The heterogeneous response of financial uncertainty to monetary policy

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August 19, 2025

Abstract

Understanding monetary policy transmission to financial markets is crucial for policymakers and investors, but existing literature focuses on first-order effects and market-wide aggregated measures. To address this gap, the present paper investigates the responses of asset class-specific financial uncertainty to distinct dimensions of monetary policy shocks. We conduct our analysis with a Bayesian extended stochastic volatility model, allowing for the effect of monetary policy shocks on second-order moments used to compute our uncertainty measures. Then, we decompose monetary policy shocks into changes in the yield curve's level, slope, and curvature during a high-frequency time window around policy announcements, refining previous approaches relying on daily changes. Applying this approach to a wide array of 47 sovereign bonds, corporate bonds, stocks, and exchange rates in the euro area, we document heterogeneous and persistent effects of these shocks on asset-specific financial uncertainty.

Keywords: high-frequency identification, uncertainty, stochastic volatility

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1 Introduction

Over the past two decades, a substantial body of research has examined how financial markets respond to monetary policy (see Bhattarai and Neely, 2022 and Bernanke, 2020, for a review). Understanding how monetary policy influences asset prices and other major financial developments is essential for both macroeconomics and finance[1]. In macroeconomics, interest in this question has been particularly reinforced after the Great Financial Crisis (GFC) and the emergence of the zero lower bound (ZLB), a low-interest rate environment spurring central banks all over the world to rely more extensively on so-called unconventional monetary policies (UMPs) to stabilize disrupted financial markets. In addition, structural macroeconomic models (Bernanke et al., 1999; Adrian and Shin, 2014; Brunnermeier and Sannikov, 2014; Christiano et al., 2014; Adrian et al., 2019) attach increasing importance to financial conditions in explaining real business cycles, making the financial sector a particularly dominant element in the transmission of monetary policy (Gertler and Karadi, 2015; Bernanke, 2020; Swanson, 2021). The importance of such a question also applies to finance, where understanding the impact of monetary policy on the term structure of interest rates and risk premia is fundamental for asset pricing models (see, e.g., Campbell and Cochrane 1999; Bansal and Yaron 2004; Bekaert et al. 2009; He and Krishnamurthy 2013; Greenwood et al. 2018).

While the existing literature provides extensive theoretical and empirical insights into how monetary policy shapes the functioning of financial markets and the pricing of securities, a notable feature is that these studies typically focus on first-order (mean) effects. Surprisingly, much less is known about how and the extent to which monetary policy influences uncertainty (i.e., the second-order effects) surrounding asset prices, especially at the disaggregated level. This paper addresses this gap by analyzing how monetary policy affects daily asset-specific financial uncertainty, explicitly measured as future expected conditional stochastic volatility of asset returns. We do so for multiple asset classes in the euro area, thereby characterizing possible heterogeneity in uncertainty responses to monetary policy at the asset class level. In addition, this paper offers a new perspective by analyzing how these responses vary according to the dimension of the yield curve that is impacted by specific monetary policy actions, including traditional interest rate setting, forward guidance, large-scale asset purchases, or liquidity measures (Gürkaynak et al., 2005; Inoue and Rossi, 2021; Swanson, 2021; Bernanke,

[1] This fundamental research question has also been notably addressed by Eichenbaum and Evans (1995); Kuttner (2001); Cochrane and Piazzesi (2002); Rigobon and Sack (2004); Bernanke and Kuttner (2005); Gürkaynak et al. (2005); D'Amico and King (2013); Hanson and Stein (2015); Neely (2015); Swanson (2021), among others

2020). Indeed, since these various tools affect the yield curve in different ways, such as influencing future short-term rates expectations or altering term and risk premia between maturities, it results in variations in the level, slope, or curvature of the yield curve, reflecting different channels of transmission of monetary policy to the financial markets. Our analysis explicitly accounts for these various mechanisms, along the lines advocated by Inoue and Rossi (2021).

Evidence for the existence of an effect of monetary policy on financial uncertainty can be found in existing macro-financial theories. For example, by shaping the long-run and near-term expectations of future short-term rates, monetary policy directly affects the level and slope of the yield curve, altering discount rates applied to future cash flows over time (Gürkaynak et al., 2005; Bernanke and Kuttner, 2005). Simultaneously, adjustments in the slope and curvature can reveal changes in the expected economic outlook and revisions of future short rates (Christensen and Rudebusch, 2012; Bauer and Rudebusch, 2014) as well as more complex adjustments in term (or risk) premia (Rogers et al., 2014; Hanson and Stein, 2015; Rogers et al., 2018), driven notably by a modified supply-demand balance for duration risk (Vayanos and Vila, 2021; Greenwood and Vayanos, 2014). These various effects on the yield curve, in turn, map into broader monetary policy transmission channels. In particular, persistently low yields encourage risk-taking and portfolio rebalancing (Gagnon et al., 2011; Swanson, 2011; Borio and Zhu, 2012; Vissing-Jorgensen and Krishnamurthy, 2011; Greenwood and Vayanos, 2014; Bauer et al., 2023), prompting shifts into riskier assets, compressing risk premia, and amplifying price responses. The signaling component of forward guidance and asset purchases (Woodford et al., 2012; Bauer and Rudebusch, 2014) shapes medium- to long-term expectations, often triggering pronounced market reactions, particularly when guidance reveals new information about future policy paths and economic outlook (Campbell et al., 2012; Nakamura and Steinsson, 2018; Miranda-Agrippino and Ricco, 2021; Andrade and Ferroni, 2021). Finally, variations in yield curve components trigger exchange rate movements, notably through interest rate differentials and international risk premia, transmitting policy shocks in foreign markets through capital flows (Rey, 2015; Gabaix and Maggiori, 2015; Rogers et al., 2018). Therefore, all these forces, taken together, do not merely shift the average trajectory of asset prices but also influence the dispersion of responses that define how markets simultaneously incorporate new information about economic fundamentals and re-price future risks. Thus, it suggests a connection with second-order effects.

Empirically, however, evidence is scarcer. Using the VIX, Bekaert et al. (2013) uncovers significant interconnections between monetary policy, risk aversion, and uncertainty. More recently, Bauer et al. (2023) offers further insights into this, showing that high-frequency policy surprises[2] affect the aggregate risk appetite and the VIX itself, with expansionary shocks lowering implied equity volatility and contractionary shocks raising it. In addition, Kang and Park (2024) examines the effects of monetary policy shocks on macro and financial uncertainty indices in a structural VAR framework, using empirical uncertainty measures of Jurado et al. (2015). Note that, unlike Bekaert et al. (2013) and Bauer et al. (2023), uncertainty is found to decrease after a policy tightening. Closer to our modelling approach, Carriero et al. (2021) uses a structural VAR with stochastic volatility to capture uncertainty endogenously from the data, but they do not study its response to monetary policy. Contrary to the present paper, these studies investigate financial (or macro) uncertainty dynamics either at the aggregate level of the economy or assuming a single dimension of monetary policy.[3] This approach neglects the fact that assets differ in their sensitivities to various policy-driven shifts in interest rates, liquidity conditions, and credit spreads, implying that the aforementioned effects may not be uniform across asset classes. Hence, the same yield curve surprises can lower uncertainty in low-risk government bonds while heightening it in riskier corporate debt or equity markets. Accordingly, to provide a deeper and finer understanding of the macro-financial implications of monetary policy-making over the financial system, we conduct our analysis at the asset class level, examining how uncertainty around asset class-specific prices evolves across different dimensions of changes in the yield curve.

The perspective taken in this paper, to consider three novel dimensions of analysis (second-order effects, disaggregation at the asset-class level, and decomposition in level-, slope- and curvature-related monetary policy events), is essential, not only for understanding monetary policy transmission towards financial markets (Krishnamurthy et al., 2018; Bauer et al., 2023; Kashyap and Stein, 2023), but also for macroprudential considerations. In particular, the proposed mapping may help identify emerging financial imbalances and guard against the buildup of systemic risks or vulnerabilities (Adrian and Shin, 2014; Adrian et al., 2019). Moreover, this paper also echoes significant strand of the macro literature which recognizes

[2]Note that Bauer et al. (2023) relies on Bauer and Swanson (2023b) for the identification of policy shocks, and summarizes the four different types of monetary-policy news (based on four principal components of Eurodollar rates) in a single number. Consequently, the authors do not explicitly dissociate the respective effect of each of these components (contrary to the present paper) in their empirical analysis of the risk-taking channel.

[3]To a lesser extent, Lewis (2025) also documents effects of policy surprises on uncertainty and proposes a decomposition of policy announcement surprises into multiple dimensions. However, his approach, based on exploiting the heteroskedasticity of intraday data, differs from what is proposed in our paper.

uncertainty as a central driver of business cycle fluctuations (Bloom, 2009, 2014; Gilchrist et al., 2014; Jurado et al., 2015; Baker et al., 2016; Ludvigson et al., 2021), and emphasizes the importance of distinguishing between macroeconomic and financial uncertainty, given their distinct origins, transmission channels, and endogenous responses to monetary policy (Jurado et al., 2015; Ludvigson et al., 2021; Carriero et al., 2018, 2021; Castelnuovo, 2023).

From a methodological standpoint, assessing the multidimensional effects of monetary policy on financial uncertainty calls for two essential elements: an explicit statistical model for modeling uncertainty from the data, as well as a rigorous identification of exogenous policy changes. To do so, we employ a Bayesian stochastic volatility framework augmented with exogenous covariates (denoted SV-X), which allows us to quantify the effects of distinct dimensions of monetary policy shocks in asset price dispersion dynamics. In our framework, changes in financial uncertainty associated with monetary policy are defined as changes in expected stochastic asset-price dispersion (stochastic volatility) due to monetary policy shocks. To identify monetary policy shocks and decompose their effects along various dimensions, we rely on the bulk of the literature making use of high-frequency surprises.[4]

In particular, our methodology for recovering monetary policy shocks follows Inoue and Rossi (2021). Indeed, we exploit information on changes in factors of the term structure, respectively, level, slope, and curvature, around monetary policy announcements. The major advantage of using this approach lies in the fact that we can capture multiple dimensions of monetary policy, as monetary policy shocks are defined as shifts in factors (level, slope, and curvature) defining the yield curve. However, while Inoue and Rossi (2021) records those changes on the day of the monetary policy announcement dates, we adapt their methodology and record variations of the term structure at a higher frequency (i.e., a couple of hours) by exploiting the database of Altavilla et al. (2019). As such, our approach strengthens the economic identifications of the functional shocks proposed in Inoue and Rossi (2021).

Covering the period 1999–2020, we conduct our empirical analysis using 47 daily series of financial returns, encompassing a wide spectrum of financial instruments across European markets, following the call of Altavilla et al. (2024) to improve our understanding of policy transmission heterogeneity in the euro area. Our dataset comprises sovereign and corporate bond indices, equity indices disaggregated by country, sector, and market capitalisation, as

[4]A non-exhaustive list of this strand of literature encompasses Kuttner 2001; Bernanke and Kuttner 2005; Gürkaynak et al. 2005; Faust et al. 2007; Gertler and Karadi 2015; Nakamura and Steinsson 2018; Cieslak and Schrimpf 2019; Jarociński and Karadi 2020; Miranda-Agrippino and Ricco 2021; Swanson 2021; Bauer and Swanson 2023a. See also Bauer and Swanson (2023b) for a thorough discussion on this.

well as major exchange rates relative to the Euro. Our objective is not limited to measuring the immediate effects of these shocks, but to extend our understanding of how they shape the dynamics of uncertainty. We follow a stepwise approach to progressively uncover how the different dimensions of monetary policy shape financial uncertainty at a granular, asset-level: We first estimate the response of asset-specific uncertainty to monetary policy–induced shifts in the entire yield curve. These responses are then decomposed into the contributions of the level, slope, and curvature dimensions, with the respective impact of each evaluated separately for conventional (pre-ZLB) and ZLB regimes. In the latest part, we employ impulse response functions (à la Koop et al., 1996), historical variance decompositions, and counterfactual exercises to quantify the dynamics, historical importance, and episodic relevance of each component.

Our empirical findings reveal significant effect and heterogeneity across asset classes and yield curve dimensions (level, slope, curvature), offering some insights into the broad existing channels, such as discount rate revisions and risk-premium adjustments, through which monetary policy shapes financial uncertainty differently across assets. Furthermore, we also observe that the structural dynamics associated with monetary policy regimes, both before and during ZLB, affect the relationship under study. Finally, in historical decomposition exercises, we document a major influence of monetary policy on uncertainty fluctuations beyond standard time series dynamics, especially when its affects the curvature of the yield curve. Notably, in a counterfactual analysis, we estimate that the 2015 expanded Asset Purchase Program led to a reduction of financial uncertainty for country-specific stock indices up to -7.7 percentage points compared to a no-intervention scenario.

Notice that, although our framework will treat variations in the level, slope, and curvature factors of the yield curve as economically meaningful dimensions of policy surprises, we do not aim to uncover the structural determinants of these movements or disentangle the specific channels through which these latter connect with asset prices and uncertainty[5]. Instead, as explained in Section 2.2, we will interpret variations in these factors as empirically tractable measures of different components of monetary shocks and analyze their implications in reduced-form terms.

The paper is organized as follows: Section 2 describes both the features of the stochastic volatility model and our approach to recovering monetary policy shocks. Section 3 details

[5]See Hanson and Stein (2015), Rogers et al. (2014), and Rogers et al. (2018) for examples of studies that explicitly decompose the effects of monetary policy into changes in expected short rates (the expectations hypothesis component) and adjustments in term premia. Bauer and Rudebusch (2014) similarly disentangles these components and contrasts the signaling and portfolio rebalancing channels.

the data used for the empirical part of the paper. Section 4 reports and discusses the results. Section 5 concludes.

2 Methodology

In this section, we outline the methodology used to estimate the dynamic effects of monetary policy on financial uncertainty. We first specify our general modeling approach in Subsection 2.1 before detailing our identification strategy for the monetary policy shocks in Subsection 2.2.

2.1 Modeling strategy

Our approach is based on an extended stochastic volatility (SV) framework for daily data, which allows us to capture the time-varying nature of uncertainty in financial asset returns, while explicitly incorporating the role of monetary policy shocks. We specify a daily stochastic volatility for financial asset returns as:

$$r_t = \exp\{h_t/2\}\xi_t, \tag{1}$$

where ξ_t follows a standard normal distribution with mean zero and variance one, i.e. $\xi_t \sim \mathcal{N}(0, 1)$. The logarithm of the conditional variance, denoted as h_t, follows a stochastic process given by:

$$h_t = \mu_h + \phi(h_{t-1} - \mu_h) + \mathbf{x}_t^* \boldsymbol{\theta} + \nu_t, \tag{2}$$

where ν_t is an independent and identically distributed innovation, normally distributed with zero mean and variance ω^2, i.e. $\nu_t \sim \mathcal{N}(0, \omega^2)$. The term μ_h captures the long-run mean of log variance (h_t), while ϕ accounts for the persistence of volatility over time, ensuring that the process is stationary when $|\phi| < 1$. The vector $\mathbf{x}_t^*$ encompasses the different components of monetary policy shocks, which are, similar to Inoue and Rossi (2021), defined as the changes in factors of the yield curve around monetary policy announcements. These shocks are included in the transition equation with coefficients $\boldsymbol{\theta}$, allowing us to measure how monetary policy affects financial uncertainty. The motivation for using a stochastic volatility model stems from the theoretical conceptualization of uncertainty as proposed by Jurado et al. (2015). According to their definition, financial uncertainty at a given horizon h should be understood as the conditional standard deviation of the unforecastable component of a given economic or financial variable for the same horizon. Formally, for a return series r_t, h-period ahead uncertainty measure (ending in $t+h$) is given by:

$$\mathcal{U}_t^r(h) = \sqrt{\mathbb{E}\left[(r_{t+h} - \mathbb{E}[r_{t+h}|\mathcal{I}_t])^2 \mid \mathcal{I}_t\right]}. \tag{3}$$

This definition highlights that financial uncertainty represents the degree of unpredictability of future realizations of r_t, given past information. As advocated in Jurado et al. (2015), the use of stochastic volatility in calculating (3) explicitly accounts for the time variation and the stochastic nature of the conditional variance of r_t, aligned with their definition. It also permits the construction of a shock to the second moment that is independent of innovations to r_t itself, an important feature in the theoretical literature on uncertainty (Bloom, 2009; Christiano et al., 2014; Gilchrist et al., 2014; Basu and Bundick, 2017) which presumes the existence of such an independent uncertainty shock. GARCH-type models (for example) do not share this feature.

An important feature of Jurado et al. (2015) approach is that $\mathbb{E}[r_{t+h}|\mathcal{I}_t]$ needs to be a forecast of the h-step-ahead conditional expectation of r_t. Indeed, Jurado et al. (2015) are interested in monthly data, for which a certain consensus exists regarding the predictability of the conditional mean (see, e.g. Rapach et al., 2009). At the daily level, however, the consensus goes in the direction of an absence of mean dynamics (Herwartz, 2017), in line with the efficient market hypothesis (Fama, 1970) at short-horizon. Thus, in our setting, since $\mathbb{E}[r_{t+h}|\mathcal{I}_t]$ can be validly set to 0, uncertainty at horizon $h = 0, 1, 2, \cdots$ reduces to:

$$\mathcal{U}_t^r(h) = \sqrt{\mathbb{E}[r_{t+h}^2|\mathcal{I}_t]}. \tag{4}$$

By substituting the return equation (1), we have

$$\mathbb{E}[r_{t+h}^2|\mathcal{I}_t] = \mathbb{E}[(\exp\{h_{t+h}/2\}\xi_{t+h})^2|\mathcal{I}_t], \tag{5}$$

which reduces to:

$$\mathbb{E}[\exp(h_{t+h})\xi_{t+h}^2|\mathcal{I}_t]. \tag{6}$$

Since $\xi_t \sim \mathcal{N}(0,1)$, it follows that $\mathbb{E}[\xi_{t+h}^2|\mathcal{I}_t] = 1$, so that:

$$\mathcal{U}_t^r(h) = \sqrt{\mathbb{E}[\exp(h_{t+h})|\mathcal{I}_t]}. \tag{7}$$

Consequently, our stochastic volatility model enables us to directly estimate uncertainty as the expected conditional variance of returns, aligning with the definition given by Jurado et al. (2015). Moreover, the stochastic nature of h_t ensures that uncertainty evolves dynamically over time, and can be decomposed between a component depending on past levels of volatility and the influence of monetary policy shocks, and a pure random component (ν_t). For $h = 0$, contemporaneous uncertainty corresponds to observed stochastic volatility. For $h \geq 1$, Eq. (7) can be obtained from the generalized impulse function of the model, which we discuss below.

As advocated by Jurado et al. (2015), removing the predictable part $\mathbb{E}[r_{t+h}|\mathcal{I}_t]$ from the return series is essential before estimating the stochastic volatility of the remaining series. This step is simplified by assuming it is equal to zero. Although this assumption seems to contradict Jurado et al. (2015) insights, notice again that here we consider financial returns at a *daily* frequency (contrary to a monthly frequency in the aforementioned article), since we wish to capture the instantaneous effect of monetary policy announcements. In the literature, daily expected returns are usually assumed to be time-invariant (contrary to volatility, sign, or density) and not forecastable, or if forecastable, only over very brief periods (see Farmer et al., 2023 for a recent discussion). Thus, to avoid generating additional detrimental noise in a preliminary mean-forecast estimation step, we set $\mathbb{E}[r_{t+h}|\mathcal{I}_t]$ equal to zero.

The formulation of our SV model is similar to formulations encountered in the financial literature on stochastic volatility (Kim et al., 1998; Omori et al., 2007), except for the inclusion of shock components in the transition equation (2). The inclusion of observable variables or shock components in stochastic volatility modeling has been proposed notably by Hol and Koopman (2000); Koopman et al. (2005); Ulm and Hambuckers (2022); Fu and Mendieta-Munoz (2025) and Fu et al. (2025). We estimate the model using Bayesian methods[6] via Markov Chain Monte Carlo (MCMC). Specifically, we rely on the No-U-Turn Sampler (NUTS) developed by Hoffman et al. (2014), a variant of Hamiltonian Monte Carlo that adapts the path length automatically and improves convergence in high-dimensional or correlated parameter spaces. This approach is well-suited to the nonlinear and latent-state structure of stochastic volatility models with exogenous shocks and allows for efficient exploration of the posterior distribution of the model parameters.

For our analysis, this framework is particularly well-suited, as it enables us to estimate the dynamic response of financial uncertainty to monetary policy shocks $x^*_{i,t}$. Specifically, we define $\mathbf{\Psi}_i^h$, the h-ahead generalized impulse response function (GIRF, following Koop et al.

[6]See section B of the supplementary material for the calibration of priors model's parameters and additional details regarding the estimation.

1996) of the log-variance process h_t to a one-unit change in the i-th monetary policy shock component as:

$$\Psi_i^h = \mathbb{E}[h_{t+h} \mid x_{i,t}^* = 1, \mathcal{I}_t] - \mathbb{E}[h_{t+h} \mid \mathcal{I}_t], \quad h = 0, 1, \ldots, H. \tag{8}$$

This formulation captures the marginal contributions of respective shock components (level, slope and curvature) to the conditional path of financial uncertainty.[7]

Given our model and the linear structure of (2), this impulse response has the following intuitive and analytically convenient closed-form solution:

$$\Psi_i^h = \theta_i \phi^h, \tag{9}$$

where θ_i explicitly captures the initial impact of the shock component $x_{i,t}^*$, and ϕ dictates the persistence of responses. The estimation and interpretation of these quantities form the core of our empirical analysis.

In the next Subsection, we explain how we extract monetary policy shocks from high-frequency yield curve movements, as they form the basis of our econometric analysis.

2.2 Capturing multiple dimensions of monetary policy

In the following, we describe how we identify and construct the vector $\mathbf{x}_t^*$, the exogenous changes in factors implied by pure monetary policy shocks, denoted ε_t^*. We follow Inoue and Rossi (2021) in the way to conceive such shocks. More specifically, we define a pure monetary policy shock as the functional change in the yield curve due to monetary policy announcements d_t. As a monetary policy shock is defined by a change in a function, it influences not only, e.g., the short-term rate, but also the rates at other maturities (denoted by τ), depending on its nature. However, using directly the functional representation ε_t^* in (2) would be impractical from an econometric standpoint due to its high dimensionality. Therefore, following Inoue and Rossi (2021), we reduce the dimension of the problem by using the approach of Nelson and Siegel (1987) and Diebold and Li (2006): the variations captured by ε_t^* can be summarized by the variations in three distinct and economically interpretable factors $\boldsymbol{\beta}_t = (\beta_{1,t}, \beta_{2,t}, \beta_{3,t})$. To extract those factors, Inoue and Rossi (2021) model explicitly the dynamics of the yield

[7] Although the impulse responses are formulated directly in terms of logarithmic counterparts (h_t), they can easily be translated into economically meaningful uncertainty measures defined earlier in (3) and (7).

curve $y_t(\tau)$ according to:

$$y_t(\tau) = \beta_{1,t} + \beta_{2,t}\left(\frac{1-e^{-\lambda\tau}}{\lambda\tau}\right) + \beta_{3,t}\left(\frac{1-e^{-\lambda\tau}}{\lambda\tau} - e^{-\lambda\tau}\right), \tag{10}$$

where the three-dimensional and time-varying parameter vector $\beta_t = (\beta_{1,t}, \beta_{2,t}, \beta_{3,t})$ denotes respectively level, slope and curvature factors. The parameter τ is the maturity associated with each yield to maturity $y_t(\tau)$. Expressing $y_t(\tau)$ as a function, monetary policy shocks for a specific maturity are defined as the shifts in the yield curve $(\Delta y_t(\tau))$ observed on monetary policy announcement dates d_t:

$$\varepsilon_t^*(\tau) = \Delta y_t(\tau)\, d_t, \tag{11}$$

$$= \Delta\beta_{1,t}^d + \Delta\beta_{2,t}^d\left(\frac{1-e^{-\lambda\tau}}{\lambda\tau}\right) + \Delta\beta_{3,t}^d\left(\frac{1-e^{-\lambda\tau}}{\lambda\tau} - e^{-\lambda\tau}\right), \tag{12}$$

where d_t is a dummy variable equal to one if there is a monetary policy announcement at time t and $\Delta\beta_{j,t}^d = \Delta\beta_{j,t}\, d_t$ denotes daily changes in factors composing the "functional" monetary policy shock. Using this approach, one can construct the vector x_t^* by taking directly the variations of level, slope, and curvature induced by the monetary policy shock, i.e. $x_t^* = \Delta\beta_t^d = (\Delta\beta_{1,t}^d, \Delta\beta_{2,t}^d, \Delta\beta_{3,t}^d)$, or by taking a linear combination[8] $x_t^* = f(\Delta\beta_t^d)$ of these variations (e.g., the sum or difference) which encompass the different dimensions of the monetary policy shock and do not need to be indexed by the maturity.

Suppose now that, instead of observing $y_t(\tau)$ and extracting $\mathbf{x}_t^*$ on a daily window, we observe directly high-frequency (HF) reactions of yields $\Delta y_t^{hf}(\tau)$ captured around monetary policy announcements for different maturities, i.e. for a short period of intra-day time (e.g. a couple of hours) around the announcement. For example, such surprises $\Delta y_t^{hf}(\tau)$ are provided by Altavilla et al. (2019). Since those variations are captured within monetary policy announcement episodes, we may assume that they constitute solely the response of yields to monetary policy shocks. Consequently, considering that $\Delta y_t^{hf}(\tau) = \frac{\partial y_t(\tau)}{\partial \varepsilon_t^*}$ and following (10),

[8] In particular, $\Delta(\beta_{1,t}+\beta_{2,t})$ corresponds to the change in the instantaneous yield (instrument/short-end dimension), while $\Delta(\beta_{3,t} - \beta_{1,t})$ captures non-parallel shape movements (curvature net of level) that, in an affine-term-structure perspective, load on the expected future path of short rates and/or term premia. We report these for completeness but do not analyze them further.

we can write explicitly:

$$\Delta y_t^{hf}(\tau) = \frac{\partial y_t(\tau)}{\partial \varepsilon_t^*}, \tag{13}$$

$$= \frac{\partial y_t(\tau)}{\partial \beta_t} \frac{\partial \beta_t}{\partial \varepsilon_t^*}, \tag{14}$$

$$= \Delta\beta_{1,t}^{hf} + \Delta\beta_{2,t}^{hf} \left(\frac{1 - e^{-\lambda\tau}}{\lambda\tau} \right) + \Delta\beta_{3,t}^{hf} \left(\frac{1 - e^{-\lambda\tau}}{\lambda\tau} - e^{-\lambda\tau} \right). \tag{15}$$

The representation of the model (15) is analogous to (12) as it enables, similarly to Inoue and Rossi (2021) to capture variations in level, slope, and curvature associated with ε_t^*. Alternatively to the classical approach of Nelson and Siegel (1987) and Diebold and Li (2006), this representation makes use of variations of the term structure $\Delta y_t^{hf}(\tau)$ for which regression coefficients $\Delta\beta_{1:3,t}^{hf}$ are directly interpreted as variations in level, slope, and curvature to monetary policy shocks. However, a substantial difference is that those factors are identified in a much narrower window.[9] This approach allows for better control over the endogenous responses of the yield curve to other economic or financial developments that may occur simultaneously with monetary policy announcements but are unrelated to the policy itself. In the spirit of Inoue and Rossi (2021), this approach provides a more comprehensive measure of the effects of monetary policy shocks, as it captures multiple structural dimensions of their impacts on the yield curve. These dimensions are summarized by the vector of changes in factors, $\mathbf{x}_t^* = \Delta\boldsymbol{\beta}_t^{hf} = (\Delta\beta_{1,t}^{hf}, \Delta\beta_{2,t}^{hf}, \Delta\beta_{3,t}^{hf})$ which underlie the model shown in (15).

Figure 1 shows the evolution of our estimated $\Delta\boldsymbol{\beta}_t^{hf}$ over time, describing how monetary policy shocks propagate through the yield curve. Following (15), these quantities have been obtained by regressing, for each day of a monetary policy announcement, the intra-day German government bond yield suprises of Altavilla et al. (2019) for 11 maturities (ranging between 2 and 30 years) on the Nelson and Siegel (1987) loadings, in the spirit of Diebold and Li (2006). In Table 1, we report associated summary statistics across different policy regimes.[10] The financial implications of the factor variations can be retrieved from (10): with λ set at the usual value of 0.609, a one-unit level shock shifts all maturities by 100 basis points (so 0.1, as observed in 2016, corresponds to a 10 bps parallel move); a one-unit slope

[9] In the online appendix, we provide further documentation on the differences and similarities of these shock components with those identified by Altavilla et al. (2019) and Inoue and Rossi (2021).

[10] We also report two standard linear combinations used to give a structural reading of curve movements: $\Delta(\beta_{1,t} + \beta_{2,t})$, which equals the change in the instantaneous yield as $\tau \to 0$ and thus approximates an instrument (short-end) shock; and $\Delta(\beta_{3,t} - \beta_{1,t})$, which holds the level fixed and isolates non-parallel (curvature-net-of-level) movements associated with revisions to the expected policy path and/or term premia. These combinations aid interpretation only and are not used in our empirical analysis. See Inoue and Rossi (2021) for more details.

shock raises yields by about 75 bps at 1-year, 31 bps at 5-year, and 16 bps at 10-year (so 0.1 implies roughly +7.5, +3.1, and +1.6 bps at those maturities); and a one-unit curvature shock produces a hump centered at 2–3 years, lifting those maturities by about 28–30bps (about 27 bps at 5-year and 16 bps at 10-year; hence 0.1 maps to ≈ 3 bps near the hump). Moreover, this visualization allows us to give an economic interpretation to each shock component, depending on its relationship with the factors, as well as monetary policy influence on the yield curve. For example, the level component ($\Delta\beta_{1,t}^{hf}$) captures parallel shifts across all maturities, generally shows smoother changes, and reflects broad-based monetary policy adjustments associated with expectations regarding the long-term stance of monetary policy. In contrast, the slope component ($\Delta\beta_{2,t}^{hf}$) accounts for changes in the steepness of the yield curve, driven by differences between short- and long-term rates. This factor relates notably to expectations about the future path of policy rates and growth prospects. Positive changes in the slope indicate a steepening of the yield curve, which is often interpreted as an indicator of anticipated economic expansion. Conversely, negative changes indicate flattening, typically associated with policy tightening and concerns about economic downturns. Finally, the curvature component, displaying higher volatility in the figure, reflects effects on medium-term yields, often associated with risk premia.

Beyond factor dynamics, the plot also reveals notable differences across monetary policy regimes. Pre-ZLB, monetary policy shocks predominantly influenced the level and slope factors, consistent with the reliance on conventional policy tools targeting short-term interest rates. In the post-ZLB period, the prominence of the slope and curvature factors underscores the increased use of unconventional tools, such as forward guidance and quantitative easing, which primarily impacted medium- and long-term yields. These results highlight the unique and evolving nature of monetary policy transmission across the yield curve, emphasizing how different policy tools affect the yield curve via multiple dimensions.

Nevertheless, unlike Hanson and Stein (2015) or Rogers et al. (2018), our approach provides a characterization of monetary policy shocks through changes in the level, slope, and curvature of the yield curve, but does not rely on structural decompositions that explicitly disentangle movements in expectations of future short-term rates from changes in term (risk) premia. Such decompositions typically require a no-arbitrage affine term-structure framework combined with a macroeconomic structure and identifying assumptions, as developed among others by Duffie and Kan (1996); Dai and Singleton (2000, 2002); Rudebusch and Wu (2008); Adrian et al. (2013) and Joslin et al. (2014). High-frequency surprises may also embed central bank information effects (Nakamura and Steinsson, 2018; Cieslak and Schrimpf, 2019; Jarociński and Karadi, 2020; Miranda-Agrippino and Ricco, 2021; Bauer and Swanson, 2023a)[11], such that non-parallel movements can arise even without a pure instrument change or forward guidance about the future policy path. While these considerations would further investigations beyond the scope of this paper, our stance is to focus on a reduced-form identification strategy: we use high-frequency yield curve responses to monetary announcements as exogenous policy-induced shocks, summarizing their multidimensional effects on the term structure. Similar to Inoue and Rossi (2021), it summarizes the responses to monetary policy in an economically meaningful way, allowing us to assess their impact on the uncertainty (stochastic volatility) surrounding asset prices, although this approach does not isolate structural components behind yield curve movements.

Table 1: Summary statistics of shocks by period.

Period	Statistic	$\Delta\beta_{1,t}$	$\Delta\beta_{2,t}$	$\Delta\beta_{3,t}$	$\Delta(\beta_{1,t}+\beta_{2,t})$	$\Delta(\beta_{3,t}-\beta_{1,t})$
Panel A. Full Sample						
1999-01-05 to 2020-01-31	Mean	-0.0001	0.0023	-0.0018	-0.0017	0.0022
	SD	0.0297	0.0827	0.1847	0.1938	0.0794
Panel B. Pre-ZLB Period						
1999-01-05 to 2011-12-31	Mean	-0.0006	-0.0012	0.0045	0.0051	-0.0017
	SD	0.0249	0.0771	0.1611	0.1682	0.0742
Panel C. Post-ZLB Period						
2012-01-01 to 2020-01-31	Mean	0.0013	0.0108	-0.0173	-0.0186	0.0121
	SD	0.0394	0.0953	0.2341	0.2467	0.0909
Panel D. Conventional Period						
1999-01-05 to 2008-10-31	Mean	-0.0019	-0.0003	0.0083	0.0102	-0.0022
	SD	0.0240	0.0714	0.1501	0.1583	0.0681
Panel E. Unconventional Period						
2008-11-01 to 2020-01-31	Mean	0.0024	0.0057	-0.0152	-0.0176	0.0082
	SD	0.0359	0.0959	0.2229	0.2329	0.0923

Notes: $\Delta\beta_{1,t}, \Delta\beta_{2,t}, \Delta\beta_{3,t}$ are (high-frequency) changes in level, slope, and curvature. $\Delta(\beta_{1,t}+\beta_{2,t})$ approximates the instrument (short-end) dimension; $\Delta(\beta_{3,t}-\beta_{1,t})$ captures non-parallel shape movements associated with expected-path and/or term-premium components.

[11] The literature on "information effects" in high-frequency surprises has offered many competing views: (i) a *private-information* view in which central bank announcements reveal new private information on economic outlook, so markets adjust simultaneously and stocks and yields move together (e.g., Nakamura and Steinsson, 2018; Cieslak and Schrimpf, 2019; Jarociński and Karadi, 2020); (ii) a *public-news* view where co-movements mainly reflect data known before the meeting, so empirical analyses should control for pre-announcement news (Miranda-Agrippino and Ricco, 2021); and (iii) a *Fed-response-to-news* channel for which surprises mostly reflect how the Fed systematically reacts to public data that markets under-anticipate (Bauer and Swanson, 2023a,b). For a clear overview, see Bauer and Swanson, 2023a,b.

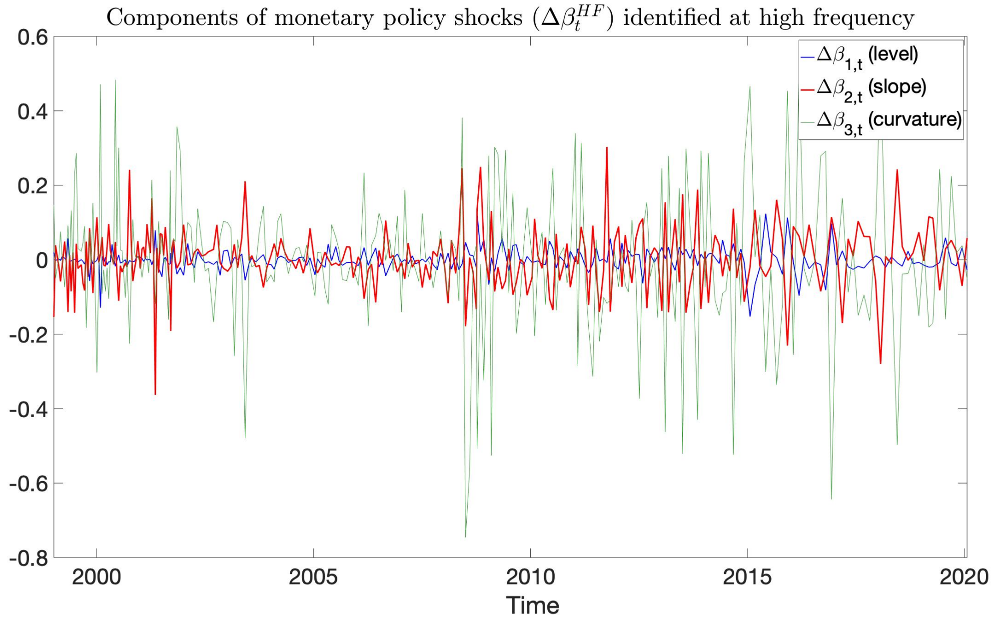

Figure 1: Components of monetary policy shocks ($\Delta\beta^{hf}_{1:3,t}$) captured at high-frequency.

Notes: The figure plots changes in the Nelson and Siegel (1987) factors ($\Delta\beta_{1,t}$: level, $\Delta\beta_{2,t}$: slope, $\Delta\beta_{3,t}$: curvature) extracted from yield curve surprises within a narrow window around monetary policy announcements. The vertical scale can be read in terms of yield changes: with $\lambda = 0.609$, a one-unit variation in the level, slope, or curvature factor maps into shifts of approximately 100 bps in parallel, 72 bps at the short end (1-year), and 52 bps at the medium hump (2–3 years), respectively. Typical observed shocks of 0.1 therefore correspond to yield changes of about 5–10 basis points depending on the factor.

3 Data

Table 2 describes the time series[12] considered in our analysis. Our dataset comprises daily log returns for a wide cross-section of 47 financial indices spanning five distinct market segments for the euro area. The sovereign bond group **(Government bonds)** includes benchmark government securities from both core and peripheral euro-area countries, offering variation in credit risk, liquidity conditions, and exposure to interest rate movements. The corporate bond group **(Corporate bonds)** contains investment-grade indices across different maturities, capturing sensitivity to both credit spreads and interest rates. Concerning stocks, the group "**Stocks (countries)**" consists of broad national equity indices for major euro-area economies, reflecting market-wide responses within each country. The other equity group, **"Stocks (sectors)"**, disaggregates equity markets by industry sector (e.g., financials, industrials, consumer goods,etc.) and by size segments (large-cap versus mid/small-cap), enabling us to identify differences related to industry structure and firm size. Finally, the foreign exchange group **(Exchange rates)** contains the euro's bilateral exchange rates against a few

[12]The data are taken from Reifinitiv. Table A3 in Appendix provides summary statistics.

Table 2: Time series description

Name	Group	Region	Observations	Start date	End date
1. BD BENCHMARK 10 YEAR DS GOVT. INDEX - CLEAN PRICE INDEX	Government bonds	Germany	5499	1999-01-05	2020-01-31
2. BG BENCHMARK 10 YEAR DS GOVT. INDEX - CLEAN PRICE INDEX	Government bonds	Belgium	5499	1999-01-05	2020-01-31
3. ES BENCHMARK 10 YEAR DS GOVT. INDEX - CLEAN PRICE INDEX	Government bonds	Spain	5499	1999-01-05	2020-01-31
4. FR BENCHMARK 10 YEAR DS GOVT. INDEX - CLEAN PRICE INDEX	Government bonds	France	5499	1999-01-05	2020-01-31
5. GR BENCHMARK 10 YEAR DS GOVT. INDEX - CLEAN PRICE INDEX	Government bonds	Greece	5437	1999-04-01	2020-01-31
6. IR BENCHMARK 10 YEAR DS GOVT. INDEX - CLEAN PRICE INDEX	Government bonds	Ireland	5499	1999-01-05	2020-01-31
7. IT BENCHMARK 10 YEAR DS GOVT. INDEX - CLEAN PRICE INDEX	Government bonds	Italy	5499	1999-01-05	2020-01-31
8. UK BENCHMARK 10 YEAR DS GOVT. INDEX - CLEAN PRICE INDEX	Government bonds	UK	5499	1999-01-05	2020-01-31
9. EMU BENCHMARK 10 YR. DS GOVT. INDEX - CLEAN PRICE INDEX	Government bonds	EMU	5499	1999-01-05	2020-01-31
10. IBOXX EURO CORPORATES - Cln Prc Indx Today	Corporate bonds	Europe	5499	1999-01-05	2020-01-31
11. IBOXX EURO OVERALL - Cln Prc Indx Today	Corporate bonds	Europe	5499	1999-01-05	2020-01-31
12. IBOXX EURO EUROZONE - Cln Prc Indx Today	Corporate bonds	Europe	5499	1999-01-05	2020-01-31
13. ICE BofA AAA Euro Corporate Index - Clean price	Corporate bonds	Europe	5499	1999-01-05	2020-01-31
14. ICE BofA BBB Euro Corporate Index - Clean price	Corporate bonds	Europe	5239	2000-01-04	2020-01-31
15. ICE BofA 1-3 Year BBB Euro Corporate Index - Clean price	Corporate bonds	Europe	5239	2000-01-04	2020-01-31
16. ICE BofA 1-10 Year AAA Euro Corporate Index - Clean price	Corporate bonds	Europe	5239	2000-01-04	2020-01-31
17. FTSE100PRICEINDEX	Stocks (countries)	UK	5499	1999-01-05	2020-01-31
18. FRANCECAC40PRICEINDEX	Stocks (countries)	France	5499	1999-01-05	2020-01-31
19. IBEX35PRICEINDEX	Stocks (countries)	Spain	5499	1999-01-05	2020-01-31
20. FTSEMIBINDEXPRICEINDEX	Stocks (countries)	Italy	5499	1999-01-05	2020-01-31
21. BEL20PRICEINDEX	Stocks (countries)	Belgium	5499	1999-01-05	2020-01-31
22. ISEQALLSHAREINDEXPRICEINDEX	Stocks (countries)	Ireland	5499	1999-01-05	2020-01-31
23. AEXINDEXAEXPRICEINDEX	Stocks (countries)	Netherlands	5499	1999-01-05	2020-01-31
24. ATHEXCOMPOSITEPRICEINDEX	Stocks (countries)	Greece	5499	1999-01-05	2020-01-31
25. STOXXEUROPE600EPRICEINDEX	Stocks (sectors and market cap)	Europe	5499	1999-01-05	2020-01-31
26. EUROSTOXX50PRICEINDEX	Stocks (sectors and market cap)	Europe	5499	1999-01-05	2020-01-31
27. STOXXEUROPELARGE200PRICEINDEX	Stocks (sectors and market cap)	Europe	5499	1999-01-05	2020-01-31
28. STOXXEUROPESMALL200PRICEINDEX	Stocks (sectors and market cap)	Europe	5499	1999-01-05	2020-01-31
29. STOXXEUROPEMID200PRICEINDEX	Stocks (sectors and market cap)	Europe	5499	1999-01-05	2020-01-31
30. STOXXEUROPE600BASICMATSEPRICEINDEX	Stocks (sectors and market cap)	Europe	5499	1999-01-05	2020-01-31
31. STOXXEUROPE600INDUSTRIALSEPRICEINDEX	Stocks (sectors and market cap)	Europe	5499	1999-01-05	2020-01-31
32. STOXXEUROPE600TECHNOLOGYEPRICEINDEX	Stocks (sectors and market cap)	Europe	5499	1999-01-05	2020-01-31
33. STOXXEUROPE600UTILITIESEPRICEINDEX	Stocks (sectors and market cap)	Europe	5499	1999-01-05	2020-01-31
34. STOXXEUROPE600FINANCIALSEPRICEINDEX	Stocks (sectors and market cap)	Europe	5499	1999-01-05	2020-01-31
35. STOXXEUROPE600HEALTHCAREEPRICEINDEX	Stocks (sectors and market cap)	Europe	5499	1999-01-05	2020-01-31
36. STOXXEUROPE600TELECOMEPRICEINDEX	Stocks (sectors and market cap)	Europe	5499	1999-01-05	2020-01-31
37. EUROSTOXXFINANCIALSVSEPRICEINDEX	Stocks (sectors and market cap)	Europe	5499	1999-01-05	2020-01-31
38. EUROSTOXXFINANCIALSEPRICEINDEX	Stocks (sectors and market cap)	Europe	5499	1999-01-05	2020-01-31
39. EUROSTOXXHEALTHCAREEPRICEINDEX	Stocks (sectors and market cap)	Europe	5499	1999-01-05	2020-01-31
40. EUROSTOXXINDSGDSSVSEPRICEINDEX	Stocks (sectors and market cap)	Europe	5499	1999-01-05	2020-01-31
41. EUROSTOXXINDUSTRIALSEPRICEINDEX	Stocks (sectors and market cap)	Europe	5499	1999-01-05	2020-01-31
42. EUROSTOXXTECHNOLOGYEPRICEINDEX	Stocks (sectors and market cap)	Europe	5499	1999-01-05	2020-01-31
43. EUROSTOXXTELECOMEPRICEINDEX	Stocks (sectors and market cap)	Europe	5499	1999-01-05	2020-01-31
44. USTOEURORFVEXCHANGERATE	Exchange rates	EUR/USD	5499	1999-01-05	2020-01-31
45. SWISSFRANCTOEUROWMREXCHANGERATE	Exchange rates	EUR/CHF	5499	1999-01-05	2020-01-31
46. GBPTOEURBOEEXCHANGERATE	Exchange rates	EUR/GBP	5499	1999-01-05	2020-01-31
47. JAPANESEYENTOEUROWMREXCHANGERATE	Exchange rates	EUR/JPY	5499	1999-01-05	2020-01-31

major advanced-economy currencies, incorporating assets with different exposures to global risk factors and external monetary conditions. We consider daily log returns (r_t) for a period spanning from January 1999 to January 2020 ($T = 5499$) when available. This segmentation ensures substantial diversity across asset classes, geographies, sectors, and risk profiles, which enables us to examine how monetary policy shocks propagate differently across assets with varying sensitivities to yield curve movements.

4 Empirical results

Our empirical analysis is designed to explore how monetary policy shocks influence financial uncertainty across the various asset classes described in the previous section. To achieve this goal, the analysis is structured into three interconnected subsections that progressively deepen the understanding of these effects.

Section 4 explores the overall responses of financial uncertainty to monetary policy shocks, where the shocks are represented by the sum of the level, slope, and curvature components of the yield curve. Therefore, in this configuration, $\mathbf{x}_t^*$ and

We analyze financial uncertainty responses ($\tilde{\theta}$) to broad yield curve movements, representing monetary policy shocks (x_t^*) as the sum of level, slope, and curvature components. This provides an initial assessment of heterogeneity in uncertainty responses across asset classes, forming the basis for disentangling the specific contributions of each component in the following subsections.

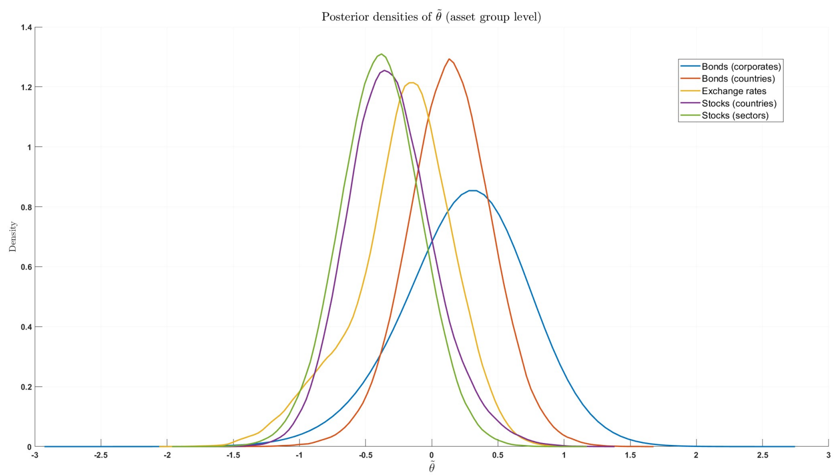

Figure 2: Spectrum of uncertainty responses (asset group level).

Figure 2 summarizes the posterior densities of $\tilde{\theta}$, aggregated by asset group, capturing the overall spectrum of uncertainty responses to yield curve variations. The modes of these densities reveal significant differences across asset classes. Sovereign bonds (red) and corporate bonds (blue) display positive central tendencies, suggesting that uncertainty increases in response to monetary policy shocks for these asset types. However, the range (dispersion) of responses is notably wider for corporate bonds, reflecting greater heterogeneity within this asset class, potentially attributable to differences in exposures to some underlying risk factors (e.g., credit risk or liquidity conditions). Exchange rates (orange) exhibit a density centered near zero, indicating aggregate neutrality in their sensitivity to overall changes in the yield curve captured in x_t^*. In contrast, the behavior of stock responses is substantially different. Indeed, both country-level indices (purple) and sectoral indices (green) have negative central tendencies and less within-group variation. This suggests that the uncertainty attached to stock prices connects differently to yield curve components summarized in x_t^*.

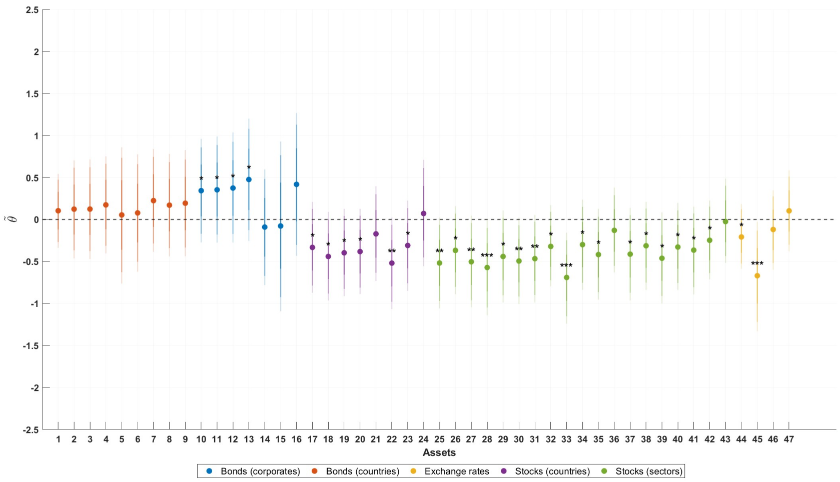

Figure 3: Point-wise (posterior medians) estimates of uncertainty responses across all assets.

Figure 3 presents the posterior median estimates for individual assets within each different group, alongside their 68% (*), 90% (**), and 95% (***) highest posterior density intervals (HPDIs). Sovereign bonds consistently exhibit positive medians, reflecting a uniform response profile within the group. In contrast, corporate bonds display a wider range of positive responses, indicating greater heterogeneity. For exchange rates, the EUR/CHF pair stands out with a notably significant negative response, surpassing that of other currencies. Stocks reveal distinct patterns: country-level indices concentrate around negative responses, while sectoral stocks show broader dispersion, potentially reflecting their more diverse and specific exposure to term-structure fundamentals.

The results presented above highlight significant heterogeneity in uncertainty responses both across and within asset classes. More specifically, sovereign bonds and corporate bonds exhibit positive responses, while equities consistently display negative responses, and exchange rates tend to remain near-neutral on average. Within groups, the broader dispersion observed for corporate bonds, exchange rates, and sectoral equities reflects varying exposures to yield curve dynamics and monetary policy transmission channels. This heterogeneity establishes a foundation for exploring the specific contributions of level, slope, and curvature shocks in the subsequent analysis.

4.2 Decomposing yield curve components: level, slope, and curvature effects

We now focus on how asset uncertainty responds to the level (θ_1), slope (θ_2), and curvature (θ_3) components of monetary policy shocks. These three components constitute distinct aspects of monetary policy transmission on the term structure of interest rates, encompassing both changes in expectations about future short-term policy rates and adjustments in term and risk premia. Consequently, as assets valuations are intrinsically linked to expectations about discount rates and risk premia, financial uncertainty is fundamentally shaped by how investors reprice assets in response to revisions in the expected path of interest rates (Gürkaynak et al., 2005; Bauer and Rudebusch, 2014), intermediary constraints (Adrian and Shin, 2010; He and Krishnamurthy, 2013), default and liquidity risk (Duffie and Singleton, 1999; Chen et al., 2007), and time-varying risk aversion (Campbell and Cochrane, 1999; Bansal and Yaron, 2004). While the level factor is primarily related to persistent shifts in the long-run stance of monetary policy, giving long-run anchor to expectations about discount rates across financial assets, slope, and curvature factors can lead to heterogeneous uncertainty responses due to the distinct economic signals they convey. Indeed, shocks to the slope mainly capture revisions in the expected path of short-term interest rates induced by near-term macroeconomic outlook, which can in turn influence uncertainty in credit markets through adjustments in refinancing risks and cyclical credit spreads (Gilchrist and Zakrajšek, 2012). In contrast, monetary policy shocks affecting the curvature account for adjustments in term and risk premia, induced by the use of unconventional measures such as quantitative easing (QE) or targeted credit interventions, which alter the duration and risk structure across maturities. Therefore, decomposing these effects enables a more precise and nuanced understanding of monetary policy's propagation through financial markets, highlighting how the economic signals embedded in different dimensions of the yield curve interact with different channels that can affect financial uncertainty. In the following, we discuss and interpret the empirical results observed both within and across asset classes.

Effects across asset classes

Beginning with the responses at the group level, Figure (4) shows that uncertainty responses to shocks in the level component are relatively homogeneous across asset classes. This is consistent with the interpretation of the level factor reflecting shifts in long-run behavior of future interest rates and macroeconomic trends. Since these expectations changes affect

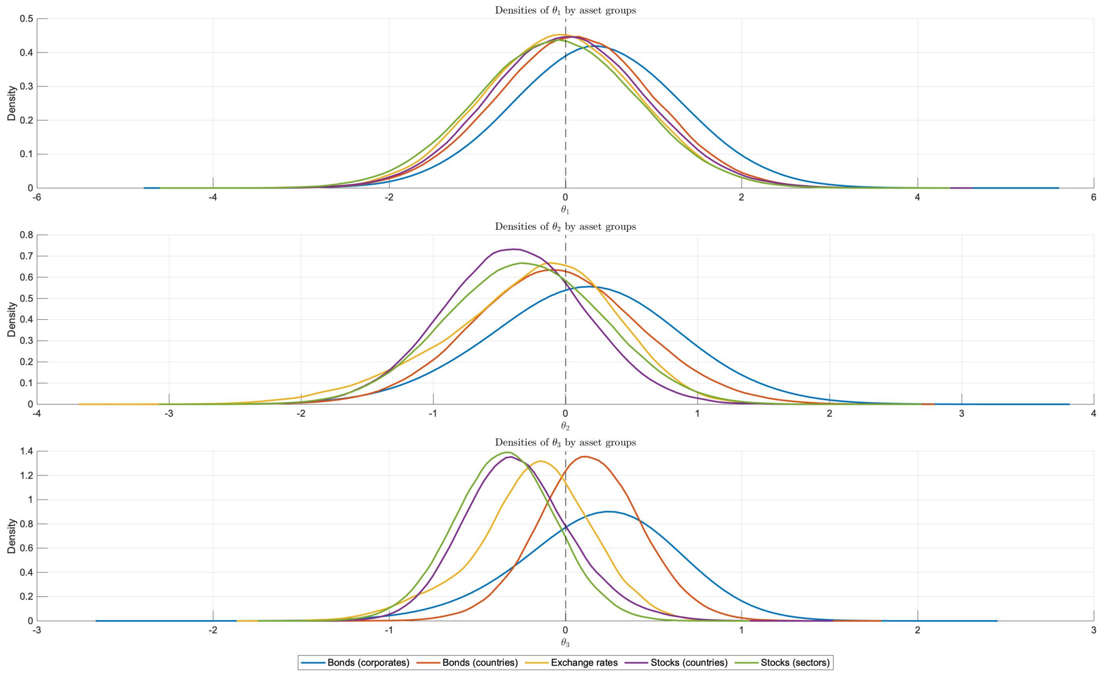

Figure 4: Spectrum of uncertainty responses to each component (asset group level).

the discount rate broadly across maturities, the repricing across assets is relatively uniform, leading to a common response of uncertainty. In contrast, the responses to slope and curvature components display significant heterogeneity. The strongest divergence in uncertainty responses emerges in corporate bonds (blue), which react more strongly and positively to changes in the slope factor, and in equities (purple and green), where the response to the curvature component differs markedly from that of bonds.

The positive response of corporate bond uncertainty to slope shocks is consistent with the heightened sensitivity of credit markets to changes in refinancing conditions. When monetary policy steepens the yield curve, typically by increasing long-term interest rates relative to short-term rates, firms with outstanding (short-term) debt face higher refinancing costs. This elevates refinancing risk, tightens credit conditions, and increases uncertainty about expected returns from holding those bonds. In contrast, sovereign bonds and equities exhibit muted or even negative responses to upward revision (positive slope shock) of the slope. Our interpretation of this pattern aligns with the expectations hypothesis of the term structure, which posits that a steeper yield curve reflects upward revisions in future short-term rate expectations due to anticipated economic expansion (Ang et al., 2006; Wright, 2006). For sovereign bonds, our findings suggest that such revisions reflect improved macroeconomic expectations, which may lower the probability of fiscal stress or sovereign risk default. Overall, this contributes to a decline in uncertainty about sovereign bonds. Similarly, equity markets respond to more favorable economic outlooks with a decrease in uncertainty for most indices. A plausible explanation for this pattern is that a steeper yield curve signals stronger near-term growth expectations and reduced macroeconomic risk. In habit formation models (Campbell and Cochrane, 1999), such conditions lower risk aversion, dampening perceived risk. These mechanisms help explain why uncertainty declines for several equity indices following slope shocks.

Concerning responses to the curvature component, our results indicate that positive shocks to the curvature, i.e., disproportionate increases in medium-term yields relative to short and long maturities, lead to increased uncertainty in bond markets and decreased uncertainty in equity markets. This pattern is consistent with term premia adjustments rather than shifts in short-term rate expectations. In the context of ECB monetary policy, such shocks could signal changes in forward guidance or tapering of asset purchase programs, where the central bank moderates its commitment to maintaining low rates in the medium term or signals a slower pace of asset purchases. This prompts investors to demand greater compensation to keep such bonds, raising their yields and increasing uncertainty. Therefore, this observation is consistent with the theoretical framework of Vayanos and Vila (2021), which posits that financial markets are segmented across maturities and that central bank interventions exert targeted effects on term premia by altering the supply-demand balance at specific horizons. If monetary policy announcements suggest reduced intervention at the medium-term segment, term premia at those horizons increase, resulting in higher yield volatility and thus greater bond return uncertainty. This mechanism is amplified when investors with maturity-specific preferences are less willing to absorb duration risk without central bank support. At the same time, the observed decline in equity uncertainty could reflect portfolio rebalancing effects (Gagnon et al., 2011; Vissing-Jorgensen and Krishnamurthy, 2011; Koijen et al., 2021), whereby investors reallocate their portfolios towards riskier assets such as equities.

Effects within asset classes

In addition to differences between asset classes, Figure 5 also reveals heterogeneous[13] responses within asset classes. More specifically, at the corporate bond level, differences in uncertainty responses emerge more clearly when comparing indices by credit quality and duration. The ICE BofA Euro AAA Corporate Index (index 13) shows the strongest and most statistically significant response to curvature shocks, followed closely by broader iBoxx indices (indices

[13] See also Figure A1 in Appendix for a complementary visualization of the heterogeneity in responses.

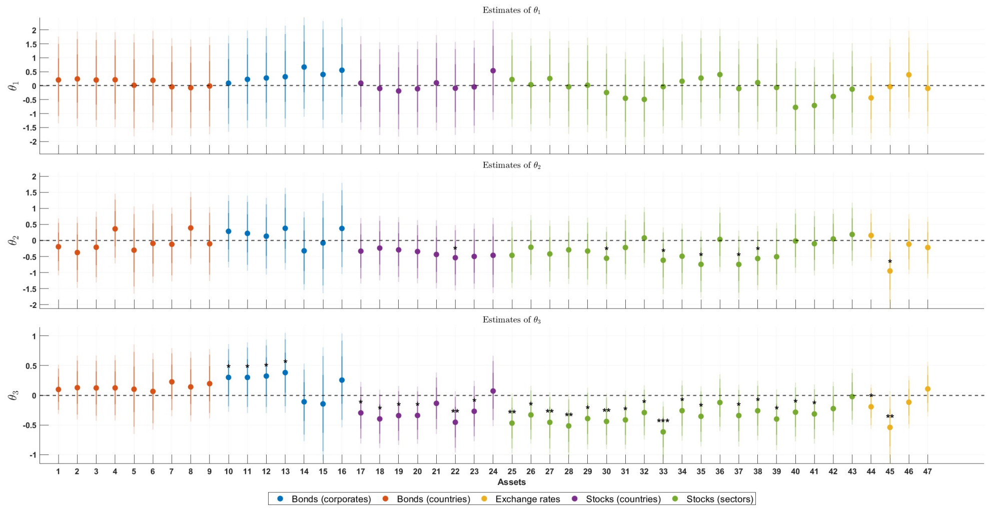

Figure 5: Point-wise (posterior medians) estimates of uncertainty responses to each component across all assets.

10–12). In contrast, lower-rated and shorter-duration bonds, such as the ICE BofA Euro BBB Index and the 1–3 Year BBB Index (indices 14 and 15), exhibit weaker or near-zero responses. These patterns suggest that uncertainty is more sensitive to monetary policy shocks in higher-rated, longer-duration corporate bonds, possibly reflecting their greater exposure to term premium adjustments. Responses to the slope component also appear more pronounced in AAA-rated indices, while the level component elicits uniformly modest effects across credit segments.

For sovereign bonds, uncertainty responds modestly to level shocks, with slightly stronger effects in core euro area countries such as Germany (index 1) and Belgium (index 2). Responses to slope shocks show greater dispersion, with Spain (index 3) and Ireland (index 6) exhibiting more pronounced reactions, suggesting some heterogeneity in sensitivity to expected short-term rate revisions. Curvature shocks lead to uniformly weak responses across sovereign indices (indices 1–9), indicating that medium-term term premium adjustments have limited influence on sovereign bond uncertainty

Exchange rates display moderate heterogeneity in their responses to monetary policy shocks, consistent with differential sensitivities to interest rate expectations and risk premia adjustments (Engel, 2016; Rogers et al., 2018). The EUR/CHF exchange rate (index 45) reacts significantly to slope and curvature shocks, while EUR/USD (index 44) shows a more moderate sensitivity to curvature. In contrast, the EUR/GBP and EUR/JPY currency pairs (indices 46 and 47) exhibit minimal responses across all components, suggesting more muted monetary policy transmission in these exchange rate pairs.

Equity responses exhibit clear within-group heterogeneity, particularly between country and sector indices. Country-level indices (17–24) respond negatively to slope and curvature shocks, suggesting a decline in uncertainty when monetary policy is perceived as signaling improved macroeconomic conditions. In contrast, sector indices (25–43) show more pronounced dispersion, especially in response to curvature shocks. Financials (34, 37), technology (32, 42), and telecom (36, 43) display the largest increases in uncertainty, consistent with their greater sensitivity to interest rate paths and exposure to long-duration cash flows or intermediation margins (especially for banks). These patterns align with the idea that sectors more reliant on forward-looking valuations or net interest spreads may be more affected by shifts in the shape of the yield curve. Defensive sectors, such as healthcare (35, 39) and consumer goods (40), exhibit more moderate responses, though not uniformly muted. Level shocks generate relatively uniform and modest responses across both country and sector indices.

4.3 The role of monetary policy regimes: a pre- and ZLB comparative analysis

The GFC and the subsequent emergence of the ZLB marked a major regime shift in the conduct of monetary policy. With short-term interest rates constrained near the effective lower bound, central banks in advanced economies, including the European Central Bank (ECB) and the Federal Reserve (Fed), moved from conventional tools to various non-standard measures, relying more extensively on the financial sector in monetary pass-through (Bernanke, 2020). This novel economic environment and policy framework fundamentally altered the behavior of interest rates (Wright, 2012; Swanson and Williams, 2014; Bauer and Rudebusch, 2016), the pricing of risk (Gourio and Ngo, 2020), and the mechanisms through which monetary policy shocks propagate through financial markets and the broader economy.[14]

To account for these structural changes, we conduct a simple comparative analysis by estimating the same model as in the previous section on two distinct samples: a pre-ZLB period (1999–2012) and a ZLB period (2012–2020). This allows us to examine whether the relationship between shock components and financial uncertainty has evolved between the two regimes, shedding light on potential shifts in monetary policy transmission and its impact on financial markets.

[14] See notably Bhattarai and Neely (2022) for a survey of the literature about the effects and operating mechanisms of UMPs.

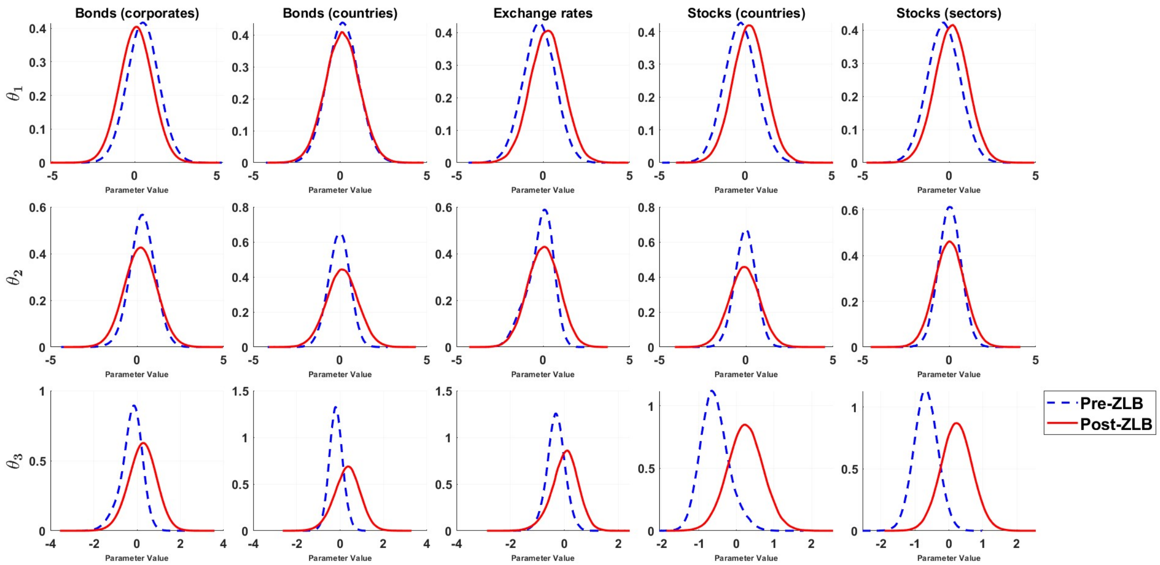

Figure 6: Spectrum of uncertainty responses to each component (Pre- vs ZLB, asset group level).

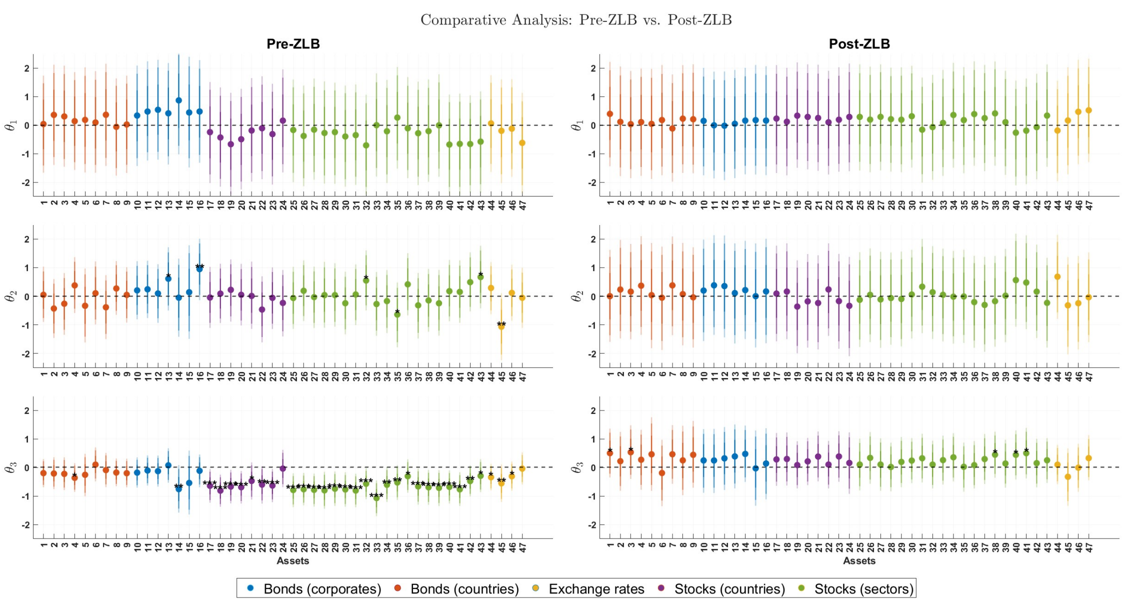

Figure 7: Comparison of uncertainty impact responses estimates (θ) between (left) pre- and (right) ZLB.

Figures 6 and 7 contrast uncertainty responses to shocks across pre- and ZLB periods, both at the aggregate group level and at the more granular asset level. Multiple patterns emerge from this analysis. At the group level, responses to level shocks (θ_1) exhibit relatively modest changes between the two regimes. Corporate bond responses appear to decline slightly for ZLB, sovereign bond responses remain broadly stable, while uncertainty responses for equities and exchange rates increase moderately. For slope shocks (θ_2), responses are broadly similar across periods and asset classes, although cross-asset heterogeneity observed in Section 4.2 appears somewhat reduced during ZLB. Slope shocks tend to generate more uniform responses in the ZLB period. The most notable difference concerns curvature shocks (θ_3). Indeed, uncertainty responses to these shocks become notably more pronounced in the ZLB period. This increase is visible across all asset classes, but is particularly evident in equities, where curvature shocks emerge as a dominant source of uncertainty. These patterns are confirmed and further refined when examining asset-level responses in Figure 7. Pre-ZLB, uncertainty responses to curvature shocks displayed a more pronounced dispersion across assets, most notably between bonds and equities, reflecting strong within-group and cross-asset heterogeneity. In contrast, ZLB estimates reveal more uniform increases in uncertainty across individual assets, suggesting financial uncertainty across markets respond more synchronously to these type of shocks. The bond-equity dichotomy previously observed in earlier (4.2) is no longer evident, and responses appear more synchronized across and within asset classes.

Interpreting these patterns requires considering the broader shifts in monetary policy frameworks and financial market conditions associated with the ZLB and unconventional policy period. The reduced heterogeneity in responses to level and slope shocks during ZLB may reflect, at least in part, the stronger anchoring of interest rate expectations in this environment. With short-term rates constrained by the effective lower bound and central banks relying increasingly on forward guidance, the scope for surprises in expected short-term policy rates may have diminished. This could result in more homogeneous uncertainty responses across assets, as markets place less weight on divergent interpretations of short rate trajectories. In contrast, the greater prominence and uniformity of responses to curvature shocks across asset classes after the introduction of the ZLB indicates the rising importance of medium-term risk pricing and term premia dynamics in monetary transmission. In an environment characterized by large-scale asset purchases and expectations of low interest rates, investors may have become more sensitive to shifts in the perceived risk compensation embedded in medium-term yields. As a result, curvature shocks appear to have become a more systematic driver of financial uncertainty across markets.

Overall, these patterns suggest that monetary policy transmission to financial uncertainty became increasingly shaped by medium-term yield and risk premia channels during the ZLB period and unconventional times. However, given the reduced-form nature of our empirical framework, these interpretations should be viewed as suggestive and consistent with, rather than definitive evidence of, underlying structural mechanisms.

4.4 Monetary policy shocks and uncertainty dynamics

This section extends and complements our analysis carried out so far by (i) understanding the dynamic effects of monetary policy shocks components on uncertainty (h_t), (ii) assessing the historical contribution of shocks to fluctuations in financial uncertainty, and (iii) performing counterfactual exercises on certain key historical monetary policy announcements. We analyze and discuss this in the following sections.

4.4.1 Dynamic responses to shocks

We rely on (8) and (9) to quantify uncertainty responses to each shock component and compute it for the different asset categories encompassing our dataset. Beyond the heterogeneity in responses at impact, i.e., when $h = 0$, Figure (8) also reveals substantial differences, across and within groups, on the enduring impact of each distinct type of shock.[15]

Each response corresponds to a one-percentage-point change in the level, slope, or curvature factor driven by the monetary policy shock. Given (10), each shock component loads differently on the yield curve. A shock to the level shifts all yields uniformly across all maturities, causing a one-percentage-point increase in yields at both short and long horizons. A unit shock to the slope steepens the yield curve, leading to a larger rise in short-term rates (e.g., around 0.7 percentage points at 1 year) than in long-term yields (e.g., 0.27 percentage points at 5 years). A shock to the curvature component leads to a more localized movement, with intermediate maturities (e.g., 2 years) shifting by about 0.3 percentage points relative to short- and long-term rates.

We notice some differences regarding the speed at which uncertainty (h_t) dissipates. Corporate bond uncertainty declines more quickly, suggesting a faster resolution of uncertainty in credit markets. However, responses of sovereign bonds remain elevated for a longer period, indicating a slower resolution of monetary policy effects. Exchange rate uncertainty exhibits the slowest decay, reflecting prolonged adjustments in currency markets. Concerning equities, uncertainty returns faster to its steady state compared to bonds and exchange rates, with sectoral stocks showing more heterogeneous persistence across industries. From our model, the overall duration of uncertainty effects is determined by the persistence parameter ϕ, which

[15] The responses, expressed in terms of deviations of h_t, show the dynamic evolution of uncertainty to a unit change of shock components $\Delta\beta^{HF}_{1:3,t}$. As h_t expresses log variations, they represent uncertainty deviations in percentage from a state, with responses that can be linked to the actual level of uncertainty: a response of magnitude Δh_t translates into a multiplicative effect of $e^{\Delta h_t}$ on the uncertainty level of the underlying financial asset. This allows us to quantify not only the direction and magnitude of uncertainty shifts but also their persistence over time.

dictates how long uncertainty remains elevated after a shock in level, slope, or curvature dimension. It should be noted that the above patterns are shaped by the structure of our model. Exploiting models with richer persistency dynamics, or other channels, could offer further insights into the transmission of monetary policy shocks to financial uncertainty.[16]

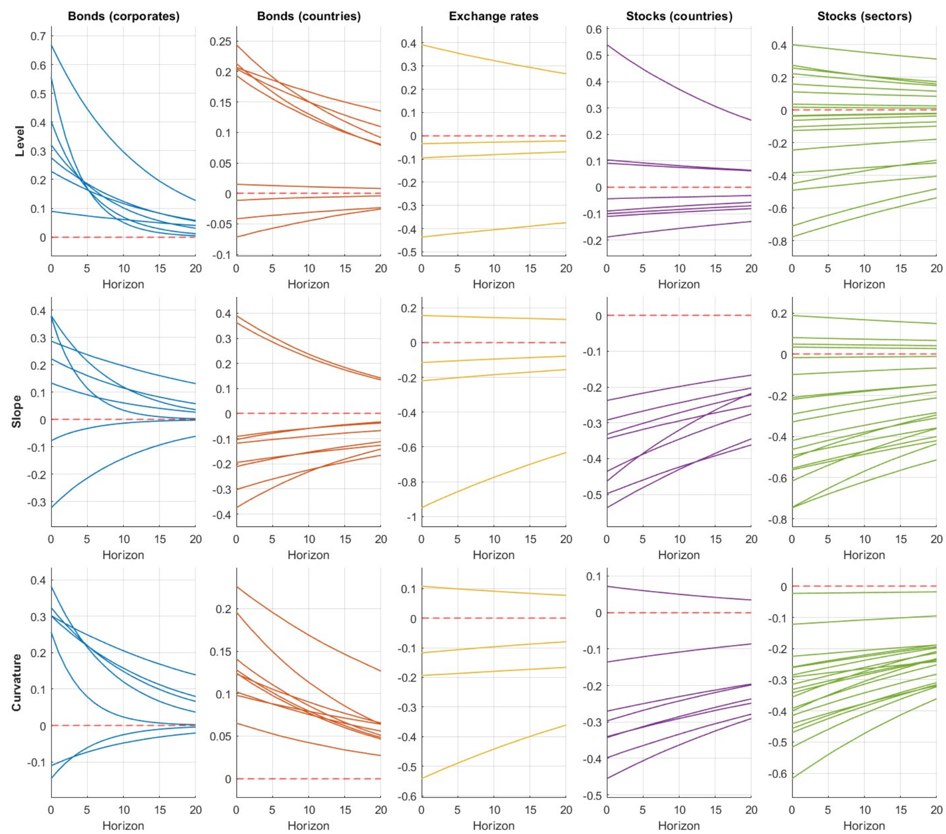

Figure 8: Uncertainty responses to monetary policy shocks components over time.

4.4.2 Historical contribution of shocks to financial uncertainty fluctuations

To what extent has monetary policy contributed to historical fluctuations in financial uncertainty? To explore this more closely, we decompose, for each monetary policy announcement, uncertainty deviations attributed to monetary policy shocks and random noise (ν_t). This approach reveals how policy-driven uncertainty has evolved across asset classes, highlighting periods dominated by specific shock dimensions. Figure (9) visualizes these contributions for five assets representative of their group, respectively, the **BD Benchmark 10-Year DS Govt. Index** (Germany, index 1), the **ICE BofA BBB Euro Corporate Index** (index 14), the **FTSE100 Price Index** (UK, index 17), the **EUROSTOXX Technology Price**

[16] See notably Alessandri and Mumtaz (2019) regarding this point.

Index (index 42), and the **EUR/USD** exchange rate (index 44), offering a historical perspective on the impact of monetary policy shocks on financial uncertainty fluctuations beyond usual time series dynamic, denoted h_t^*. Formally, we define this quantity by

$$h_t^* = h_t - (\mu - \phi(h_{t-1} - \mu)) = \theta \mathbf{x}_t^* + \nu_t,$$

and report the relative contributions of level, slope, curvature, and stochastic noise to deviations from the long-run uncertainty trajectory.

Figure (10) and Table (A1) provide further insights regarding this, summarizing respectively: (i) the average historical contribution of shocks to uncertainty fluctuations (h_t^*) across all assets considered in our analysis, and (ii) a measure of their dispersion across assets and groups for each respective component, i.e., level, slope, curvature, and noise.

The observed results suggest that shock contributions, taken together, account for a non-negligible and greater proportion of h_t^* deviations than noise contributions (52.74% vs 47.26% on average). Among the three components, curvature has the highest mean contribution across all groups (28.77%), followed by slope (18.37%) and level (5.60%), underscoring its dominant role in explaining yield curve adjustments and affecting financial uncertainty. Moreover, the level component displays lower dispersion, involving more uniform effects across assets, while slope and curvature show greater variability, suggesting a higher heterogeneity regarding their contributions. In particular, the mean contribution of the slope factor ranges from 10.96% for corporate bonds to 23.48% for country-level stocks. The curvature component also differs, with contributions between 19.77% for sovereign bonds and 34.82% for sector-level stocks.

4.4.3 Counterfactuals and monetary policy episodes

The high-frequency surprises of Altavilla et al. (2019) encompass a range of key policy announcements and significant episodes in the ECB's monetary policy history[17]. This enables us to quantify further the monetary policy's role in shaping financial uncertainty during some specific historical episodes. To achieve this, we assess the contribution of shocks to financial uncertainty for particular key historical dates. More specifically, given the baseline model estimates (see Section 4.2), we conduct a series of counterfactual exercises and estimate how financial uncertainty would have evolved in the absence of these shocks. We focus on four par-

[17] Table A2 in Appendix provides a detailed description of the key policy announcements and episodes, including decisions made during the "conventional" period (before the zero lower bound, ZLB) and the "non-conventional" period, characterized by the adoption of non-standard policy measures.

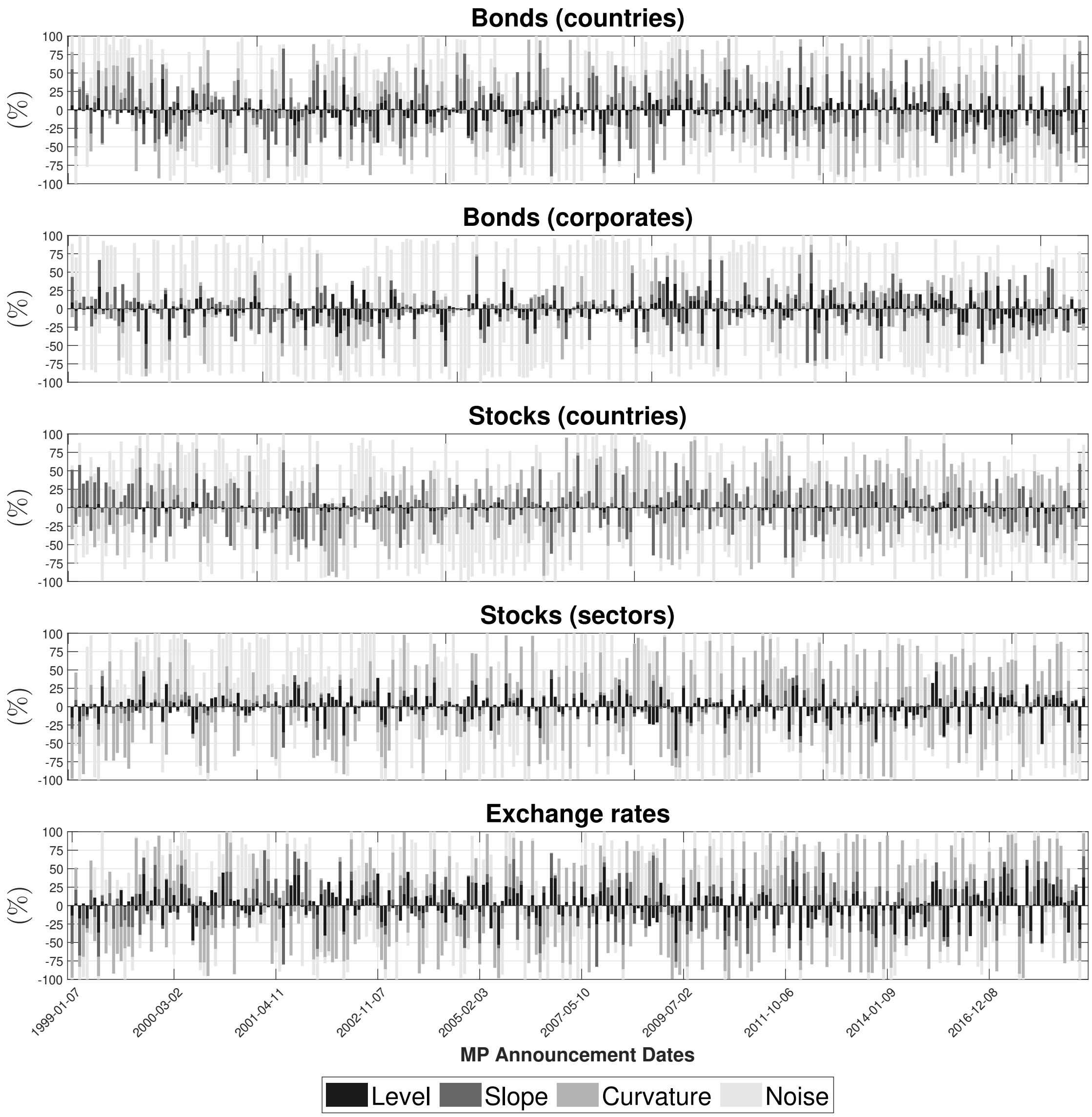

Figure 9: Historical relative contributions (in %) of shock components and noise to uncertainty fluctuations. Each panel corresponds to a representative asset from each asset class group: (i) Bonds (countries): BD Benchmark 10-Year DS Govt. Index (Germany, index 1); (ii) Bonds (corporates): ICE BofA BBB Euro Corporate Index (index 14); (iii) Stocks (countries): FTSE100 Price Index (UK, index 17); (iv) Stocks (sectors): EUROSTOXX Technology Price Index (index 42); and (v) Exchange rates: EUR/USD exchange rate (index 44). See Table 2 for more details about these time series.

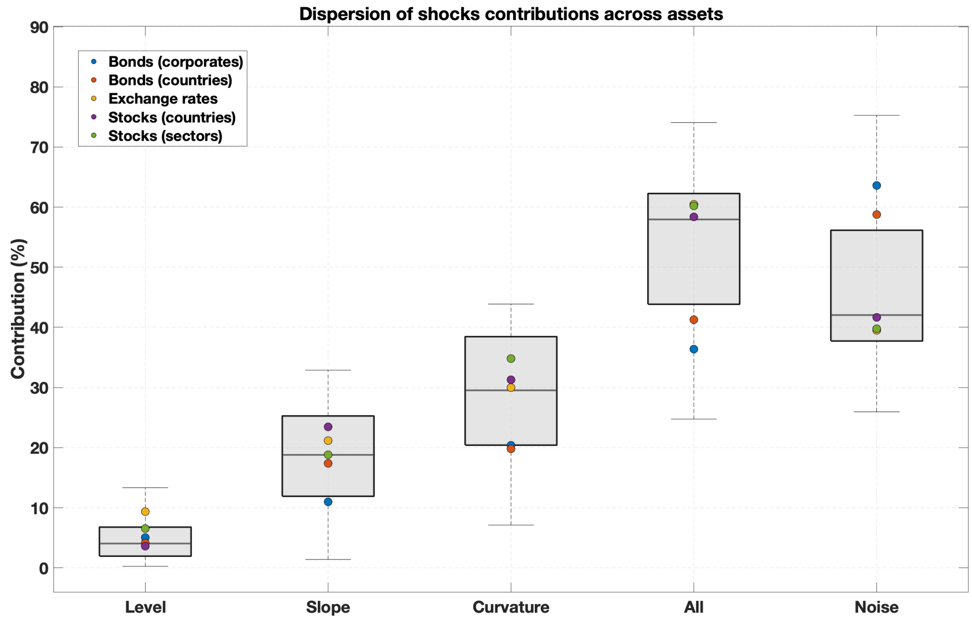

Figure 10: Boxplots of shocks contributions and noise across assets.

ticular monetary policy announcements: two unconventional announcements, the Securities Markets Programme (SMP) on 4/08/2011, and the announcement of the (expanded) Asset Purchase Programme (APP) 22/01/2015; and two during conventional periods (5/06/2003 and 2/07/2009) as detailed in Table A2. Figures (11) and (12) plot respectively the counterfactual uncertainty level trajectories (dashed dotted for the full effect, expressed in terms of h_t and σ_t) alongside their actual realized paths (thick solid) for the same five representative assets as before (see Subsection 4.4.2). Analyzing these counterfactual trajectories reveals distinct effects of monetary policy shocks on uncertainty. These differences highlight how the specific components (level, slope, and curvature) have shaped diverse uncertainty responses across financial markets and policy announcements. For the SMP announcement (Figure 11, upper panel), monetary policy shocks collectively led to significant increases in uncertainty, notably by approximately +4.94% for country-level stocks, +2.4% for sector-level stocks, and +4.76% for sovereign bonds[18]. These effects were primarily driven by slope and curvature components, reflecting substantial shifts in risk premia and interest rate expectations. Conversely, the QE announcement (Figure 11, lower panel) substantially reduced uncertainty, with notable decreases of around -7.77% in country-level stocks and -6.98% in corporate bonds. The curvature dimension of the shock particularly contributed to this stabilization, reflecting

[18]The magnitude of these effects are obtained from the vertical distances between thick solid and dashed-dotted lines at day zero, for the graphs expressed in terms of σ_t.

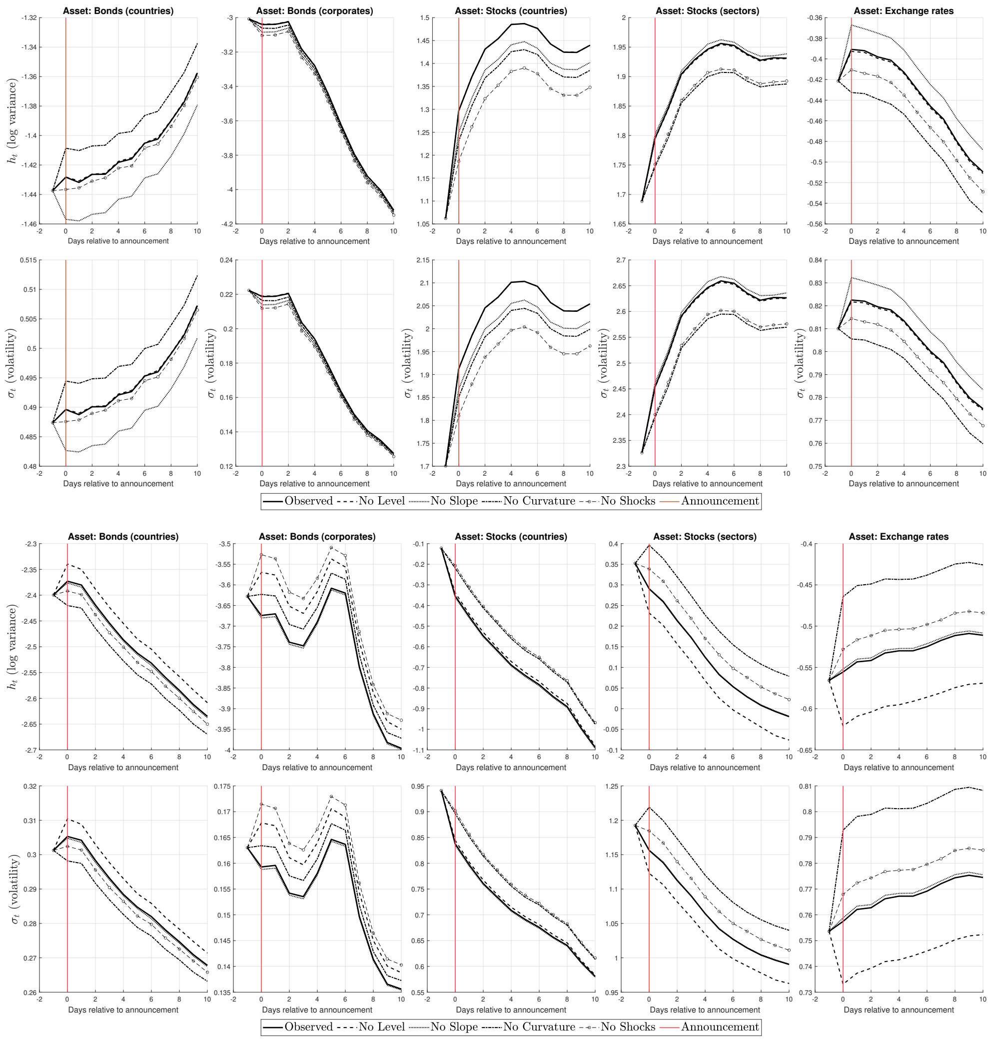

Figure 11: Counterfactual uncertainty trajectories for two unconventional policy announcements: SMP (4/08/2011, top) and APP (22/01/2015, bottom). See Table A2 for more information about these announcements. The counterfactuals are computed on the same five representative assets as those in Figure 9.

QE's effectiveness in stabilizing financial markets and calming investor concerns about future risks.

For the conventional policy announcement on 05/06/2003 (12, upper panel), the observed impacts on uncertainty varied significantly across asset classes. Sovereign bonds experienced a notable reduction of approximately -4.87%. However, other asset classes showed moderate increases: country-level stocks (+2.64%), sector-level stocks (+6.86%), and exchange rates (+7.85%). The announcement on 02/07/2009 (lower panel) exhibited smaller uncertainty changes, with minimal effects on sovereign bonds (-0.82%), moderate increases in sector-level stocks (+1.72%), and exchange rates (+1.1%). Thus, the largest uncertainty impact among all episodes analyzed occurred during the QE announcement, particularly in country-level stocks, where uncertainty decreased by approximately -7.77% relative to the no-shocks baseline.

Overall, the findings observed in this section, as well as those in Subsection 4.4.2, offer a complementary and historical perspective regarding the role of monetary policy shocks in affecting financial uncertainty. By focusing on these specific policy announcements, our analysis illustrates that monetary policy has influenced financial markets through varying combinations of yield curve components across time. While curvature-related shocks tend to dominate on average, the contributions of level and slope components exhibit meaningful variations across episodes and asset classes. These results, consistent with the heterogeneous sensitivities documented previously, highlight that monetary policy shocks have historically materialized through different dimensions of the yield curve, with differentiated implications for financial uncertainty across market segments.

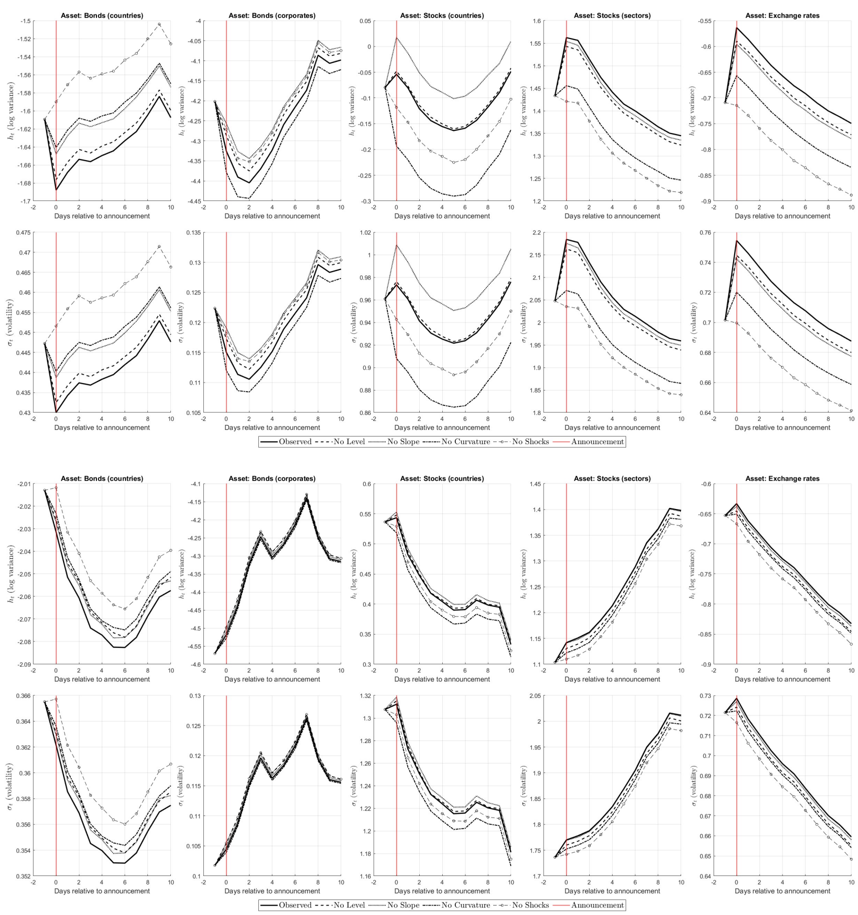

Figure 12: Counterfactual uncertainty trajectories for two conventional policy announcements (5/06/2003, top) 2/07/2009, bottom). See Table A2 for more information about these announcements. Counterfactuals are computed on the same five representative assets as those in Figure 9.

5 Conclusion

This paper brings a different perspective on the effects of monetary policy on financial markets. We empirically investigate how monetary policy shocks influence financial uncertainty in various asset classes in the euro area. We highlight distinct responses to shocks manifesting on various yield curve dimensions, specifically through level, slope, and curvature components.

To do so, we measure financial uncertainty, conceived explicitly as the expected stochastic time-varying dispersion of asset returns arising from yield curve shifts driven by monetary policy shocks. The various marginal effects of these shifts are estimated through a standard reduced-form stochastic volatility model augmented with empirical measures of monetary policy shocks captured extracted from high-frequency yield curve variations around policy announcements provided by Altavilla et al. (2019).

We highlight the relevance of considering second-order effects in the transmission of monetary policy on financial markets. The decomposition into level, slope, and curvature components provides a tractable way to empirically characterize how different dimensions of monetary policy shape the yield curve and are associated with changes in financial uncertainty. This framework highlights the importance of recognizing the multidimensional nature of monetary policy surprises and their differentiated influence across asset classes.

Observed empirical results reveal heterogeneous uncertainty responses across shock dimensions and asset classes. Sovereign bonds tend to show moderate increases in uncertainty following level shocks, which may reflect adjustments in long-term expectations about future policy rates. In contrast, corporate bonds display more pronounced increases in uncertainty in response to slope shocks, potentially indicating heightened sensitivity to short-term refinancing risks and liquidity conditions. Equity markets, broadly, exhibit reductions in uncertainty following monetary policy shocks, particularly those associated with the curvature component. Nevertheless, these patterns appear to differ across monetary policy regimes, with curvature shocks gaining prominence during the ZLB period. While these findings suggest possible interpretations related to changes in risk premia or expectations, we remain cautious about making strong structural claims and acknowledge that the observed heterogeneity may stem from a range of underlying mechanisms that merit further investigation.

Future research could rely on prior works, notably those of Rogers et al. (2014); Hanson and Stein (2015); Rogers et al. (2018); Swanson (2021), and extend this analysis by considering a framework capable of jointly identifying changes in expectations and risk premia behind the yield curve's factor surprises. Integrating these elements more explicitly, as well as the role of the ZLB, into fully-fledged macro-finance dynamic term structure models (DTSMs) as Rudebusch and Wu (2008); Christensen and Rudebusch (2012); Joslin et al. (2014); Swanson and Williams (2014); Wu and Xia (2016) would further clarify the expectations vs risk-based components of monetary policy transmission on financial uncertainty. Finally, taking into account any potential information effects (see Bauer and Swanson (2023a,b)) in high-frequency surprises is a natural extension of our empirical analysis that merits further investigation.

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Appendix

Table A1: Contributions of shock components in explaining h_t^* across assets.

Name	Group	Region	Level (%)	Slope (%)	Curvature (%)	Noise (%)
1. BD BENCHMARK 10 YEAR DS GOVT. INDEX - CLEAN PRICE INDEX	Government bonds	Germany	10.07	24.82	24.71	40.40
2. BG BENCHMARK 10 YEAR DS GOVT. INDEX - CLEAN PRICE INDEX	Government bonds	Belgium	6.39	25.08	16.93	51.59
3. ES BENCHMARK 10 YEAR DS GOVT. INDEX - CLEAN PRICE INDEX	Government bonds	Spain	5.75	16.60	18.89	58.76
4. FR BENCHMARK 10 YEAR DS GOVT. INDEX - CLEAN PRICE INDEX	Government bonds	France	5.25	24.04	16.41	54.30
5. GR BENCHMARK 10 YEAR DS GOVT. INDEX - CLEAN PRICE INDEX	Government bonds	Greece	0.27	14.13	10.48	75.12
6. IR BENCHMARK 10 YEAR DS GOVT. INDEX - CLEAN PRICE INDEX	Government bonds	Ireland	5.60	7.66	11.48	75.26
7. IT BENCHMARK 10 YEAR DS GOVT. INDEX - CLEAN PRICE INDEX	Government bonds	Italy	1.41	9.70	31.01	57.88
8. UK BENCHMARK 10 YEAR DS GOVT. INDEX - CLEAN PRICE INDEX	Government bonds	UK	1.98	25.66	19.33	53.02
9. EMU BENCHMARK 10 YR. DS GOVT. INDEX - CLEAN PRICE INDEX	Government bonds	EMU	0.36	8.63	28.71	62.30
10. IBOXX EURO CORPORATES - Cln Prc Indx Today	Corporate bonds	Europe	1.96	16.42	28.97	52.64
11. IBOXX EURO OVERALL - Cln Prc Indx Today	Corporate bonds	Europe	4.22	11.65	27.46	56.66
12. IBOXX EURO EUROZONE - Cln Prc Indx Today	Corporate bonds	Europe	5.29	7.41	28.86	58.44
13. ICE BofA AAA Euro Corporate Index - Clean price	Corporate bonds	Europe	3.83	12.75	23.72	59.70
14. ICE BofA BBB Euro Corporate Index - Clean price	Corporate bonds	Europe	10.96	15.48	11.51	62.06
15. ICE BofA 1-3 Year BBB Euro Corporate Index - Clean price	Corporate bonds	Europe	3.90	2.23	8.08	85.80
16. ICE BofA 1-10 Year AAA Euro Corporate Index - Clean price	Corporate bonds	Europe	5.24	10.80	13.92	70.04
17. FTSE100PRICEINDEX	Stocks (countries)	UK	2.31	21.51	34.81	41.36
18. FRANCECAC40PRICEINDEX	Stocks (countries)	France	2.46	15.92	42.83	38.78
19. IBEX35PRICEINDEX	Stocks (countries)	Spain	4.81	19.22	38.48	37.49
20. FTSEMIBINDEXPRICEINDEX	Stocks (countries)	Italy	2.66	21.17	37.71	38.46
21. BEL20PRICEINDEX	Stocks (countries)	Belgium	2.96	29.67	19.24	48.13
22. ISEQALLSHAREINDEXPRICEINDEX	Stocks (countries)	Ireland	1.69	24.86	38.04	35.41
23. AEXINDEXAEXPRICEINDEX	Stocks (countries)	Netherlands	1.08	29.69	30.19	39.04
24. ATHEXCOMPOSITEPRICEINDEX	Stocks (countries)	Greece	10.87	25.79	8.78	54.56
25. STOXXEUROPE600EPRICEINDEX	Stocks (sectors and market cap)	Europe	4.04	22.05	38.68	35.23
26. EUROSTOXX50PRICEINDEX	Stocks (sectors and market cap)	Europe	1.01	15.72	40.15	43.11
27. STOXXEUROPELARGE200PRICEINDEX	Stocks (sectors and market cap)	Europe	4.85	20.89	38.84	35.42
28. STOXXEUROPESMALL200PRICEINDEX	Stocks (sectors and market cap)	Europe	0.73	14.76	42.92	41.58
29. STOXXEUROPEMID200PRICEINDEX	Stocks (sectors and market cap)	Europe	0.38	18.80	38.78	42.05
30. STOXXEUROPE600BASICMATSEPRICEINDEX	Stocks (sectors and market cap)	Europe	4.77	26.31	38.30	30.61
31. STOXXEUROPE600INDUSTRIALSEPRICEINDEX	Stocks (sectors and market cap)	Europe	9.34	12.87	40.52	37.28
32. STOXXEUROPE600TECHNOLOGYEPRICEINDEX	Stocks (sectors and market cap)	Europe	13.34	6.98	40.34	39.33
33. STOXXEUROPE600UTILITIESEPRICEINDEX	Stocks (sectors and market cap)	Europe	0.58	25.06	43.88	30.48
34. STOXXEUROPE600FINANCIALSEPRICEINDEX	Stocks (sectors and market cap)	Europe	3.71	27.97	28.66	39.66
35. STOXXEUROPE600HEALTHCAREEPRICEINDEX	Stocks (sectors and market cap)	Europe	4.95	32.41	30.06	32.58
36. STOXXEUROPE600TELECOMEPRICEINDE	Stocks (sectors and market cap)	Europe	15.83	4.27	26.65	53.26
37. EUROSTOXXFINANCIALSVSEPRICEINDEX	Stocks (sectors and market cap)	Europe	1.97	32.88	29.53	35.62
38. EUROSTOXXFINANCIALSEPRICEINDEX	Stocks (sectors and market cap)	Europe	2.62	31.13	28.73	37.52
39. EUROSTOXXHEALTHCAREEPRICEINDEX	Stocks (sectors and market cap)	Europe	1.26	25.30	36.47	36.97
40. EUROSTOXXINDSGDSSVSEPRICEINDEX	Stocks (sectors and market cap)	Europe	19.57	1.40	37.11	41.93
41. EUROSTOXXINDUSTRIALSEPRICEINDEX	Stocks (sectors and market cap)	Europe	15.72	6.83	35.64	41.82
42. EUROSTOXXTECHNOLOGYEPRICEINDEX	Stocks (sectors and market cap)	Europe	13.03	5.37	39.17	42.44
43. EUROSTOXXTELECOMEPRICEINDEX	Stocks (sectors and market cap)	Europe	6.88	26.89	7.11	59.12
44. USTOEURORFVEXCHANGERATE	Exchange rates	EUR/USD	17.39	17.98	38.69	25.94
45. SWISSFRANCTOEUROWMREXCHANGERATE	Exchange rates	EUR/CHF	0.42	28.56	31.36	39.66
46. GBPTOEURBOEEXCHANGERATE	Exchange rates	EUR/GBP	15.51	13.67	25.80	45.02
47. JAPANESEYENTOEUROWMREXCHANGERATE	Exchange rates	EUR/JPY	4.05	24.37	24.07	47.52

Table A2: Examples of key ECB monetary policy announcements (conventional vs. unconventional episodes)

Date	**Policy decision or key speech**	**Excerpt**	**Reference**
Panel A: Conventional episodes			
08-Jun-2000	MRO rate raised by 50 bps to 4.25%	*"The interest rate on the main refinancing operations of the Eurosystem will be raised by 0.50 percentage point to 4.25% and applied in the two operations (which will be conducted as fixed rate tenders) to be settled on 15 and 21 June 2000."*	ECB Press Release, 8 June 2000

Date	Policy Decision or Key Communication	Excerpt	Reference
30-Aug-2001	MRO rate cut by 25 bps to 4.25%	*"The minimum bid rate on the main refinancing operations of the Eurosystem will be reduced by 0.25 percentage point to 4.25%, starting from the operation to be settled on 5 September 2001."*	ECB Press Release, 30 August 2001
05-Jun-2003	MRO rate cut by 50 bps to 2.00%	*"The Governing Council decided to lower the interest rate on the main refinancing operations of the Eurosystem by 0.50 percentage points to 2.00%."*	ECB Monthly Bulletin, June 2003, p. 9
08-Jun-2006	MRO rate raised by 25 bps to 2.75%	*"The Governing Council decided to increase the interest rate on the main refinancing operations of the Eurosystem by 0.25 percentage points to 2.75%."*	ECB Monthly Bulletin, June 2006, p. 6
02-Jul-2009	MRO rate held at 1.00% during crisis	*"The Governing Council decided to keep the interest rate on the main refinancing operations of the Eurosystem unchanged at 1.00%."*	ECB Monthly Bulletin, July 2009, p. 4
Panel B: Unconventional Episodes			
04-Aug-2011	Resumption of bond purchases under SMP	*"The Governing Council decided to conduct a liquidity-providing supplementary longer-term refinancing operation with a maturity of approximately six months."*	ECB Monthly Bulletin, August 2011, p. 3
08-Dec-2011	Launch of 3-year LTROs	*"The Governing Council decided to conduct two longer-term refinancing operations (LTROs) with a maturity of approximately three years."*	ECB Monthly Bulletin, December 2011, p. 4

Date	Policy Decision or Key Communication	Excerpt	Reference
04-Jul-2013	Introduction of forward guidance	*"The Governing Council expects the key ECB interest rates to remain at present or lower levels for an extended period of time."*	ECB Monthly Bulletin, July 2013, p. 6
22-Jan-2015	Launch of Expanded APP (including PSPP)	*"The Governing Council decided to launch an expanded asset purchase programme encompassing the existing purchase programmes for asset-backed securities and covered bonds."*	ECB Press Release, 22 January 2015
07-Mar-2019	Launch of TLTRO-III	*"A new series of quarterly targeted longer-term refinancing operations (TLTRO-III) will be launched, starting in September 2019 and ending in March 2021, each with a maturity of two years."*	ECB Press Release, 7 March 2019

Table A3: Summary Statistics of log returns (r_t).

Variable name	**Mean**	**Sd**	**Min**	**Max**	**Skewness**	**Kurtosis**	**Q1**	**Median**	**Q3**
1. BD BENCHMARK 10 YEAR DS GOVT. INDEX - CLEAN PRICE INDEX	0.01	0.34	-1.85	2.25	-0.21	1.92	-0.18	0.01	0.21
2. BG BENCHMARK 10 YEAR DS GOVT. INDEX - CLEAN PRICE INDEX	0.01	0.42	-17.46	2.35	-13.28	548.95	-0.17	0.01	0.21
3. ES BENCHMARK 10 YEAR DS GOVT. INDEX - CLEAN PRICE INDEX	0.00	0.77	-47.50	6.50	-42.02	2588.95	-0.21	0.01	0.23
4. FR BENCHMARK 10 YEAR DS GOVT. INDEX - CLEAN PRICE INDEX	0.02	0.73	-2.02	48.06	50.85	3324.97	-0.18	0.01	0.21
5. GR BENCHMARK 10 YEAR DS GOVT. INDEX - CLEAN PRICE INDEX	0.04	3.09	-29.19	198.54	48.76	3127.92	-0.27	0.00	0.27
6. IR BENCHMARK 10 YEAR DS GOVT. INDEX - CLEAN PRICE INDEX	0.02	1.02	-5.09	66.60	51.17	3349.00	-0.17	0.01	0.20
7. IT BENCHMARK 10 YEAR DS GOVT. INDEX - CLEAN PRICE INDEX	0.03	1.77	-3.69	126.63	66.80	4781.20	-0.21	0.01	0.23
8. UK BENCHMARK 10 YEAR DS GOVT. INDEX - CLEAN PRICE INDEX	0.04	2.42	-1.91	176.85	71.33	5218.94	-0.21	0.00	0.23
9. EMU BENCHMARK 10 YR. DS GOVT. INDEX - CLEAN PRICE INDEX	0.04	2.50	-1.85	183.81	72.07	5290.71	-0.18	0.01	0.21
10. IBOXX EURO CORPORATES - Cln Prc Indx Today	0.02	1.20	-1.08	88.42	71.81	5265.43	-0.09	0.00	0.10
11. IBOXX EURO OVERALL - Cln Prc Indx Today	0.02	1.12	-1.04	81.50	70.73	5160.70	-0.10	0.01	0.11
12. IBOXX EURO EUROZONE - Cln Prc Indx Today	0.02	1.13	-1.23	82.16	69.61	5051.92	-0.12	0.00	0.13
13. ICE BofA AAA Euro Corporate Index - Clean price	0.00	0.22	-5.17	3.32	-3.44	87.43	-0.10	0.00	0.11
14. ICE BofA BBB Euro Corporate Index - Clean price	0.00	0.18	-2.86	1.72	-0.51	21.24	-0.08	0.00	0.09
15. ICE BofA 1-3 Year BBB Euro Corporate Index - Clean price	0.00	0.13	-2.17	2.63	1.02	95.14	-0.03	0.00	0.03
16. ICE BofA 1-10 Year AAA Euro Corporate Index - Clean price	0.00	0.19	-4.09	4.33	0.07	134.53	-0.07	0.00	0.08
17. FTSE100PRICEINDEX	0.00	1.14	-9.27	9.38	-0.17	6.51	-0.52	0.00	0.57
18. FRANCECAC40PRICEINDEX	0.01	1.38	-9.47	10.59	-0.06	5.36	-0.64	0.01	0.70
19. IBEX35PRICEINDEX	0.00	1.41	-13.19	13.48	-0.10	6.45	-0.69	0.02	0.70
20. FTSEMIBINDEXPRICEINDEX	-0.01	1.47	-13.33	10.87	-0.22	5.31	-0.70	0.01	0.72
21. BEL20PRICEINDEX	0.00	1.20	-8.32	9.33	-0.03	6.31	-0.55	0.01	0.60
22. ISEQALLSHAREINDEXPRICEINDEX	0.01	1.31	-13.96	9.73	-0.64	8.77	-0.58	0.02	0.65
23. AEXINDEXAEXPRICEINDEX	0.00	1.36	-9.59	10.03	-0.14	6.98	-0.59	0.03	0.64
24. ATHEXCOMPOSITEPRICEINDEX	-0.02	1.82	-17.71	13.43	-0.32	6.67	-0.84	0.00	0.84
25. STOXXEUROPE600EPRICEINDEX	0.01	1.17	-7.93	9.41	-0.20	5.71	-0.53	0.03	0.58
26. EUROSTOXX50PRICEINDEX	0.00	1.40	-9.01	10.44	-0.08	4.98	-0.64	0.01	0.68
27. STOXXEUROPELARGE200PRICEINDEX	0.00	1.20	-8.18	9.82	-0.15	5.84	-0.55	0.03	0.58
28. STOXXEUROPESMALL200PRICEINDEX	0.02	1.09	-8.03	7.07	-0.48	5.04	-0.47	0.07	0.57
29. STOXXEUROPEMID200PRICEINDEX	0.02	1.11	-8.40	7.85	-0.42	5.35	-0.49	0.07	0.58
30. STOXXEUROPE600BASICMATSEPRICEINDEX	0.02	1.53	-12.42	13.29	-0.16	7.58	-0.69	0.03	0.78
31. STOXXEUROPE600INDUSTRIALSEPRICEINDEX	0.02	1.28	-9.61	9.98	-0.21	5.95	-0.57	0.04	0.68
32. STOXXEUROPE600TECHNOLOGYEPRICEINDEX	0.01	1.86	-12.22	10.76	-0.09	4.03	-0.83	0.06	0.90
33. STOXXEUROPE600UTILITIESEPRICEINDEX	0.00	1.13	-8.69	14.86	-0.03	11.68	-0.53	0.01	0.60
34. STOXXEUROPE600FINANCIALSEPRICEINDEX	-0.01	1.55	-13.59	14.67	-0.03	8.67	-0.68	0.00	0.68
35. STOXXEUROPE600HEALTHCAREEPRICEINDEX	0.02	1.07	-6.82	8.60	-0.09	4.82	-0.52	0.02	0.56
36. STOXXEUROPE600TELECOMEPRICEINDEX	-0.01	1.45	-9.44	9.66	0.05	4.12	-0.71	0.00	0.68
37. EUROSTOXXFINANCIALSVSEPRICEINDEX	0.01	1.40	-10.39	12.25	-0.22	6.66	-0.59	0.04	0.67
38. EUROSTOXXFINANCIALSEPRICEINDEX	-0.01	1.67	-14.71	15.36	0.00	7.62	-0.74	0.00	0.75
39. EUROSTOXXHEALTHCAREEPRICEINDEX	0.01	1.30	-8.71	9.67	-0.08	3.68	-0.66	0.02	0.71
40. EUROSTOXXINDSGDSSVSEPRICEINDEX	0.02	1.39	-10.36	11.58	-0.17	5.88	-0.66	0.02	0.74
41. EUROSTOXXINDUSTRIALSEPRICEINDEX	0.02	1.36	-10.47	11.05	-0.16	6.39	-0.62	0.03	0.71
42. EUROSTOXXTECHNOLOGYEPRICEINDEX	0.01	1.87	-14.02	11.22	-0.09	4.19	-0.84	0.03	0.91
43. EUROSTOXXTELECOMEPRICEINDEX	-0.01	1.49	-9.97	10.47	0.06	4.18	-0.72	0.00	0.69
44. USTOEURORFVEXCHANGERATE	0.00	0.61	-2.78	3.73	0.06	1.71	-0.35	0.00	0.33
45. SWISSFRANCTOEUROWMREXCHANGERATE	-0.01	0.41	-13.13	7.92	-5.20	241.71	-0.14	0.00	0.13
46. GBPTOEURBOEEXCHANGERATE	0.00	0.51	-2.93	6.22	0.46	6.51	-0.27	0.00	0.27
47. JAPANESEYENTOEUROWMREXCHANGERATE	0.00	0.73	-6.79	4.84	-0.30	5.37	-0.38	0.02	0.38

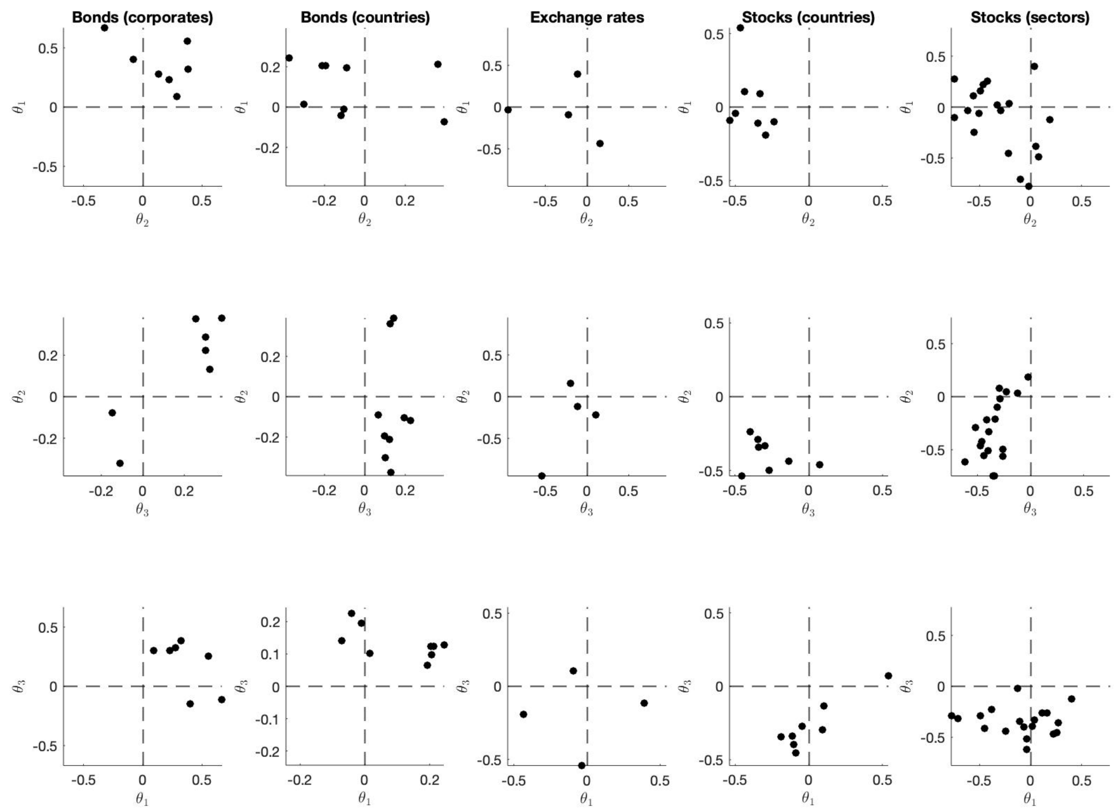

Figure A1: Pairwise scatter plots of θ estimates by asset group.

Notes: Columns correspond to asset groups: bonds (corporates), bonds (countries), exchange rates, stocks (countries), stocks (sectors). Rows show the three pairwise combinations of coefficients: top (θ_1, θ_2), middle (θ_1, θ_3), bottom (θ_2, θ_3). Axes are centered at zero to highlight the sign of responses. This figure complements the main figure (see Figure 5) in Section 4.2 by visualizing joint patterns across components.