purpose of this paper is to provide an equivalent characterization of PER in terms of asset prices and use asset market data to identify investors' preference for the timing of resolution of uncertainty.

Preferences are often the starting point of macroeconomic analysis and asset pricing studies. Modern economic theory implies that asset prices are evaluated using marginal utilities and therefore the empirical evidence from asset markets can potentially provide valuable guidance for the choice of preferences in macroeconomic analysis in general, and in policy studies in particular. However, results that allow researchers to use relevant asset market based evidence to identify exact properties of preferences are rare. In this paper, we provide a general result that allow researchers to build such links and apply our result to establish a necessary and sufficient condition for PER in terms of asset prices. We show that the representative investor prefers early resolution of uncertainty if and only if claims to market volatility requires a positive premium during the period of *resolution of informativeness*, that is, a period in which the uncertainty about the informativeness of macroeconomic announcements is resolved. We provide empirical evidence for investors' preference for timing of resolution of uncertainty based on our theoretical insights and found evidence supportive of PER.

Our main theorem builds on the notion of generalized risk sensitivity (GRS) developed in Ai and Bansal [2]. Ai and Bansal [2] define GRS to be the class of all preferences where marginal utility of consumption decreases with respect to continuation utility. The Theorem of Generalized Risk Sensitivity in Ai and Bansal [2] demonstrates that a non-negative announcement premium for all assets that are comonotone with continuation utility is equivalent to GRS. However, GRS is a very general condition that includes many examples of non-expected utility as special cases, for example, the Gilboa and Schmeidler [16] maxmin expected utility which is indifferent between the timing of resolution of uncertainty, and the Kreps and Porteus [28] utility that prefers early resolution of uncertainty. The announcement premium itself does not allow us to identify PER.

The condition of GRS, however, implies that ranking of marginal utility of consumption is the inverse ranking of the level of continuation utility and allows us to design a thought experiment to identify PER from risk premiums. PER implies that the utility level of the representative agent is higher when she expects a more informative macroeconomic announcement and lower when she expects a non-informative announcement. The key insight of our paper is that under GRS, PER is equivalent to a negative co-monotonicity between marginal utility and the expected informativeness of the upcoming macroeconomic announcement. Because more informative macroeconomic announcements are associated with higher realized stock market volatility upon announcements, the risk premium on claims to market volatility can be used to detect the ranking of marginal utility with respect to the informativeness of macroeconomic announcements, and therefore, PER. The asset pricing test implied by our theorem is easily implementable as claims to market volatility can be replicated using a portfolio of options.

Based on the above insight, we design an empirical exercise to identify PER from the asset market data. Our empirical exercise contains two steps. The first step is to identify a period of resolution of the informativeness of macroeconomic announcements. Empirically, we use the predictability of the informativeness of FOMC announcements by the term structure of implied volatility ahead of announcements to identify the period of resolution of informativeness of FOMC announcements. The second step is to estimate the risk premium for claims to market vocality associated with FOMC announcements to identify PER. Based on standard results from option pricing, for example, Carr and Madan [7], Britten-Jones and Neuberger [5], and Jiang and Tian [23], we construct a replicating portfolio for market volatility and found evidence of a positive premium, which is consistent with preference for early resolution of uncertainty.

Related literature Our theoretical work builds on the literature that studies decision making under non-expected utility. We adopt the general representation of dynamic preferences of Strzalecki [39]. The generality of our approach is important given that our purpose is to identify the property of preferences from asset market data and given that PER if often intertwined with other aspects of preferences in the popular recursive utility formulation used in applied asset pricing work.[1] In particular, the general setup allows us to distinguish different decision theoretic concepts such as generalized risk sensitivity, uncertainty aversion, and preference for early resolution of uncertainty.

Our framework includes most of the non-expected utility models in the literature as special cases, such as the maxmin expected utility of Gilboa and Schmeidler [16], the dynamic version of which is studied by Chen and Epstein [8] and Epstein and Schneider [11]; the recursive preference of Kreps and Porteus [28] and Epstein and Zin [13]; the robust control preference of Hansen and Sargent [21, 22] and the related multiplier preference of Strzalecki [38]; the variational ambiguity-averse preference of Maccheroni, Marinacci, and Rustichini [31, 32]; the smooth ambiguity model of Klibanoff, Marinacci, and Mukerji [26, 27]; and the disappointment aversion preference of Gul [18].

Earlier work on the reveal preference approach for expected utility includes Green and Srivastava [17] and Epstein [14]. More recently, Kubler, Selden, and Wei [29] and Echenique and Saito [9] developed asset market based characterizations of the expected utility model. None of the above papers focus on GRS and aim to connect their result to asset market data as we do.

Our paper is also related to several papers that study PER in asset pricing models. Ai [1] demonstrate that in a production economy with long-run risk, most of the welfare gain from knowing more information about future is due to PER, not due to the fact that agents can use the information to improve intertemporal allocation of resources. Epstein, Farhi, and Strzalecki [10] show that in the calibrated long-run risk model, the representative agent is willing to pay more than 30% of her permanent income to resolve all future uncertainty and they argue that this magnitude is implausibly high by introspection. They also state that "*We are not aware of any market-based or experimental evidence that might help with a quantitative assessment*". Kadan and Manela [25] estimate the value of information in a model with recursive utility. Schlag, Thimme, and Weber [36] find supporting evidence for PER using options market data. Both the above papers assume the CES form of utility function and do not distinguish PER from GRS, or uncertainty aversion.

[1] For example, in the constant elasticity case, as shown in Ai and Bansal [2], PER is equivalent to risk aversion being higher than IES, which is also equivalent to GRS.

A vast literature applies the above non-expected utility models to the study of asset prices and the equity premium. We refer the readers to Epstein and Schneider [12] for a review of asset pricing studies with the maxmin expected utility model, Ju and Miao [24] for an application of the smooth ambiguity-averse preference, Hansen and Sargent [20] for the robust control preference, Routledge and Zin [34] for an asset pricing model with disappointment aversion, and Bansal and Yaron [4], Bansal [3] and Hansen, Heaton, and Li [19] for the long-run risk model that builds on recursive preferences. Skiadas [37] provides an excellent textbook treatment of recursive preferences based asset pricing theory.

Our empirical results are related to the previous research on stock market returns on macroeconomic announcement days. The previous literature documents that stock market returns and Sharpe ratios are significantly higher on days with macroeconomic news releases in the United States (Savor and Wilson [35]) and internationally (Brusa, Savor, and Wilson [6]). Lucca and Moench [30] find similar patterns and document a pre-FOMC announcement drift. Mueller, Tahbaz-Salehi, and Vedolin [33] document an FOMC announcement premium on the foreign exchange market and attribute it to compensation to financially constrained intermediaries.

The rest of the paper is organized as follows. We begin with a simple example in Section 2 to illustrate the concept of preference for early resolution of uncertainty and generalized risk sensitivity. In Section 3, we develop a thought experiment that allows us to identify PER from risk premiums of claim to market volatility. Building on these theoretical insights, in Section 4, we develop an identification strategy and present evidence for PER based on option prices on S&P 500 index options. Section 5 concludes.

2 PER and GRS

In this section, we illustrate the concepts of preference for early resolution of uncertainty and generalized risk sensitivity in a simple three-period model. We also provide simple examples for both properties of preferences. To set up some notation, we consider an economy with three periods, 0, 1, 2. Let (S, Σ, μ) be a finite probability space with equal probabilities. We denote $S = \{1, 2, \cdots n\}$, where $\mu(s) = \frac{1}{n}$ for $s = 1, 2, \cdots$. Let $(\Omega, \mathcal{F}, P) = (S, \Sigma, \mu)^3$ be the product space, and let $\mathcal{L}(\Omega, \mathcal{F}, P)$ be the set of real-valued random variables. A typical realization of states is denoted as (s_0, s_1, s_2), where for $t = 0, 1, 2$, s_t is the realization of the state in period t. A consumption plan is denoted as $\boldsymbol{C} = [C_0(s_0), C_1(s_0, s_1), C_2(s_0, s_1, s_2)]$, where consumption in each period is a measurable function of history: $C_t : (S, \Sigma)^{t+1} \to \boldsymbol{Y}$.

Here, the feasible set of consumption, $\boldsymbol{Y}$ is a subset of the positive orthant of the real line $\boldsymbol{R}$.

As in Ai and Bansal [2], we consider conditional preferences induced by a triple $\{u, \beta, \mathcal{I}\}$, where $u : \boldsymbol{Y} \to \boldsymbol{R}$ mapps consumption into utility units, β is the discount rate, and $\mathcal{I} : \mathcal{L}(\Omega, \mathcal{F}, P) \to \boldsymbol{R}$ is a certainty equivalent functional that mapps continuation utility, which is a random variable, into the real line. In our setup, date-t utility is constructed recursively using

$$V_t(\boldsymbol{C}) = u(C_t) + \beta \mathcal{I}[V_{t+1}(\boldsymbol{C})], \quad (1)$$

for $t = 0, 1, 2$, where we use the convention $V_3(\boldsymbol{C}) = 0$ for all $\boldsymbol{C}$.[2]

2.1 Preference for early resolution of uncertainty

To provide a definition of preference for early resolution of uncertainty in the above simple setup, we denote $y : (S, \Sigma, \mu) \to \boldsymbol{Y}$ to be a random variable that depends only on s. Let $\bar{y} \in \boldsymbol{Y}$ be a constant. We consider two consumption plans, $C^E = [\bar{y}_0, \bar{y}_1, y(s_1)]$ and $C^L = [\bar{y}_0, \bar{y}_1, y(s_2)]$. Note that both plans, C^E and C^L have the same unconditional distribution, because s_1 and s_2 do. However, under C^E, which represents early resolution, period-2 consumption, $y(s_1)$ is known in period 1, because s_1 is realized in period 1. By contrast, under C^L, which represents late resolution, the uncertainty in s_2 only realizes in period 2.

A dynamic preference represented by $\{u, \beta, \mathcal{I}\}$ is said to satisfy preference for early resolution of uncertainty if $V_0(\bar{y}_0, \bar{y}_1, y(s_1)) \geq V_0(\bar{y}_0, \bar{y}_1, y(s_2))$ for all $\bar{y}_0$, $\bar{y}_1$ and all measurable functions $y(s)$. Our concept of PER is the same as Kreps and Porteus [28]. Figure 1 provides a graphic illustration of C^E (top panel) and C^L (bottom panel). The squares represent the consumption in each period, and the circles represent the agent's information node. Under C^E, the agent can distinguish note 1^H from node 1^L in period 1. That is, the uncertainty about date 2 consumption is resolved in period 1 before the consumption is realized. Under C^L, the agent does not know period-2 consumption until reaching period 2.

Recursion (1) allows us to compute the utility associated with C^E and C^L. Under C^E, there is no uncertainty in period 1 because period-2 consumption is perfectly predictable. Therefore, period-1 utility is computed as: $V_1(C^E)(s_1) = u(\bar{y}_1) + \beta u(y(s_1))$. The time 0

[2] Strictly speaking, to emphasize the dependence of $\mathcal{I}_t$ on period-t information, we should allow $\mathcal{I}_t : L(\Omega, \mathcal{F}, P) \to \boldsymbol{R}$ to be a family of certainty equivalent functionals indexed by t. For each t, $\mathcal{I}_t$ mapps $(S, \Sigma)^{t+2}$ measurable functions into $(S, \Sigma)^{t+1}$ measurable functions.

Figure 1: **Early and late resolution of uncertainty**

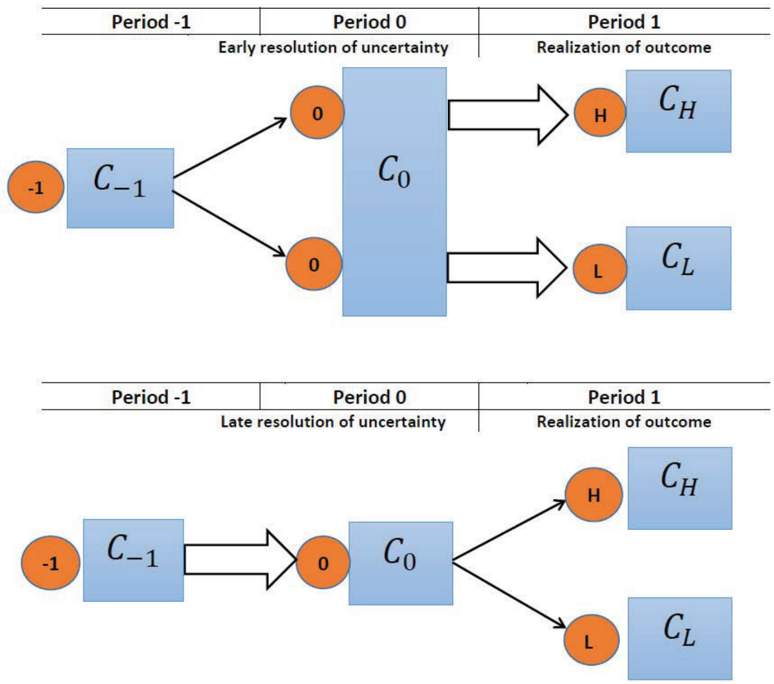


Figure 1 illustrates the notion of PER. Both panels have identical distributions of consumption. The top panel is a situation with early resolution, as the uncertainty about C_1 is resolved one period earlier, in period 0. The bottom panel corresponds to the case of late resolution, because C_1 is not revealed to the consumption until period 1.

utility is given by:

$$V_0\left(C^E\right) = u\left(\bar{y}_0\right) + \beta\mathcal{I}\left[u\left(\bar{y}_1\right) + \beta u\left(y\left(s_1\right)\right)\right]. \tag{2}$$

In the case of late resolution (bottom panel), because uncertainty is resolved in period 2, we need first to aggregate over uncertain states of the world when computing period 1 utility: $V_1\left(C^L\right) = u\left(\bar{y}_1\right) + \beta\mathcal{I}\left[u\left(y\left(s_2\right)\right)\right]$, and simply aggregate over time in period 0 to get:

$$V_0\left(C^L\right) = u\left(\bar{y}_0\right) + \beta\left\{u\left(\bar{y}_1\right) + \beta\mathcal{I}\left[u\left(y\left(s_2\right)\right)\right]\right\}. \tag{3}$$

Comparing equations (2) and (3), it is clear that PER can be formulated as the following property of the certainty equivalent functional:

$$\mathcal{I}\left[u\left(\bar{y}_1\right) + \beta u\left(y\left(s_1\right)\right)\right] \geq u\left(\bar{y}_1\right) + \beta\mathcal{I}\left[u\left(y\left(s_2\right)\right)\right]. \tag{4}$$

Below we provide a simple example of recursive preference that may satisfy preference for early or later resolution of uncertainty depending on the value of the discount factor.

Examples Consider the following preference. $u : \boldsymbol{Y} \to \boldsymbol{R}$ is strictly increasing, and $\mathcal{I}(u) = -\theta \ln E\left[e^{-\frac{1}{\theta}u}\right]$. Assume also that $u(C) = \ln(C)$ and $\ln y(s) \sim N(\mu, \sigma^2)$. To calculate the utility associated with early resolution,

$$\begin{aligned} V_0\left(C^E\right) &= \ln \bar{y}_0 + \beta \mathcal{I}\left[\ln \bar{y}_1 + \beta \ln y(s_1)\right] \\ &= \ln \bar{y}_0 - \beta\theta \ln E\left[e^{-\frac{1}{\theta}\left[\ln \bar{y}_1 + \beta \ln y(s_1)\right]}\right] \\ &= \ln \bar{y}_0 + \beta \ln \bar{y}_1 + \beta^2 \mu - \frac{1}{2\theta}\beta^3\sigma^2. \end{aligned}$$

The utility associated with late resolution is:

$$\begin{aligned} V_0\left(C^L\right) &= \ln \bar{y}_0 + \beta \ln \bar{y}_1 + \beta^2 \mathcal{I}\left[\ln y(s_1)\right] \\ &= \ln \bar{y}_0 + \beta \ln \bar{y}_1 - \beta^2\theta \ln E\left[e^{-\frac{1}{\theta}\ln y(s_1)}\right] \\ &= \ln \bar{y}_0 + \beta \ln \bar{y}_1 + \beta^2 \mu - \frac{1}{2\theta}\beta^2\sigma^2. \end{aligned}$$

Clearly, $V_0\left(C^E\right) > V_0\left(C^L\right)$ if $\beta < 1$ and $V_0\left(C^E\right) < V_0\left(C^L\right)$ if $\beta > 1$. In the appendix we show that the above comparison holds for all consumption distributions such that the utility is defined. As a result, this utility function has preference for early resolution of uncertainty if $\beta < 1$ and preference for late resolution of uncertainty if $\beta > 1$. It is indifferent towards the timing of resolution of uncertainty if $\beta = 1$.

As shown in Strzalecki [39], general characterizations of property (4) in terms of the functional form of $\mathcal{I}$ can be quite complicated. Directly testing the functional form of $\mathcal{I}$ from asset prices seems to be extremely hard. The asset pricing test we propose in this paper takes advantage of the notion of generalized risk sensitivity developed in Ai and Bansal [2], which we briefly review in the following section.

2.2 Generalized risk sensitivity

An intertemporal preference represented by $\{u, \beta, \mathcal{I}\}$ is said to satisfy generalized risk sensitivity if $\mathcal{I}$ is increasing in second order stochastic dominance (see (Ai and Bansal [2])). To illustrate the concept of GRS, we consider the top panel of Figure 1 and interpret the event in period 0 that reveals the true value of C_1 as an announcement. The utility of the agent at time 0 can be computed in two steps:

$$V_0 = u(\bar{y}_0) + \beta \mathcal{I}[V_1(s_1)],$$

where

$$V_1(s_1) = u(\bar{y}_1) + \beta u(y(s_1)).$$

We compute the announcement stochastic discount factor (A-SDF) that prices period-0 state contingent payoff into period -1 consumption units. As in standard equilibrium models, stochastic discount factor can be constructed as the ratio of marginal utilities. Therefore, if we interpret $V_1 = [V_1(1), V_1(1), \cdots V_1(n)]$ as a finite-dimensional vector and denote $\frac{\partial \mathcal{I}[V_1]}{\partial V_1(s_1)}$ as the partial derivative of the certainty equivalent with respect to the value of $V_1(s_1)$ is state s_1,

$$A\text{-}SDF(s_1) = \frac{\beta \frac{\partial \mathcal{I}[V_1]}{\partial V_1(s_1)} u'(\bar{y}_1)}{u'(\bar{y}_0)} \propto \frac{\partial \mathcal{I}[V_1]}{\partial V_1(s_1)},$$

where in the last step, we suppressed the term $\beta \frac{u'(\bar{y}_1)}{u'(\bar{y}_0)}$, which does not depend on s_1 and does not affect risk premium. Clearly, if $\frac{\partial \mathcal{I}[V_1]}{\partial V_1(s_1)}$ is a decreasing function of $V_1(s_1)$, then any payoff that is positively correlated with continuation utility, $V_1(s_1)$ will require a positive risk premium at announcement.

Formally, we consider an endowment economy where aggregate consumption is of the form $\boldsymbol{C} = [\bar{y}_0, \bar{y}_1, y(s_1)]$. We think of period 1 as the macroeconomic announcement period where the value of $y(s_1)$ is revealed. We consider a state contingent payoff $X(s_1)$ and denote the present value of $X(s_1)$ from the perspective of period 0 as $P_0(X)$. We say asset X provides an announcement premium if $\frac{E[X]}{P_0(X)} > R_{f,1}$, where $R_{f,1}$ is the risk-free rate between period 0 and period 1. The following theorem is the discrete-state version of the Theorem of Generalized Risk Sensitivity in Ai and Bansal [2].

Theorem 1. *(Theorem of Generalized Risk Sensitivity) Suppose both u and $\mathcal{I}$ are strictly increasing and continuously differentiable, the following statements are equivalent:*

1. The announcement premium for any asset comonotone with $y(s_1)$ is (strictly) positive.

2. The certainty equivalent functional, $\mathcal{I}$ is (strictly) increasing in second-order stochastic dominance.

3. For any continuation utility, $V : \{\Omega, \mathcal{F}\} \to R$, the vector of partial derivatives of $\mathcal{I}$ with respect to V, $\left\{\frac{\partial \mathcal{I}[V_1]}{\partial V_1(s)}\right\}_{s=1,2,\cdots,n}$ is (strictly) negatively comonotone with $\{V_1(s)\}_{s=1,2,\cdots,n}$.

Examples Using the result from Ai and Bansal [2], aggregators of the form $\mathcal{I}(u) = \phi^{-1}(E[\phi(u)])$ satisfy generalized risk sensitivity if ϕ is concave. It follows immediately that the example in the last section, that is, $\mathcal{I}(u) = -\theta \ln E\left[e^{-\frac{1}{\theta}u}\right]$ satisfy generalized risk sensitivity as long as $\theta > 0$. As a result, this utility function may exhibit preference for early or later resolution of uncertainty, depending on the value of β, but it always satisfies generalized risk senstivity.

In the rest of the paper, we will restrict our attention to preferences that satisfy generalized risk sensitivity. The assumption of generalized risk sensitivity is appealing in our setup for two reasons. First, it is motivated by the empirical fact of the macroeconomic announcement premium. Second, it links the level of utility, which is a property of preference, to marginal utilities, which can be conveniently tested from asset prices. In particular, under the assumption of GRS, the ranking of the level of utility is exactly the reverse of the ranking of continuation utility, a property which we exploit in the following sections.

3 An asset pricing test for PER

3.1 A thought experiment

In this section, we extend the three-period model above to construct a thought experiment where asset prices can be used to identify preference for early resolution of uncertainty in preferences. To do so, we combine the early resolution of uncertainty case and the late resolution of uncertainty case in Figure 1 and add a period -1 to construct a four-period model as illustrated in Figure 2.

In our four-period model, a general consumption plan is denoted as $\boldsymbol{C} = [C_{-1}, C_0(s_0), C_1(s_0, s_1), C_2(s_0, s_1, s_2)]$. To identify PER, it is enough to restrict attention to a small class of consumption plans where $C = \left[\bar{y}_{-1}, \bar{y}_0, \bar{y}_1, y\left(s_{\iota(s_0)}\right)\right]$, where as before, $y : (S, \Sigma, \mu) \to \boldsymbol{Y}$ is a random variable taking values in the consumption set $\boldsymbol{Y}$, and $\bar{y}_t$ are constants for $t = -1, 0, 1$. In addition, $\iota : (S, \Sigma, \mu) \to \{1, 2\}$ is a random variable that takes a value of either 1 or 2. As illustrated in the previous example, $\iota(s_0) = 1$ represents the case of early resolution of uncertainty and $\iota(s_0) = 2$ represents the case with late resolution of uncertainty.

As illustrated in Figure 2, early and late resolution are a stochastic outcome to be learned in period 0. We call period 0 the period of *resolution of informativeness.* If $\iota(s_0) = 1$, the continuation utility of the agent, $V_0(s_0)$ can be cacluated as in (2), and if $\iota(s_0) = 2$, $V_0(s_0)$ is

Figure 2: **Resolution of informativeness**

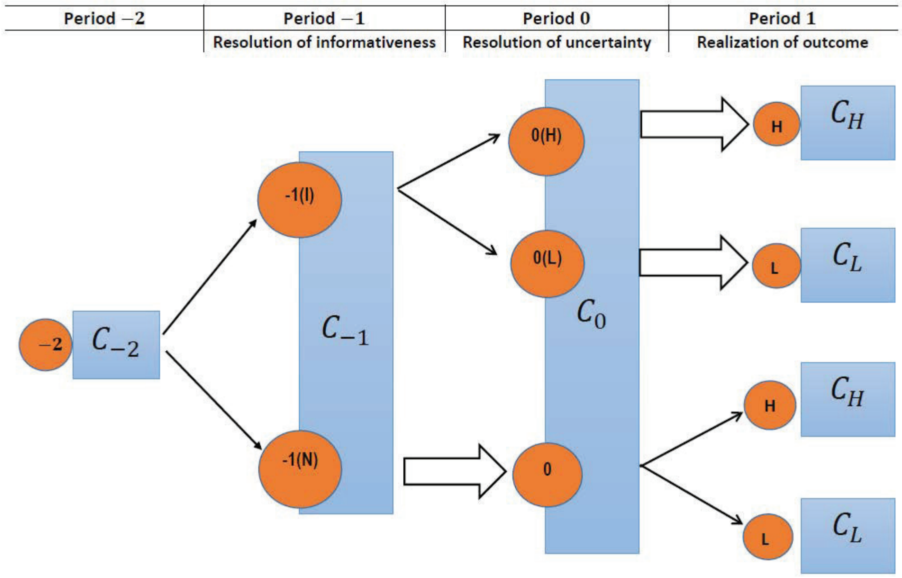


Figure 2 represents our thought experiment of resolution of informativeness. $-1\,(I)$ is node where the agent expects the uncertainty about C_1 to be resolved in period 0 with an informative macroeconomic announcement. Node $-1\,(I)$ represents the situation where the upcoming announcement is expected to be completely uninformative about future.

cacluated as in (3). In period -1, before the resolution of informativeness, the agent's utility is calculated as $V_{-1} = u\left(\bar{y}_{-1}\right) + \beta\mathcal{I}\left[V_0\left(s_0\right)\right]$. In our model, the stochastic discount factor that converts period 0 payoff into period -1 consumption units is therefore

$$SDF = \frac{\beta\frac{\partial\mathcal{I}[V_0]}{\partial V_0(s_0)}u'\left(\bar{y}_0\right)}{u'\left(\bar{y}_{-1}\right)} \propto \frac{\partial\mathcal{I}\left[V_0\right]}{\partial V_0\left(s_0\right)}.$$

By Theorem 1, under the assumption of generalized risk sensitivity, the ranking of the level of utility is the inverse of the ranking of the marginal utilities. That is, for any s_0 and s_0', where s_0 is more informative than s_0', preference for early resolution implies $V\left(s_0\right) \geq V\left(s_0'\right)$. Under GRS, this is true if and only if $\frac{\partial\mathcal{I}[V_0]}{\partial V_0(s_0)} \geq \frac{\partial\mathcal{I}[V_0]}{\partial V_0\left(s_0'\right)}$.

Although the ranking of the level of continuation utility is hard to observe, the ranking of marginal utilities can be detected from the asset market. Consider any payoff $X\left(s_0\right)$ that is increasing in the informativeness of announcements, that is, $X\left(s_0\right) \geq X\left(s_0'\right)$. Let the period

-1 value of a claim to $X(S_0)$ be denoted as $P_{-1}[X(S_0)]$. Equation (3.1) implies that

$$P_{-1}[X(S_0)] = \frac{E\left[\frac{\partial \mathcal{I}[V_0]}{\partial V_0(s_0)} X(S_0)\right]}{E\left[\frac{\partial \mathcal{I}[V_0]}{\partial V_0(s_0)}\right]}.$$

Clearly, PER implies $Cov\left(\frac{\partial \mathcal{I}[V_0]}{\partial V_0(s_0)}, X(s_0)\right) \leq 0$. As a result, $E\left[\frac{\partial \mathcal{I}[V_0]}{\partial V_0(s_0)} X(S_0)\right] \leq E\left[\frac{\partial \mathcal{I}[V_0]}{\partial V_0(s_0)}\right] E[X(S_0)]$ and $P_{-1}[X(S_0)] \leq E[X(S_0)]$, which implies a positive announcement premium.

Building on the intuition of the above example, the next section of the paper presents a formal theorem that provides an asset price based characterization of preference for early resolution of uncertainty, which can be used to empirically identify PER.

3.2 An equivalence result

Consider any asset with payoff $X : \Omega \rightarrow R$. The payoff X is said to be co-monotone with informativeness if for any s_0 and s_0', $\iota(s_0) = 1$ and $\iota(s_0') = 2$ implies $X(s_0) > X(s_0')$. Asset X is said to requires a positive resolution of informativeness premium if

$$E\left[\frac{X(S_0)}{P_{-1}[X(S_0)]}\right] > R_{f,-1},$$

where $R_{f,-1}$ is the risk-free interest rate from period -1 to period 0. That is, if the strategy of purchasing the asset right before the resolution of informativeness and selling it right afterwards earns an expected return higher than the risk-free interest rate.

Theorem 2. *Suppose both u and $\mathcal{I}$ are strictly increasing, continuously differentiable and satisfies GRS, the following statements are equivalent:*

1. *The announcement premium for any asset comonotone with informativeness is positive (negative).*

2. *The certainty equivalent functional, $\mathcal{I}$ satisfy preference for early (late) resolution of uncertainty.*

That fact that under GRS, PER implies a positive risk premium for payoffs increasing in the informativeness of the upcoming announcement is straightforward given the discussion in the last section. The converse of this statement is non-trivial and is the theoretical basis for the identification exercise in this paper. If we have a rich enough set of assets with payoff increasing in informativeness, and the risk premium of all of these assets are positive, then we can safely conclude that the representative agent prefers early resolution of uncertainty.

Examples We continue with the example of recursive utility discussed in Section 2. Given the functional form of the preference, the marginal utilities can be computed as

$$\frac{\partial \mathcal{I}\left[V_0\right]}{\partial V_0\left(s_0\right)}=\frac{P\left(s_0\right) e^{-\frac{1}{\theta} V_0\left(s_0\right)}}{\sum_{s_0=1}^n P\left(s_0\right) e^{-\frac{1}{\theta} V_0\left(s_0\right)}}=\frac{e^{-\frac{1}{\theta} V_0\left(s_0\right)}}{\sum_{s_0=1}^n e^{-\frac{1}{\theta} V_0\left(s_0\right)}},$$

where the second equality uses the fact that $P\left(s_0\right)=\frac{1}{n}$ for all s_0. Clearly, $\frac{\partial \mathcal{I}\left[V_0\right]}{\partial V_0\left(s_0\right)}$ is a strictly decreasing function of $V\left(s_0\right)$. Consider two arbitrary s_0 and s_0'. Suppose $\iota\left(s_0\right)=1$ and $\iota\left(s_0'\right)=2$. That is, s_0 corresponds to early resolution and s_0' corresponds to late resolution. Without knowing the exact functional form of $V\left(s_0\right)$, we know that preference for early resolution of uncertainty implies $\frac{\partial \mathcal{I}\left[V_0\right]}{\partial V_0\left(s_0\right)}$ must be comontone with $\iota\left(s\right)$, and preference for late resolution implies that $\frac{\partial \mathcal{I}\left[V_0\right]}{\partial V_0\left(s_0\right)}$ is negatively comontone with $\iota\left(s\right)$.

Suppose the payoff of asset X is increasing in the informativeness of the announcement at time 1: $X\left(s_0\right)>X\left(s_0'\right)$, for any s_0 and s_0' such that $\iota\left(s_0\right)=1$ and $\iota\left(s_0'\right)=2$. Then X can be used as a test asset. If the agent prefers early resolution, then the stochastic discount factor $\frac{\partial \mathcal{I}\left[V_0\right]}{\partial V_0\left(s_0\right)}$ is negatively comonotone with the payoff of X and X must receive a positive risk premium in a competitive equilibrium. Similarly, if the agent prefers late resolution, then the stochastic discount factor $\frac{\partial \mathcal{I}\left[V_0\right]}{\partial V_0\left(s_0\right)}$ is positively comonotone with the payoff of X and in equilibrium, X must receive a negative risk premium.

4 Empirical evidence

4.1 Key elements for identifying PER

To operationalize our thought experiment and use financial market data to test PER, we use monetary policy announcements made by the Federal Open Market Committee (FOMC) as our primary example of announcements that reveal uncertainty about the macroeconomic. In order to test PER, we need to identify the event of resolution of informativeness in the data and assets with payoff increasing in the resolution of informativeness. Below we summarize the key elements of our identification exercise, which serves as a guide for the following empirical sections of the paper.

1. The informativeness of FOMC announcements must change over time. The thought experiment in Section 3 requires that the informativeness of the announcement to be a stochastic outcome. More informative announcements correspond to the case of early resolution and less informative announcements correspond to the case of late resolution.

2. The heterogeneity in the informativeness must be perceived by the market. The thought experiment in Section 3 requires that the market must be able to distinguish early resolution (node $-1\,(I)$ in Figure 2) from late resolution (node $-1\,(N)$) so that asset payoff can respond to the informativeness of the upcoming announcement.

3. The period during which the informativeness of the upcoming FOMC announcements is perceived by the market is the period of resolution of informativeness.

4. The payoff of the test asset must be increasing in the informativeness of announcement. The key to the identification exercise is an asset with payoff increasing in the informativeness of the announcement.

   Here, we use the claim to market volatility with short maturity. To understand this construction, in the context of Figure (2), consider a claim to market volatility in period -1 which expires in period 0. At node $-1(I)$, which is the case of early resolution, the upcoming announcement is expected to informative and the market is expected to react to the announcement. The implied volatility at node $-1(I)$ with maturity at time 0 will be high. In contrast, at node $-0(N)$, which is the case of late resolution, the upcoming announcement is expected to uninformative. In this case, there is no news in period 0, and the implied volatility at node $-0(N)$ with expiration at time 0 will be low. In fact, it will be zero in this example.

   Motivated by the above observation, in the data, we use implied volatility with maturity shortly after the announcement as the test asset.

Below, we briefly summarize our identification strategy for each of the above elements.

Variations in the informativeness To establish the time-varying informativeness of FOMC announcements, we show that implied volatility reduction varies substantially across FOMC announcements.

Intuitively, when the upcoming announcement is expected to be informative, the implied volatility of the $S\&P500$ index will be high before the announcement, and will drop significantly afterwards. The time variations in the implied volatility reduction across FOMC announcements therefore can be interpreted as the evidence for time-varying informativeness. To confirm the above intuition, we show that i) implied volatility of the stock market index (S&P500 index) on average drops over FOMC announcements, and ii) there is substantial variation in such reduction.

Predictability of informativeness Our identification exercise requires that the variations in informativeness be perceived by the market. We establish this empirically by showing that the amount of reduction in implied volatility is predictable by market prices. In particular, we use the ratio of short-term versus long-term implied volatility, or the inverse slope of the term structure of implied volatility, as a predictor for the implied volatility drop. Our inverse slope variable is defined as:

$$Inv\_Slope = \frac{IV^9}{IV^{90}}, \tag{5}$$

where IV^9 is the short-term implied stock market volatility, which we measure by using the implied volatility index with 9 days to maturity published by CBOE. IV^{90} is long-term implied volatility measured by the implied volatility index with 90 days to maturity.

Implied volatility from option prices may be affected by changes in the volatility of economic fundamentals (such as the volatility of aggregate productivity shocks) or by the informativeness of macroeconomic news. Variations in the volatility of economic fundamentals presumably happen at a much lower frequency than the few days of macroeconomic announcements. Fundamental economic volatility is therefore likely to affect both short-term and long-term volatility. The inverse slope constructed above allows us to control for volatility of economic fundamentals and better predict the informativeness of announcements. We show in the next section that *Inv_Slope* has significant predictive powers for the implied volatility reduction on macroeconomic announcement days.

Resolution of informativeness The key to our identification exercise is the calculation of risk premium earned by the test asset during the period of resolution of informativeness. Empirically, we identify the period of informativeness as the period during which the predictability of the regression (5) is realized.

Note that the inverse slope variable in (5) can be written as a sum of an initial level and changes over time:

$$Inv\_Slope_{t-1} = \sum_{j=1}^{J-1} \Delta Inv\_Slope_{t-j} + Inv\_Slope_{t-J}, \tag{6}$$

where $\Delta Inv\_Slope_{t-j} = Inv\_Slope_{t-j} - Inv\_Slope_{t-j-1}$ is the change in inverse slope from $t-j-1$ to $t-j$. If we set the initial date $t-J$ distant enough from the announcement date, the predictability of Inv_Slope_{t-1} for the informativeness of FOMC announcements must come from a subset of days between $t-J$ and $t-1$. These are the days in which the informativeness of announcements are realized by the market.

As a result, we use regression analysis to identify the period of resolution of informativeness as the days in which the changes in slope have significant predictive power for the reduction of short-term market volatility. We show in the next section that evidence suggests that this typically corresponds to the five weekdays, or one calendar week, before the announcements.

Premium for claims to market volatility Having identified the period of resolution of informativeness, our final step is to estimate the risk premium earned on claims to short-term market volatility during this period. As commented earlier, claims to implied volatility which expires shortly after the announcements can be used as the test asset for PER.

To construct the claim to market volatility, we follow Bakshi et. al. who show that under no arbitrage, the second moment of log security returns can be constructed from option prices the following way:

$$\frac{1}{T}E^{RN}[(\ln(S_T) - \ln(S_t))^2] = \frac{e^{rT}}{T}\left(\int_0^{S_t} \frac{2(1-\ln(\frac{K}{S_t}))}{K^2} Put[K]dK + \int_{S_t}^{\infty} \frac{2(1+\ln(\frac{K}{S_t}))}{K^2} Call[K]dK\right) \tag{7}$$

Here, $E^{RN}[\cdot]$ is the risk neutral expectation. S_t is the price of the underlying security at time t, and S_T that at time T. $Put[K]$ and $Call[K]$ are prices of a put and a call option with the underlying security S, strike price K, and expiration T. The formula expresses the risk neutral squared log returns as integrals of options across strike prices. Because squared mean of returns is orders of magnitude smaller than the mean of squared returns, this quantity practically measures the risk-neutral price of return variance.

A similar equation on the fourth moment of returns is:

$$\frac{1}{T}E^{RN}[(\ln(S_T) - \ln(S_t))^4] = \frac{e^{rT}}{T}(\int_0^{S_t} \frac{12\ln(\frac{K}{S_t})^2 - 4\ln(\frac{K}{S_t})^3}{K^2} Put[K]dK + \int_{S_t}^{\infty} \frac{12\ln(\frac{K}{S_t})^2 + 4\ln(\frac{K}{S_t})^3}{K^2} Call[K]dK) \quad (8)$$

This similarly measures the price of an instrument that pays the variability in the security's returns over a fixed horizon. The distinction is here it places a higher emphasis on extreme returns and thus tail events.

Empirically, we can use the weighted sum of options with different strikes to approximate the above integral and construct the claims to aggregate variance. We additionally construct the fourth moment portfolios and verify that our results are robust to this alternative measure of return variability. We empirically estimate the excess return of this portfolio during the period of resolution of informativeness. Our Theorem 2 implies that an extra positive (negative) average return during the period of resolution of informativeness is indicative of investors' preference for early (late) resolution of uncertainty.

4.2 Resolution of informativeness

In this section, we document our empirical evidence for investors' preference for the timing of resolution of uncertainty using data from the options market. The option return data are daily and come from OptionMetrics and go from 1996 to 2019. The implied volatility data we use include the 9-day, 30-day (VIX), and 90-day implied volatility indices on S&P 500 from CBOE. The 30-day implied volatility is the VIX index, which goes back to 1990. The 9-day and 90-day IV indices have shorter history going back to 2011 and 2007 respectively. These implied volatility indices end in 2020.

The 9-day implied volatility has the shortest maturity and changes of this index on the FOMC announcement days best measure the informativeness of the announcements. It, however, has much shorter history than the 30-day implied volatility index. In what follows we use the reduction in the 30-day implied volatility index as our baseline measure of realized informativeness and use the 9-day index as an alternative measure.

Reductions in implied volatility across announcements We first show that on average there is a significant reduction in implied volatility on FOMC announcement days. The reduction in implied volatility is quite robust across all maturities. In Figure 3, we plot

Figure 3: **Log VIX around FOMC announcements**

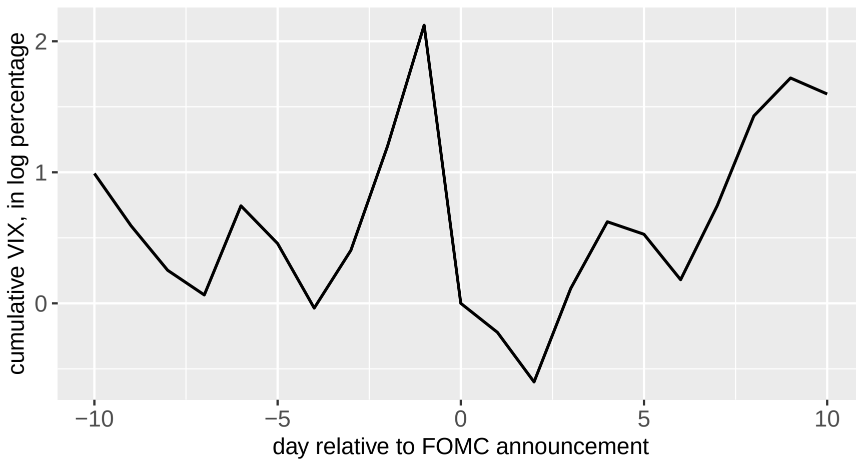


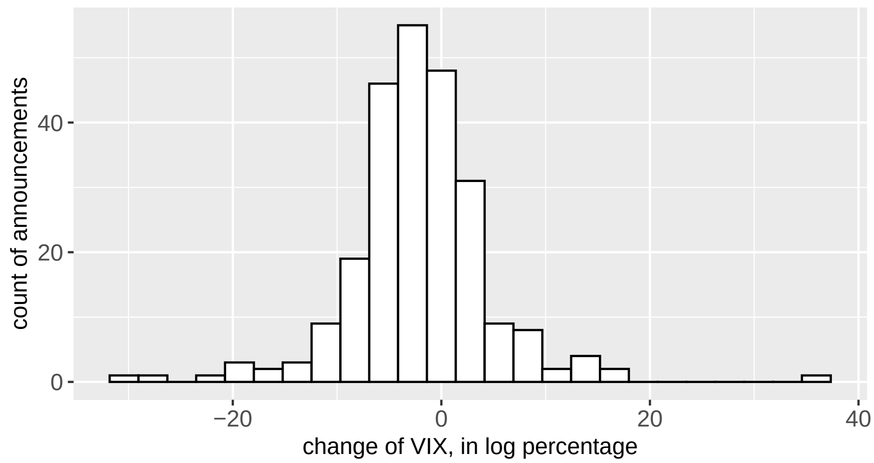
Figure 3 illustrates the average log VIX index around FOMC announcements. We normalize the (end-of-day) log VIX index to zero for the FOMC announcement day which is represented by day 0. Other days are labeled relative to the FOMC announcement day. The decline from 2.2 to 0 over day 0 means that the VIX index experienced on average a 2.2% decline on the FOMC announcement days.

the level log VIX index around FOMC announcement days with the announcement-day log VIX normalized to zero. We denote the FOMC announcement day as day 0, the day before the announce day as -1, and the day after as 1, etc. All values of the VIX are end-of-the-day values. Figure 3 shows a clear reduction in VIX on FOMC announcement days. In Table 1, we present a formal regression analysis for the reduction in the VIX index on announcement days controlling for the day-of-the-week effect.[3] The third column is the reduction in 30-day implied volatility and the fourth column is the reductions in 9-day implied volatility. The reduction in VIX on announcement days is significant with a point estimate -1.89%. Because VIX index is the average volatility of 30 days, under the assumption that stock returns are i.i.d., an -1.89% reduction roughly corresponds to a 50% higher volatility on announcement days relative to non-announcement days.[4] The estimate for 9-day implied volatility shows a similar pattern.

[3] As shown in Table 1, the VIX index has a significant day-of-week pattern. In particular, changes in VIX is typically positive on Mondays and negative on Wednesday and Fridays. Because FOMC announcements typically occur on Tuesdays and Wednesdays, it is important to control for the day-of-the-week effect.

[4] Assume that the daily volatility is σ on non-announcement days and $(1+x)\,\sigma$ on announcement days. The thirty-day volatility before announcement is $\sqrt{(1+x)^2\,\sigma^2 + 29\sigma^2}$, and the thirty-day volatility after announcement is $\sqrt{30\sigma^2}$. A log difference of 2% between the above translates into a value of $x = 49\%$.

Figure 4: **Histogram of changes in log VIX on FOMC announcement days**



This figure plots the histogram of changes in log VIX around FOMC announcements. Changes in log VIX is computed as the difference between the VIX index at the end of the announcement day and that on the day before the announcement day.

There is also substantial variation in the amount of volatility reduction across announcements. We plot the histogram for the changes in VIX index on FOMC announcement days in Figure 4. There is a fairly wide range of implied volatility changes across announcements, indicating the informativeness of announcements does change over time. Importantly, as we will show in the next section, these changes are predictable by market prices, in particular, the term structure of implied volatility ahead of announcements.

Predictability of informativeness Next, we demonstrate that the reduction of volatility across announcements can be predicted by the inverse slope of the term structure of implied volatility. We regress the changes in short-term implied volatility on the inverse slope of the previous day, a FOMC announcement day dummy, an interaction between the two terms, and control variables such as the day-of-the-week dummies.

$$\Delta \ln IV_t = \xi_0 + \xi_1 Inv\_Slope_{t-1} + \xi_2 I_t^{FOMC} + \xi_3 Inv\_Slope_{t-1} \cdot I_t^{FOMC} + \sum_{d=1}^{5} \delta_d I_{d,t}^{DOW} + \varepsilon_t. \quad (9)$$

Here, $\Delta \ln IV_t$ is the one day change in implied volatility from the end of $t-1$ to t, Inv_Slope_{t-1} is the inverse slope defined in equation (5) on day $t-1$, and I_t^{FOMC} is an indicator variable that takes a value of 1 only if day t is a pre-scheduled FOMC announcement. For $d = 1, 2, \cdots, 5$, $I_{d,t}^{DOW}$ is an indicator variable that take a value of 1 only if day t is the dth day of the week. As explained earlier, we expect short-term volatility to be higher relative to long-term volatility ahead of informative FOMC announcements, because higher informativeness of announcements, if expected by the market, should be associated with larger reactions of stock market returns with respect to these announcements.

In Table 2, we report several versions of the above regression to demonstrate the predictability of announcement-day volatility reductions. In column 1, the regression of volatility reduction on inverse slope produces a significant coefficient of -6.57, indicating that in general, the inverse slope variable has significant predictive powers for volatility reductions. It is well known that volatility is mean reverting. As shown in column 2, higher volatility on the previous day is associated with significantly larger volatility reductions as well. However, whenever the inverse slope variable is included (column 3, 4 and 5), the effect of the level of volatility on the previous day is subsumed. The regression in column 4 includes only the 77 observations on FOMC announcement days. In this case, the effect of inverse slope is much large in magnitude, although the t-statistic is much smaller due to a much smaller sample. In column 5, we report the result of the full regression. Here, Inv_Slope_{t-1} has significant predictive powers for implied volatility reductions in general. More importantly, the coefficient on the interaction term of FOMC indicator and Inv_Slope_{t-1} is significantly larger, indicating the Inv_Slope_{t-1} variable has extra predictive powers on FOMC announcement days. In the last column of the same table, we report the results of regression (9), where the dependent variable is the reduction in 9-day implied volatility. This regression shows a similar pattern with a more negative point estimate for ξ_3. These results indicate that the option market correctly understands the informativeness of the FOMC announcements ahead of time, and expresses its view via option prices. Anticipating an informative announcement, investors bid up the prices of the short-horizon options relative to long-horizon ones, creating a large 9-day/90-day implied volatility ratio before the announcement. In the next section, we investigate over what period do they come up with this expected informativeness.

Period of resolution of informativeness Our predictive variable Inv_Slope_{t-1} can be decomposed into changes over the days before the announcement, plus a very stale inverse slope level, as in 6. Since the staleness of this distant inverse slope level prevents it from being useful in predicting the informativeness of the announcements, the predictive power of Inv_Slope_{t-1} must come from the daily changes. Here, we identify a period of resolution of informativeness using the predictability regression (9) with Inv_Slope_{t-1} being replaced by changes in inverse slope on days leading up to the FOMC announcements:

$$\Delta \ln IV_t = \xi_0 + \Sigma_{j=1}^{10} \xi_{1,j} \Delta Inv\_Slope_{t-j} + \xi_2 I_t^{FOMC} + \Sigma_{j=1}^{10} \xi_{3,j} \Delta Inv\_Slope_{t-j} \cdot I_t^{FOMC} + \sum_{d=1}^{5} \delta_d I_{d,t}^{DOW} + \varepsilon_t,$$

Because including further lags does not add to the predictive power of the above regression, we report the our regression results with $J = 10$ in Table 3. Here, we include two different regressions, where the dependent variable $\Delta \ln IV_t$, is measured by the reduction of implied volatility with 30 day maturity ($\Delta \ln VIX$ in the table) and that with 9 day maturity ($\Delta \ln VIX9$ in the table), respectively. Across both regressions, the regression coefficient is significant for the changes in inverse slope occurred five weekdays before the announcement. The effect one day before the announcements is also economically large, though only marginally significant for the 30-day VIX reduction. Out of a desire to keep our period of ROI continuous, we will use the five consecutive weekdays before the announcements as our benchmark measure of the period of resolution of informativeness in the rest of our analysis.

4.3 The PER premium

Theorem 2 implies that the premium received on the claim to market volatility realized during the period of resolution of informativeness must be a premium due to preference for early resolution of uncertainty. To estimate the sign of this PER premium, we construct synthesized variance swaps on the S&P 500 index using put and call prices from OptionMetrics, the range of which is 1996 to 2019. The synthesized variance swaps are constructed according to equation 7 and are portfolios of out-of-money puts and calls. The construction details can be found in the data appendix. We also construct an alternative portfolio based on equation 8 as a robustness check. With daily returns to these variability-paying portfolios, we run the following regression:

$$r_{\tau,t} = \sum_{a=-10}^{10} \beta_a I_{a,t}^{FOMC} \cdot I_t^{After}(\tau) + \sum_{w=1}^{9} \gamma_w I_{w,t}^{Maturity}(\tau) + \sum_{d=1}^{5} \delta_d I_{d,t}^{DOW} + \epsilon_{\tau,t}. \tag{10}$$

This is a panel regression where $r_{\tau,t}$ is the log return realized on date t on a claim to market volatility constructed using an option portfolio with maturity τ. $I_a^{FOMC}(t)$ is an indicator function that takes a value of 1 only if date t is a days after a pre-scheduled FOMC announcement. $I_t^{After}(\tau)$ is an indicator function that take a value of 1 only if the options expire after the closet announcement in the future as of day t. Because the price of options that expire before announcements will not be affected by the informativeness of these announcements, we focus only on options that expire after the announcements. We also include several control variables in the above regression: $I_w^{Maturity}(\tau)$ is an indicator function for the maturity of the options, which takes a value of 1 only if the option is w weeks to maturity, for $w = 1, 2, \cdots, 11$. As before, $I_{d,t}^{DOW}$ are indicator variables that control for the day of the week effect.

We present our regression results in Table 4, where we report the coefficients β_a for $a = 0$ and over the period of resolution of informativeness. Column 1-3 report returns of the second moment portfolios, and column 4-6 report returns of the fourth moment portfolios. The columns differ also in the maturity of the options used. Column 1 and 4 include only options that matures in less than or equal to 4 weeks. Column 2 and 5 extend the limit to 8 weeks, and column 3 and 6 to 12 weeks. We first observe a significant and negative return on the FOMC announcement days, as reflected by the negative coefficients β_0. While this is not directly related to our test, this negative return is economically interesting and intuitive: it says that the return variance on the announcement days carries a negative premium, perhaps because it pays investors in volatile and difficult states. What is important for our theory is the sum of the coefficients over the period of ROI, i.e. $\sum_{a=-1}^{-5} \beta_a$. In all columns we observe a significantly positive sum. This indicates that these variability-paying portfolios see high excess returns over the period of resolution of informativeness, which is consistent with a preference for early resolution premium.

It is worth mentioning that first, these portfolios do not have higher loading on market excess returns over the period of ROI. Table 7 shows, if anything, that the market loading is somewhat lower. Second, the market return is not higher during the period of ROI. In fact, over this period the market return is about 8 basis points lower than average. Given these two empirical patterns, this premium on the variability-paying portfolios cannot be driven by exposure to the market.

4.4 Additional Results

Throughout our analysis, we use the inverse slope of the term structure of implied volatility, or the 9-day VIX divided by the 90-day VIX, as a measure of short run expected informativeness. While this is an intuitive measure that directly comes out of our theoretical framework, one may wonder whether it is consistent with more direct measures of market attention over the period of ROI. Table 5 shows exactly that. We obtain the number of Fed-related new items from RavenPack Analytics. The table shows that over the period of ROI, increase in inverse slope is strongly associated with more Fed-related news articles. In other words, announcements expected to be more informative—according to our inverse slope measure—are indeed those receiving more news reporting ahead of time. This piece of evidence provides external validity to our measure of expected informativeness.

Separately, while the FOMC announcements clearly resolve important systematic risks, there are relatively few observations. Savor and Wilson (2016) demonstrate that individual firms' earnings announcements also resolve important systematic cash flow risks. Also investors and analysts pay close attention to these earnings announcements and make forecasts about the earnings outcome ahead of time.[5] A period of ROI may therefore also exist for these individual earnings announcements. Since a 9-day implied volatility index for individual stock options cannot be constructed, we cannot perform an analogous search for the period of ROI in this context. We therefore keep using 5 weekdays before the announcement, and investigate whether the returns to the variability-paying portfolios—now on individual stock options—are also abnormally high before the earnings announcements. Table 6 shows exactly this.[6] While the premium is substantially smaller than that observed before the FOMC announcements, the statistical significance is much higher, thanks to the relative abundance of earnings announcements. This piece of evidence lends additional support to our results.

[5] A systematic dataset containing these forecasts is the I/B/E/S database, available on WRDS.

[6] This result may appears to be related to those in Johnson and So (2018), who showed that cost of trading negative news on stocks increases before earnings announcements, and that this leads to increase in stock prices prior to announcements. This would lead to elevated call prices and decreased put prices prior to the announcements, because they embed long and short positions in stocks, respecively. However, because our variation paying portfolios roughly equally weight puts and calls, this effect should largely cancel with each others.

5 Conclusion

This paper develops a revealed preference theory for preference for the timing of resolution of uncertainty based on asset pricing data and present corresponding empirical evidence. Our main theorem provides an equivalent characterization of the representative agent's preference for early resolution of uncertainty in terms of the risk premium of assets realized during the period of resolution of informativeness of macroeconomic announcements. Empirically, we found support for preference for early resolution of uncertainty based on evidence on the dynamics of the implied volatility of S&P 500 index options around FOMC announcements.

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Table 1

Changes in VIX on FOMC announcement days

	(1)	(2)	(3)	(4)
	$\Delta \ln VIX$	$\Delta \ln VIX$	$\Delta \ln VIX$	$\Delta \ln VIX9$
I_1^{DOW}	1.94***		1.94***	5.99***
	[10.20]		[10.20]	[8.86]
I_2^{DOW}	-0.26		-0.13	0.32
	[-1.59]		[-0.77]	[0.64]
I_3^{DOW}	-0.48***		-0.33**	-1.06*
	[-3.17]		[-2.12]	[-1.86]
I_4^{DOW}	-0.04		-0.03	-0.56
	[-0.22]		[-0.17]	[-1.05]
I_5^{DOW}	-1.00***		-1.00***	-3.74***
	[-5.91]		[-5.90]	[-7.01]
I_{FOMC}		-2.20***	-1.89***	-2.43*
		[-5.02]	[-4.18]	[-1.71]
N	7,766	7,766	7,766	2,477
R-sq	0.022	0.003	0.024	0.063

This table reports results from running the following daily time series regression: $\Delta \ln IV_t = \sum_{d=1}^{5} \delta_d I_{d,t}^{DOW} + \xi I_t^{FOMC} + \epsilon_t$, where $\Delta \ln IV_t$ is the change in $\ln VIX$ on day t (in percentage unit), $I_{d,t}^{DOW}$ is the indicator of whether day t is the dth weekday (e.g. $I_{1,t}^{DOW}$ takes the value of 1 when day t is Monday, and 0 otherwise), and I_t^{FOMC} is the indicator of whether day t is a FOMC announcement day. Dependent variable in column (1) is based on the 30 day VIX, and that in column (2) is based on the 9 day VIX. Data are daily from 1990-2020 in column (1)-(3), and from 2011-2020 in column 4. T-statistics are computed with White standard errors and reported in square brackets.

Table 2

Predictability of implied volatility reduction on FOMC announcement days

	(1)	(2)	(3)	(4)	(5)	(6)
	$\Delta \ln VIX$	$\Delta \ln VIX$	$\Delta \ln VIX$	$\Delta \ln VIX$	$\Delta \ln VIX$	$\Delta \ln VIX9$
Inv_Slope_{t-1}	-6.57***		-5.37***	-15.84*	-6.13***	-14.47***
	[-4.23]		[-2.85]	[-1.87]	[-3.94]	[-6.65]
VIX_{t-1}		-0.11***	-0.04	-0.13		
		[-4.11]	[-1.24]	[-0.64]		
I_{FOMC}					10.87	16.57**
					[1.58]	[2.08]
$Inv\_Slope_{t-1} \cdot I_{FOMC}$					-13.42*	-19.90**
					[-1.73]	[-2.21]
DOW Indicators	Yes	Yes	Yes	No	Yes	Yes
Constant	No	No	No	Yes	No	No
N	2477	2477	2477	77	2477	2477
R-sq	0.035	0.029	0.036	0.139	0.038	0.101

The column (5) of this table reports results from running the following daily time-series regression: $\Delta \ln IV_t = \xi_0 + \xi_1 Inv\_Slope_{t-1} + \xi_2 I_t^{FOMC} + \xi_3 Inv\_Slope_{t-1} \cdot I_t^{FOMC} + \sum_{d=1}^{5} \delta_d I_{d,t}^{DOW} + \varepsilon_t$, where $\Delta \ln IV_t$ is change in log VIX on day t (in percentage unit), Inv_Slope_{t-1} is the inverse slope, or the 9-day VIX divided by the 30-day VIX, on day $t-1$, I_t^{FOMC} is the indicator of whether day t is a FOMC day, and $I_{d,t}^{DOW}$ are indicators of whether day t is the dth weekday (e.g. $I_{1,t}^{DOW}$ takes the value of 1 when day t is Monday, and 0 otherwise). Column (1) to (3) are the regression with subsets of the independent variables and possibly adding VIX_{t-1} which is the VIX level of day $t-1$. Column (4) is restricted to FOMC announcement days only. Column 6 has a different dependent variable which is change in 9-day VIX. Data are daily from 2011-2020. T-statistics are computed with White standard errors and reported in square brackets.

Table 3

Locating the period of resolution of informativeness

	(1)		(2)	
	$\Delta \ln VIX$		$\Delta \ln VIX9$	
	Coef	T-stat	Coef	T-stat
$\xi_{3,1}$	-28.42*	[-1.95]	-25.92	[-1.23]
$\xi_{3,2}$	-12.74	[-1.20]	-13.26	[-0.93]
$\xi_{3,3}$	-9.50	[-0.89]	-13.65	[-0.96]
$\xi_{3,4}$	15.40	[0.74]	22.50	[0.76]
$\xi_{3,5}$	-37.91**	[-1.99]	-50.25*	[-1.85]
$\xi_{3,6}$	-13.24	[-0.97]	-9.57	[-0.48]
$\xi_{3,7}$	-17.32*	[-1.87]	-19.51	[-1.55]
$\xi_{3,8}$	-7.10	[-0.54]	-12.54	[-0.66]
$\xi_{3,9}$	-8.38	[-0.61]	-17.96	[-0.90]
$\xi_{3,10}$	9.22	[0.78]	10.47	[0.62]
DOW Indicators	Yes		Yes	
FOMC Indicator	Yes		Yes	
Constant	No		No	
Obs	2,467		2,467	
R^2	0.036		0.093	

The table reports the results from the following daily time-series regression: $\Delta \ln IV_t = \xi_0 + \Sigma_{j=1}^{10}\xi_{1,j}\Delta Inv\_Slope_{t-j} + \xi_2 I_t^{FOMC} + \Sigma_{j=1}^{10}\xi_{3,j}\Delta Inv\_Slope_{t-j} \cdot I_t^{FOMC} + \sum_{d=1}^{5}\delta_d I_{d,t}^{DOW} + \varepsilon_t$, where $\ln IV_t$ is the change of log VIX on day t (in percentage unit), ΔInv_Slope_{t-j} is the change of the inverse slope on day $t-j$, I_t^{FOMC} is the indicator of whether day t is a FOMC announcement day, and $I_{d,t}^{DOW}$ are indicators of whether day t is the dth weekday (e.g. $I_{1,t}^{DOW}$ takes the value of 1 when day t is Monday, and 0 otherwise). Dependent variable is computed with the 30 day VIX for column (1), and the 9 day VIX for column (2). Data are daily from 2011-2020. T-stats are computed using White standard errors and reported in square brackets on the side of the coefficient values.

Table 4

Excess returns of options during the period of resolution of informativeness

	Second Moment Portfolios			Fourth Moment Portfolios		
	(1)	(2)	(3)	(4)	(5)	(6)
	4 weeks	8 weeks	12 weeks	4 weeks	8 weeks	12 weeks
β_0	-3.63**	-3.32***	-3.080***	-6.26**	-6.19***	-5.58***
	[-2.03]	[-2.63]	[-2.94]	[-2.27]	[-2.87]	[-2.93]
$\sum_{a=-1}^{-5} \beta_a$	8.19**	6.25**	5.18**	13.96**	11.54**	10.21**
p-value	0.039	0.034	0.044	0.044	0.029	0.028
N	20,284	34,064	43,532	20,284	34,064	43,532
r2	0.134	0.118	0.113	0.318	0.271	0.254

This table reports the results of the following panel regression $r_{\tau,t} = \sum_{a=-10}^{10} \beta_a I_{a,t}^{FOMC} \cdot I_t^{After}(\tau) + \sum_{w=1}^{9} \gamma_w I_{w,t}^{Maturity}(\tau) + \sum_{d=1}^{5} \delta_d I_{d,t}^{DOW} + \epsilon_{\tau,t}$, where $r_{\tau,t}$ is the log return of the option portfolio with expiration τ on day t (in percentage unit), $I_{a,t}^{FOMC}$ is an indicator of whether day t is a weekdays away from a FOMC announcement day, $I_t^{After}(\tau)$ is an indicator of whether τ is after the next FOMC announcement as of day t, $I_{w,t}^{Maturity}(\tau)$ is an indicator of whether t is within w weeks of τ, and $I_{d,t}^{DOW}$ is an indicator of whether day t is the dth weekday (e.g. $I_{1,t}^{DOW}$ takes the value of 1 when day t is Monday, and 0 otherwise). Regressions apply equal weight on each trading day (i.e. t). Results in column (1)/(4), (2)/(5), and (3)/(6) are on options with expiration within 4, 8, and 12 weeks. Column (1)-(3) are portfolios tracking the 2nd moment of the underlying returns, and (4)-(6) tracks the 4th moment. Data are daily from 1996-2019. T-stats are computed using clustered standard errors by trading day and reported in square brackets on the side of the coefficients.

Table 5

News intensity and change in inverse slope over the period of ROI

	$News\_Intensity$	$News\_Intensity^{Strong}$
ΔInv_Slope	1.07***	1.93***
	[4.05]	[3.77]
$const$	1.40***	1.40***
	[58.08]	[31.12]
N	385	385
R-sq	0.030	0.028

Column 1 of this table reports the results of the following time-series regression $News\_Intensity_t = \alpha + \beta \Delta Inv\_Slope + \epsilon_t$ conditioning on day t being in the period of ROI. Here $News\_Intensity_t$ is the number of Fed-related news items on day t divided by the average number of items in the past 30 days. Column 2 performs the same regression with the dependent variable computed only with strong news items, determined by the relevance (provide by RavenPack) greater or equal to 50. Data are daily from 2011-2020. T-stats are computed using clustered standard errors by trading day and reported in square brackets on the side of the coefficients.

Table 6

Excess returns of options prior to earnings announcements

	Second Moment Portfolios			Fourth Moment Portfolios		
	(1)	(2)	(3)	(4)	(5)	(6)
	4 weeks	8 weeks	12 weeks	4 weeks	8 weeks	12 weeks
β_0	-2.14***	-1.62***	-1.41***	-3.40***	-2.63***	-2.30***
	[-10.16]	[-9.30]	[-9.00]	[-12.18]	[-11.39]	[-10.95]
$\sum_{a=-1}^{-5} \beta_a$	4.08***	2.50***	2.05***	5.95***	3.71***	3.07***
p-value	0.000	0.000	0.000	0.000	0.000	0.000
N	2,682,224	5,621,516	6,848,784	2,682,156	5,621,492	6,848,809
r2	0.01	0.01	0.01	0.02	0.01	0.01

This table reports the results of the following panel regression $r_{\tau,i,t} = \sum_{a=-10}^{10} \beta_a I_{a,i,t}^{EA} \cdot I_{i,t}^{After}(\tau) + \sum_{w=1}^{9} \gamma_w I_{w,t}^{Maturity}(\tau) + \sum_{d=1}^{5} \delta_d I_{d,t}^{DOW} + \epsilon_{\tau,i,t}$, where $r_{\tau,i,t}$ is the log return of the option portfolio of stock i with expiration τ on day t (in percentage unit), $I_{a,i,t}^{EA}$ is an indicator of whether day t is a weekdays away from an earnings announcement day, $I_{i,t}^{After}(\tau)$ is an indicator of whether τ is after the next earnings announcement as of day t, $I_{w,t}^{Maturity}(\tau)$ is an indicator of whether t is within w weeks of τ, and $I_{d,t}^{DOW}$ is an indicator of whether day t is the dth weekday (e.g. $I_{1,t}^{DOW}$ takes the value of 1 when day t is Monday, and 0 otherwise). Regressions apply equal weight on each stock-trading day (i.e. i, t). Results in column (1)/(4), (2)/(5), and (3)/(6) are on options with expiration within 4, 8, and 12 weeks. Column (1)-(3) are portfolios tracking the 2nd moment of the underlying returns, and (4)-(6) tracks the 4th moment. Data are daily from 1996-2019. T-stats are computed using clustered standard errors by trading day and reported in square brackets on the side of the coefficients.

Table 7

Market loadings of options prior to earnings announcements

	Second Moment Portfolios			Fourth Moment Portfolios		
	(1)	(2)	(3)	(4)	(5)	(6)
	4 weeks	8 weeks	12 weeks	4 weeks	8 weeks	12 weeks
β^{mkt}	-7.04***	-7.57***	-7.24***	-14.71***	-15.41***	-14.59***
	[-19.80]	[-26.58]	[-27.28]	[-25.21]	[-32.87]	[-32.93]
$\sum_{a=-1}^{-5}\beta_a^{mkt}$	-2.62	-2.02	-0.48	-8.48	-6.55	-4.19
p-value	0.485	0.511	0.870	0.174	0.181	0.371
N	19,568	32,867	42,019	19,568	32,867	42,019
r2	0.279	0.362	0.377	0.425	0.485	0.489

This table reports the results of the following panel regression $r_{\tau,t} = \beta^{mkt} mkt_t + \sum_{a=-1}^{-5}\beta_a^{mkt} mkt_t \cdot I_{a,t}^{EA} + \sum_{a=-10}^{10}\beta_a I_{a,t}^{EA} \cdot I_t^{After}(\tau) + \sum_{w=1}^{9}\gamma_w I_{w,t}^{Maturity}(\tau) + \sum_{d=1}^{5}\delta_d I_{d,t}^{DOW} + \epsilon_{\tau,t}$, where $r_{\tau,t}$ is the log return of the option portfolio with expiration τ on day t (in percentage unit), mkt_t is the log market return on day t in excess of the risk free rate, $I_{a,t}^{EA}$ is an indicator of whether day t is a weekdays away from an earnings announcement day, $I_t^{After}(\tau)$ is an indicator of whether τ is after the next earnings announcement as of day t, $I_{w,t}^{Maturity}(\tau)$ is an indicator of whether t is within w weeks of τ, and $I_{d,t}^{DOW}$ is an indicator of whether day t is the dth weekday (e.g. $I_{1,t}^{DOW}$ takes the value of 1 when day t is Monday, and 0 otherwise). Regressions apply equal weight on each trading day. Results in column (1)/(4), (2)/(5), and (3)/(6) are on options with expiration within 4, 8, and 12 weeks. Column (1)-(3) are portfolios tracking the 2nd moment of the underlying returns, and (4)-(6) tracks the 4th moment. Data are daily from 1996-2019. T-stats are computed using clustered standard errors by trading day and reported in square brackets on the side of the coefficients.

6 Data Appendix

Our VIX data come from CBOE's website, and option data OptionMetrics. While the VIX data are straightforward to use, the handling of the option data is more involved. Below we describe our data construction process in detail.

Starting with a big panel of option prices, we first get the data to underlying-expiration-strike price-put/call-day level, i.e. for a put or call option on a certain underlying that has a certain expiration date and strike price we should have one price per day. There are some cases where there are two prices per day.[7] In those cases, we take the average of those two available prices.

Having a panel at the underlying-expiration-strike price-put/call-day level, we take the average of bid and ask to get the price of an option. This price can be missing, however, even for large underlying such as the S&P 500 index. This is because trades can be rare for deeply in-the-money or out-of-money options. In the event that a price becomes missing and reappear in a future date, we forward fill the price, assuming a return of zero. If the price becomes missing forever, we replace the first missing price with zero if the option is a call and the last available call price is less than the put price of the same strike and expiration, and with the last available price if it is a call and the last available call price is greater than or equal to the put price. Similarly, if the option is a put, we replace the missing price with 0 if its price is less than the call with the same strike and expiration, and with the last available price if it is the greater than the put price. This logic is the roughly handle is to roughly achieve the zero implied final return of 0 if the option is in the money, and a return of -100% if it is out of money.[8] While this operation is conceptually importantly, our results are robust to alternative imputation methods such as assuming all final returns are 0.

Having non-missing prices we can construct the synthetic variance swaps behind VIX using these S&P 500 options and compute their returns. We construct these variance swaps following the formulas in Bakshi et. al. (2003), with additional data cleaning procedures taken from the construction of the VIX index, which are documented on the VIX white paper, available on CBOE's website. We describe our methodology in detail below.

[7]Such cases are because there are two types of options, e.g. standard monthly options and weekly options, that happen share the same underlying, expiration, strike price, and put/call and are both outstanding on the same day.

[8]In the context of individual stock options, this logic is expensive due to the size of the data. We instead replace all final missing price with last day's price, and additionally verify that our results do not change appreciably if we replace all final missing prices with 0, of if we conditionally replace all missing prices with 0 or last day's price based on whether last day's price is greater than a dollar.

Overall, the portfolio on any given day consists of out-of-money options, which are call options with strike prices higher than the previous close price of the underlying, and put options with strike prices lower than that close price. Out-of-money options with zero bid prices are excluded from the portfolio. Also, those with two consecutive zero bids between them and the at the money strike prices are also excluded. For instance, suppose a call with strike 100 has a non-zero bid price, and on that day the at-the-money strike price is 30. Let's say the two strike prices immediately lower than 100 is 95 and 90, and calls with those two strikes prices both have zero bids. Then the call option with strike price of 100 will be excluded even though it is an out-of-money option with non-zero bids. These data exclusion logic is adopted from the CBOE's methodology in constructing the VIX index.

Having the sample we now discuss the weight of each option in the portfolio of variance swap. Say an option has a strike price of K, and the two nearby strike prices flanking K for that underlying-expiration-day are K^- and K^+. Let the underlying's close price on the previous trading day be S. For the second moment portfolio, the relative weight on the option with strike K is $\frac{(K^+-K^-)}{2}\frac{1-\log(K/S)}{K^2}$. If the strike price is the highest or the lowest for that underlying-expiration-day, the weight is then $\frac{(K-K^-)}{2}\frac{1-\log(K/S)}{K^2}$ or $\frac{(K^+-K)}{2}\frac{1-\log(K/S)}{K^2}$, respectively. For the fourth moment portfolio, the relative weights are $\frac{(K^+-K^-)}{2}\frac{12\log(K/S)^2-4\log(K/S)^3}{K^2}$, $\frac{(K-K^-)}{2}\frac{12\log(K/S)^2-4\log(K/S)^3}{K^2}$, and $\frac{(K^+-K)}{2}\frac{12\log(K/S)^2-4\log(K/S)^3}{K^2}$. We then rescale these relative weights so that they add up to 1 for each underlying-expiration-day. Weighted-returns on these portfolios are then computed. In the context of S&P 500 option portfolios, these returns are used as is because the data can be manually examined to make sure that they are free of influential data errors. For individual stock options such manual examination is not possible. We instead winsorize these returns at the 0.5 and 99.5 percentiles, and additionally verify that our results are robust to the chosen percentiles.