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Monetary Policy and Asset Mispricing

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Monetary Policy and Asset Mispricing

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Abstract

This paper investigates whether conventional interest rate policy of central banks is a suitable instrument to attenuate excessive mispricing in stocks as suggested by the proponents of a "leaning against the wind" (LATW) monetary policy. For this, we decompose the stock price into a fundamental, a risk premium and a mispricing component. We argue that mispricing can arise for two reasons: (i) from false subjective expectations of investors about future fundamentals and equity premia, and (ii) from the inherent indeterminacy in asset pricing in line with rational bubbles. Employing a partial equilibrium asset pricing model, we show that the response of the excessive stock price component to a monetary policy shock is ambiguous in both the short- and long-run, and depends on the nature of the mispricing. Subsequently, we evaluate the scope for a LATW policy empirically by employing a time-varying parameter VAR with a flexible identification scheme based on impact and long-run restrictions using data for the S&P500 index from 1962Q1 to 2014Q4. We find that a contractionary monetary policy shock in fact lowers stock prices beyond what is implied by the response of their underlying fundamentals.

Keywords: Asset pricing, bubbles, equity pricing, financial stability, leaning against the wind, mispricing, monetary policy, time-varying parameter VAR, zero and sign restrictions.

JEL Classification: E44, E52, G12, G14

1 Introduction

The appropriate response of central banks to excessive asset price developments is subject of intense debate. While some researchers and most policy makers advance the conventional view that monetary policy should focus solely on price and output stabilization (Bernanke & Gertler, 1999; Posen, 2006), others call for a more active, "leaning against the wind" (LATW) monetary policy (Borio & Lowe, 2002; Cecchetti et al., 2002). This policy prescribes that central banks should monitor asset prices closely for the presence of bubbles, defined as periods when asset prices deviate excessively from their fundamentally justified value. If a bubble is detected, policy makers should, henceforth, raise interest rates to attenuate excessive asset mispricing and contain risks for financial and macroeconomic stability.

For an asset price targeting monetary policy to be feasible, however, two key requirements need to be fulfilled. First, a monetary policy tightening must lower the mispricing component in asset prices. Second, this response needs to be sufficiently large such that a monetary intervention is not too costly in terms of inflation or output depression.[1] The LATW policy prescription builds on the conventional view that an increase in interest rates reduces the size of an asset price bubble. Yet, this paradigm has been challenged by Galí (2014), who argues that the mispricing component in asset prices must grow in expectation at the rate of interest according to the theory on rational asset price bubbles. Raising the policy rate to combat an emerging asset price bubble would therefore carry adverse effects and exacerbate mispricing. This finding receives empirical support by Galí & Gambetti (2015), who find that speculation and hence stock prices increase following a monetary policy tightening.

In this paper, we challenge the theoretical predictions and empirical findings by Galí (2014) and Galí & Gambetti (2015) along the following dimensions. First, we extend the theoretical analysis beyond the concept of rational bubbles to a more general notion of asset mispricing following Brunnermeier & Julliard (2008). More specifically, in our model asset mispricing might occur (i) due to a violation of the transversality condition (TVC) under subjective expectations, and/or (ii) due to false subjective expectations of irrational investors about future dividends and equity premia. In this framework, the ultimate effect of a monetary policy shock on excessive stock prices is ambiguous both in the short- and the long-run and depends on the nature of the mispricing component. Only if the mispricing is restrictively assumed to take the form of a rational bubble, one can remove this ambiguity to obtain long-run bubble growth following a contractionary policy shock. In the more general framework, this conclusion does not hold.

Second, our theoretical framework suggests the presence of a time-varying required equity risk premium as a key determinant of stock prices. When this premium is ignored

[1] Furthermore, it is required that asset price bubbles can be detected in real-time. Promising real-time indicators have been proposed by Phillips et al. (2011, 2013).

as in Galí & Gambetti (2015), any deviation from the fundamental stock price would be incorrectly attributed to mispricing. Thus, to obtain an unbiased estimate of the excessive stock price component a measure for the expected equity premium is required (Cochrane, 2011). We obtain such a measure as forecasts from a stock pricing VAR model similar to Campbell (1991). We then empirically disentangle the stock price response to monetary policy shocks into its three economic sources: the responses of the fundamental component, of the equity premium, and of the mispricing component. By this, we also extend the analysis of Bernanke & Kuttner (2005) on the response of the expected equity premium to monetary policy shocks. In contrast to their results, we find a smaller response of this premium.

Third, we challenge the empirical findings of Galí & Gambetti (2015) by employing a less restrictive strategy to identify monetary policy shocks in the data. The authors employ a recursive identification scheme building on the assumption that monetary policy shocks influence stock prices instantaneously but that the central bank does not react within the quarter to idiosyncratic stock price movements. Only under this scheme they find that mispricing component in stock prices increases following a contractionary monetary policy shock. However, the assumption that the U.S. Fed does not respond contemporaneously to stock price surprises (or fundamental news shocks captured by stock price movements) is disputable. Empirical evidence indicates that the Fed reacts pro-actively to stock price innovations, at least in some periods (Rigobon & Sack, 2003; Bjørnland & Leitemo, 2009; and Furlanetto, 2011). Such a policy would also be in line with theoretical considerations outlined in Bernanke & Gertler (1999), who argue that a central bank dedicated to inflation and output stabilization should respond to asset price changes if it perceives those to be permanent and influential for inflation and output in the long-run.

We employ a less restrictive identification scheme that allows for two-way contemporaneous responses of both stock prices and the policy rate. We implement this by imposing both zero impact and long-run restrictions following Bjørnland & Leitemo (2009) and by combining those with additional sign restrictions following Arias et al. (2014) and Binning (2013). Similar to Galí & Gambetti (2015), we evaluate the response of the mispricing component in asset prices to monetary policy shocks in a time-varying parameter (TVP) VAR following Primiceri (2005). A TVP-VAR has the advantage that we can take into account that the size and direction of stock price responses to monetary policy shocks might not be constant over time but depends on the relative size of the mispricing component. Moreover, we evaluate whether a LATW monetary policy will be too costly in terms of inflation and output depression by setting the response of the mispricing component to a contractionary monetary policy shock in relation to the response of output and the inflation.

Our results suggest that a monetary policy tightening lowers stock prices significantly. However, only half of the impact response in stock prices can be attributed to future changes

in dividends, the discount factor and the expected equity premium. Hence, we conclude that the other half of the reduction in stock prices results from a decline in the mispricing component. By this, we provide tentative support to the arguments of the proponents of an active LATW monetary policy that a contractionary monetary policy helps combating excessive asset price growth.[2] However, it is important to emphasize that this comes at the cost of mild recession for about two years and persistently lower inflation. Finally, our flexible identification scheme allows shedding light on the question, whether monetary policy reacts contemporaneously to unexpected stock price movements. Here, we find a positive response of monetary policy to stock price shocks, which contradicts the identifying assumption of Galí & Gambetti (2015).

The paper is structured as follows. Section 2 formally lays out a partial equilibrium asset pricing model that disentangles stock prices into a fundamental component, the expected risk premium, and a mispricing component. Subsequently, it discusses how and through which channels monetary policy affects these different stock price determinants. Section 3 then outlines the TVP-VAR model and our identification strategy employed in our empirical analysis. Section 4 describes the data and our measure of the expected equity risk premium. Section 5 presents our results. Finally, Section 6 concludes.

2 A Partial Equilibrium Asset Pricing Model

We derive a simple partial equilibrium asset pricing model to evaluate the impact of a monetary policy shock on stock prices and their components. Our model differs from Galí (2014) and Galí & Gambetti (2015) in two ways: First, we relax the assumption that the expected stock price return (the discount factor) equals the risk free return. Instead we allow for the presence of (time-varying) expected equity risk premia. Second, we generalize their concept of the mispricing component potentially present in stock prices. The authors discuss theoretical predictions for the response of this mispricing component to monetary policy shocks under the assumption that it takes the form of a rational bubble when all investors are fully rational. We abstract from this narrow definition by following the argumentation of Campbell & Vuolteenaho (2004) and Brunnermeier & Julliard (2008) that stock mispricing may also occur due to false subjective believes of irrational investors on future fundamentals and risk premia.

We begin with the standard asset pricing equation. Let P_t and D_t be the stock's market price and dividend at the end of period t or accrued over period t, respectively. The gross

[2]This finding is, of course, subject to the Lucas' critique (Lucas, 1976).

return on the stock between date t and $t+1$ is then given by:

$$R_{t+1} = \frac{P_{t+1} + D_{t+1}}{P_t} - 1 \tag{1}$$

One can show that the stock price is a function of future dividends D_{t+i}, the required stock return R_{t+i}, and a terminal value:

$$P_t = \sum_{i=1}^{\infty} \left(\prod_{j=1}^{i} \frac{1}{1+R_{t+j}} \right) D_{t+i} + \lim_{T\to\infty} \left(\prod_{j=1}^{T} \frac{1}{1+R_{t+j}} \right) P_{t+T}. \tag{2}$$

Equivalently, in log-linear form (less a constant) the stock price is then described by:[3]

$$p_t = \sum_{i=1}^{\infty} \rho^{i-1} \left[(1-\rho) d_{t+i} - r_{t+i} \right] + \lim_{T\to\infty} \left(\rho^T p_{t+T} \right), \tag{3}$$

where logs of variables are denoted by lowercase letters, $r_{t+1} = \log(1 + R_{t+1})$ and ρ is a parameter of the linearization defined as $\rho \equiv 1/\left(1 + \exp(\overline{d-p})\right)$, where $\left(\overline{d-p}\right)$ is the average log dividend-price ratio (such that $0 < \rho < 1$).[4]

We introduce an equity premium to the pricing equation by deducting the real risk free rate, r_t^f, measured by the real return on the long term government bond, from both dividends and the required stock return. Hence, we rewrite (3) in terms of excess dividends, $d_t^e = (1-\rho)d_t - r_t^f$, and excess returns (the equity premium) on stock markets, $r_t^e = r_t - r_t^f$, as:

$$p_t = \sum_{i=1}^{\infty} \rho^{i-1} d_{t+i}^e - \sum_{i=1}^{\infty} \rho^{i-1} r_{t+i}^e + \lim_{T\to\infty} \left(\rho^T p_{t+T} \right) \tag{4}$$

Thus, the stock price can be interpreted as the sum of three components: a fundamental component, $p_t^F = \sum_{i=1}^{\infty} \rho^{i-1} d_{t+i}^e$, measured by the discounted value of future excess dividends, an equity premium, $ep_t = \sum_{i=1}^{\infty} \rho^{i-1} r_{t+i}^e$, measured by the discounted value of future excess stock returns, and a terminal value, $tv_t = \lim_{T\to\infty} \left(\rho^T p_{t+T} \right)$.

2.1 Expectations and asset (mis)pricing

Following equation (4), today's stock price depends on future, unobservable realizations of fundamental variables and the stock price itself. Therefore, agents' expectations about the future will determine the current stock price. Following Campbell & Vuolteenaho (2004) and

[3] A derivation of equation (3) is shown in Appendix A.

[4] When the dividend-price ratio is constant, then $\rho = 1/(1 + D/P)$. Campbell et al. (1996) shows with U.S. data that the average dividend-price ratio has been about 4% annually, implying $\rho \approx 0.96$.

Brunnermeier & Julliard (2008), we allow for the possibility that some investors are irrational, and hold subjective expectations at time t denoted by $\tilde{E}_t$ about future realizations of d_t^e and r_t^e. These expectations obtained under a subjective probability measure may deviate from objective expectations E_t which are consistent with the rational processing of objective data.[5] Both expectations nonetheless condition on the same information set available at time t, as indicated by the subscript on E and $\tilde{E}$. Hence, taking objective and subjective expectations of (4) yields

$$p_t = E_t\left[\sum_{i=1}^{\infty}\rho^{i-1}d_{t+i}^e\right] - E_t\left[\sum_{i=1}^{\infty}\rho^{i-1}r_{t+i}^e\right] + E_t\left[\lim_{T\to\infty}\left(\rho^T p_{t+T}\right)\right] \tag{5}$$

$$= \tilde{E}_t\left[\sum_{i=1}^{\infty}\rho^{i-1}d_{t+i}^e\right] - \tilde{E}_t\left[\sum_{i=1}^{\infty}\rho^{i-1}r_{t+i}^e\right] + \tilde{E}_t\left[\lim_{T\to\infty}\left(\rho^T p_{t+T}\right)\right], \tag{6}$$

respectively. Since both rational and irrational investors are indifferent to marginal changes to their investment, the equality of equations (5) and (6) holds and the current observed stock price is equal to their expected future dividends and equity premia. However, the path of expected future dividends and equity premia might differ between both types of investors. That means, for example, that irrational investors who require a high risk premium, $\tilde{E}_t\left[r_{t+i}^e\right]$, also expect to receive larger excess dividends in the future, $\tilde{E}_t\left[d_{t+i}^e\right]$. Yet, when irrational investors are present, the observed price p_t may deviate from its true fundamental value. This is correctly observed by rational investors who, on average, form correct expectations about future fundamentals $E_t\left[d_{t+i}^e\right]$ and therefore adjust their required future equity risk premium $E_t\left[r_{t+i}^e\right]$ such that their stock holdings are in equilibrium. This change in $E_t\left[r_{t+i}^e\right]$ then ensures that (5) and (6) hold at the observed price level (Brunnermeier & Julliard, 2008).

By adding and subtracting $\left(E_t\left[\sum_{i=1}^{\infty}\rho^{i-1}d_{t+i}^e\right] - E_t\left[\sum_{i=1}^{\infty}\rho^{i-1}r_{t+i}^e\right]\right)$ from (6), we observe that the stock price p_t can be written as the sum of three components: a fundamental component, p_t^F, measured by the discounted value of expected future excess dividends, an equity premium, ep_t, measured by the discounted value of expected future excess stock returns, and a mispricing component, ψ_t:

$$p_t = \underbrace{E_t\left[\sum_{i=1}^{\infty}\rho^{i-1}d_{t+i}^e\right]}_{p_t^F} - \underbrace{E_t\left[\sum_{i=1}^{\infty}\rho^{i-1}r_{t+i}^e\right]}_{ep_t} + \psi_t, \tag{7}$$

[5] For a further elaboration on these concepts, see Manski (2004) and Brunnermeier & Parker (2005).

where ψ_t is defined as:

$$\psi_t = (\tilde{E}_t - E_t)\left[\sum_{i=1}^{\infty} \rho^{i-1} d^e_{t+i}\right] - (\tilde{E}_t - E_t)\left[\sum_{i=1}^{\infty} \rho^{i-1} r^e_{t+i}\right] + \tilde{E}_t\left[\lim_{T\to\infty}\left(\rho^T p_{t+T}\right)\right]. \tag{8}$$

Thus, the observed stock price p_t deviates from its objectively justified fundamental value, when (i) irrational investors are present, whose subjective expectations deviate from objective expectations of rational investors, or (ii) the transversality condition (TVC) under the subjective measure does not hold, i.e. $\tilde{E}_t\left[\lim_{T\to\infty}\left(\rho^T p_{t+T}\right)\right] \neq 0$. If one assumes, however, that all agents form expectations under the objective probability measure, which excludes the presence of irrational investors with subjective expectations from the model, mispricing would be represented as a violation of the TVC under objective expectations, i.e. $\psi_t = E_t\left[\lim_{T\to\infty}\left(\rho^T p_{t+T}\right)\right]$. This can be seen by subtracting (6) from (5). Thus, only if all investors are of the rational type and ψ_t is non-zero, mispricing occurs due to the existence of a rational bubble and investors are fully aware of it.[6] Without these restrictive assumptions, however, mispricing can result from false subjective expectations of investors. This is in line with Adam et al. (2015), who also show that subjective belief dynamics can temporarily delink stock prices from their fundamental value and give rise to asset price booms. For a further extensive survey on the literature relating speculative behavior to irrational and behavioral factors, see Scherbina (2013). As such, the concept presented here is less restrictive than the one described by Galí (2014) and Galí & Gambetti (2015), who explain mispricing entirely with the occurrence of a rational bubble.

2.2 Effects of monetary policy on stock prices

In this section, we assess the expected effect of a contractionary monetary policy shock on the identified stock price components from theoretical and empirical evidence.

Economic theory unambiguously points to a decrease of the fundamental component of stock prices in response to a contractionary monetary policy shock for two reasons: First, a monetary tightening decreases future economic growth, and by this also firms' profits and future dividend pay-outs. Moreover, since inflation is likely to decrease following the contractionary policy shock and nominal interest rates rise, real risk-free rates and hence the discount factor also rise (Bernanke & Kuttner, 2005). As a result, the expected sum of discounted future excess dividends is predicted to fall in response to a contractionary

[6] This can be explained for example in the context of overlapping generations models (see the survey of Stiglitz (1990) for a larger discussion), or in the context of intrinsic bubbles as introduced by Froot & Obstfeld (1991).

monetary policy shock:

$$\frac{\partial p^F_{t+k}}{\partial \varepsilon^m_t} = \left[\sum_{i=1}^{\infty} \rho^{i-1} \frac{\partial E_t(d^e_{t+k+i})}{\partial \varepsilon^m_t} \right] < 0 \tag{9}$$

The second channel through which a monetary policy shock propagates to stock prices is through its effects on the expected equity risk premium, which measures the additional return that investors demand for holding risky equity instead of alternative safe investments such as government bonds of long-maturity. The expected equity premium is likely to rise following an exogenous monetary tightening for two reasons. First, there is evidence for a non-linear financial accelerator mechanism of monetary policy via balance sheet effects of firms and banks, which implies that a monetary tightening is associated with higher borrowing costs and reduced loan supply. This in effect raises the risk of lower future firm profits. Importantly, due to the non-linearity in the mechanism, this increase in risk is expected to be larger during times of already tight monetary policy when loan supply is already low and firms' financial health is poor (Patelis, 1997). Second, as outlined by Gust & López-Salido (2009), a contractionary monetary policy shock may not only lower future consumption of households but also increases consumption volatility, which would result in a higher equity risk premium required by investors today. Hence, an exogenous monetary tightening is predicted to raise the equity premium that investors require to be compensated for the increase in risk, i.e.

$$\frac{\partial ep_{t+k}}{\partial \varepsilon^m_t} = \left[\sum_{i=1}^{\infty} \rho^{i-1} \frac{\partial E_t(r^e_{t+k+i})}{\partial \varepsilon^m_t} \right] > 0. \tag{10}$$

Since the expected equity risk premium enters the stock pricing equation negatively, this lowers the current stock price further. Therefore, in absence of a mispricing component, a contractionary monetary policy shock would induce an immediate fall in stock prices through both the fundamental and the risk channel.

In contrast to the consensus about monetary policy effects on the fundamental and risk components in stock prices, the response of the mispricing component ψ_t is open to debate. The conventional view of proponents of a LATW policy builds on the notion that (excessive) stock prices typically fall in response to a contractionary monetary policy shock. In a similar vein, a monetary loosening should therefore propagate stock overpricing. This claim has found empirical support by e.g. Borio & Lowe (2002), who argue that accommodative monetary policy may, in a low-inflationary environment, stimulate asset price bubbles. Similarly, Bordo & Landon-Lane (2013) find that several measures of loose monetary policy can be consistently related to periods that are demarcated as asset price booms, even when control-

ling for other explanatory variables such as credit and current account imbalances. However, these papers are silent about whether the observed asset price boom is driven by fundamental and risk factors or by mispricing, which does not allow to draw any conclusion on the justification for a LATW monetary policy. Nonetheless, the findings by Adam et al. (2015) also suggest that a contractionary monetary policy shock may help to attenuate excessive stock price behavior. The authors find that about two thirds of the fluctuations in U.S. stock prices are not due to fundamental factors, but result from self-reinforcing beliefs in the sense that agents become more optimistic (pessimistic) about future capital gains whenever they are positively (negatively) surprised by past capital gains. A positive (negative) surprise for the capital gains observed in the previous period then increases (decreases) optimism about the capital gains associated with investing in the asset today and leads to periods of asset price booms (busts). Thus, this result indicates that an unexpected decrease in capital gains in response to a contractionary monetary policy shock would lead to a downward correction of the excessive stock price component.

The view that contractionary monetary policy helps to reduce excessive stock prices, has been, however, questioned by Galí (2014). If all investors are fully rational and form objective expectations about the future, mispricing may only occur in the form of a rational bubble. In this case, the bubble component must grow at the required rate of return on stocks in expectation. Thus, since both the risk-free interest rate and the expected equity premium are predicted to increase in response to a contractionary policy shock, an increase in the policy rate will also raise the expected long-run growth rate of the bubble component.[7] However, Galí (2014) disregards that mispricing may also occur from behavioral factors as suggested by equation (8).

Thus, the impact of monetary policy shocks on the stock mispricing component seems to depend on how investors form their expectations and is therefore not only indeterminate on impact but also in the long run, i.e.:

$$\frac{\partial \psi_{t+k}}{\partial \varepsilon_t^m} = \left[\sum_{i=1}^{k} \rho^{i-1}(\tilde{E}_t - E_t)\frac{\partial d_{t+i}^e}{\partial \varepsilon_t^m}\right] - \left[\sum_{i=1}^{k} \rho^{i-1}(\tilde{E}_t - E_t)\frac{\partial r_{t+i}^e}{\partial \varepsilon_t^m}\right] + \tilde{E}_t\left[\frac{\partial \rho^T p_{t+k}}{\partial \varepsilon_t^m}\right] = ? \tag{11}$$

To summarize, the responses of the fundamental component and of the equity risk premium to a contractionary monetary policy shock unambiguously predict an immediate fall in the stock price. However, monetary policy may affect stock prices also via a response of the mispricing component. The direction of change induced through this channel is ambiguous though. As a result, the total response of the stock price to a monetary policy shock

[7] This holds, however, only in expectation for the each period *after* the policy shock. On impact, the response of a rational bubble component is, in fact, indeterminate. See Galí (2014) for a discussion of this issue.

ultimately depends on the nature and the importance of the mispricing component relative to the stock's fundamentals. Therefore, we need to opt for a flexible modelling strategy in our empirical analysis to allow for time-variation in the link between monetary policy and the components of stock prices.

3 Empirical model and identification

This section describes the empirical model that we employ to evaluate to what degree the response of stock prices to exogenous monetary policy shocks can be attributed to fundamental factors and changes in the expected risk premium, and how much may be due to stock mispricing. By simple accounting, the response of the mispricing component can be obtained by deducting implied path of the response of the fundamental component and the expected equity premium from the observed total response of asset prices following (7) similar to Galí & Gambetti (2015).

We identify monetary policy shocks in a standard monetary VAR model augmented by stock prices, excess dividends and the expected equity premium. We will rely on evidence from a constant parameter VAR and a time-varying parameter (TVP) VAR. The motivation for the latter is threefold. First, time-variation in the response of stock prices to monetary policy shocks may occur when the reaction of the individual price components differ in size or sign and their relative weights in the total stock price change over time. Second, as outlined in the previous section, we also suspect non-linearities in the relationship between measures for the business cycle, the policy rate and our measure for the expected equity risk premium following the discussion in Patelis (1997) and Gust & López-Salido (2009). Third, the TVP-VAR has the general advantage that it allows to account for structural breaks and smooth structural change in the model parameters. Since the constant parameter VAR is a limiting case of the TVP-VAR as described below, we will only outline the specifications of the TVP-VAR.

3.1 Time-varying parameter VAR

Our reduced form TVP-VAR follows closely that in Primiceri (2005) and Galí & Gambetti (2015). First, the dynamic relations between the variables are described by the measurement equation:

$$Y_t = \Theta_{0,t} + \Theta_{1,t} Y_{t-1} + \cdots + \Theta_{p,t} Y_{t-p} + u_t \tag{12}$$

where Y_t is the $K \times 1$ vector of endogenous variables. The variables included in the VAR are the following. First, we include a measure of output growth y_t, inflation π_t and the

policy variable i_t (federal funds rate) as motivated by the standard class of New-Keynesian models used to identify monetary policy shocks.[8] Following our partial equilibrium asset pricing model, the VAR is then augmented by the growth rate in real stock prices p_t, the excess dividend series d_t^e and a measure of the expected equity risk premium r_t^e.[9] We specify the model with $p = 3$ lags of endogenous variables.[10] The reduced-form residuals u_t are assumed to be independently and normally distributed with variance-covariance matrix H_t, i.e. $u_t \sim N(0, H_t)$. The time-varying parameters in $\Theta_{i,p}, i = 0, 1, \ldots, p$, evolve according to a drift-less random walk. This is given by the state equation on the joint $m \times 1$ ($m = K(Kp+1)$) vector $\theta_t = vec([\Theta_{0,t}, \Theta_{1,t}, \ldots, \Theta_{p,t}])$:

$$\theta_t = \theta_{t-1} + \eta_t. \tag{13}$$

Here, $\eta_t \sim N(0, Q)$ is a random vector, independent of u_t for all periods t and s.

As specified in the distribution of u_t, the model allows for heteroscedasticity of the reduced-form residuals. To model changes in volatility, a triangular decomposition of the covariance matrix H_t of u_t is used, given by:

$$H_t = A_t^{-1} \Sigma_t \Sigma_t' (A_t^{-1})', \tag{14}$$

where Σ_t is a diagonal matrix with elements $\sigma_{i,t}$ for $i = 1, \ldots, K$ and A_t is lower triangular with diagonal elements equal to one. Similarly to (13), the dynamics of covariances are governed by:

$$\alpha_t = \alpha_{t-1} + \omega_t, \tag{15}$$

where $\alpha_t = [a_{21,t}, \ldots, a_{K(K-1),t}]'$ captures the non-zero and non-unity elements of A_t and $\omega_t \sim N(0, W)$, with W being block-diagonal.[11] Finally, the dynamics of Σ_t are modeled according to a stochastic volatility framework, such that:

$$ln(\sigma_{i,t}) = ln(\sigma_{i,t-1}) + \nu_{i,t}, \tag{16}$$

with the vector $\nu_t = [\nu_{1,t}, \ldots, \nu_{K,t}]'$ being distributed as $\nu_t \sim N(0, V)$ where V is diagonal. The TVP-VAR nests the VAR with constant coefficients if the variance matrices Q, V, and

[8] The responses of asset prices and the underlying fundamentals are robust with respect to including variables typically employed to capture expected inflation such as commodity prices and non-energy commodity prices. Therefore, these are excluded to reduce the computational burden.

[9] In the following, the variables are ordered as $Y_t = [y_t, \pi_t, d_t^e, r_t^e, i_t, p_t]'$.

[10] The findings are robust to varying lag lengths of $p = 4$ lags as employed by Galí & Gambetti (2015).

[11] Assuming block-diagonality implies that covariances across equations evolve independently from each other. This simplifies inference and drastically increases the efficiency of the estimation algorithm (Primiceri, 2005).

W shrink to zero. The choice of prior distributions is briefly specified in Appendix B and follows Galí & Gambetti (2015).

Finally, our core interest lies in the structural shocks ε_t. These underlying shocks govern the dynamics of the reduced form innovations u_t, which are henceforth assumed to be a linear transformation of ε_t given by $u_t = S_t\varepsilon_t$, where $E[\varepsilon_t] = 0$, $E[\varepsilon_t\varepsilon'_{t-j}] = 0$ for all t and $j \neq 0$ and $E[\varepsilon_t\varepsilon'_t] = I_K$.[12] Furthermore, S_t is such that $S_tS'_t = H_t$. We identify S_t as outlined in the next subsection. With the identified S_t, we then obtain *local approximations* of the implied dynamic impulse response functions to the period t structural shocks ε_t (Galí & Gambetti, 2015).

3.2 Identification via sign restrictions

One important conclusion that one can draw from Galí & Gambetti (2015) is that their estimation results do not seem to be robust to the underlying identifying assumptions. In specific, the authors obtain diametrically opposing results on the effect of monetary policy shocks on stock prices depending on whether they assume that the central bank reacts contemporaneously, i.e. within the quarter, (by a constant, calibrated coefficient) to stock price surprises or not at all (as in the recursive identification setting). This simultaneity problem in identifying monetary policy shocks in the presence of financial variables is commonly known in the literature (Bjørnland & Leitemo, 2009). Therefore, a less restrictive identification scheme is required. The natural solution to this problem is thus to employ sign restrictions on the impact responses (Fry & Pagan, 2011) and to impose as many additional restrictions on the data as we can defend from theory and exogenous empirical evidence (Kilian & Murphy, 2012). We thus allow for two-way contemporaneous responses of both asset prices and the policy rate, and achieve identification via long-run restrictions on the effects of monetary policy on real variables following Bjørnland & Leitemo (2009). By this we nest all calibrations of Galí & Gambetti (2015) and let the data speak whether monetary policy reacts instantaneously to a stock price shock or not. Recent work by Arias et al. (2014) and Binning (2013) allows us to combine sign restrictions with long-run restrictions.

Our identifying assumptions on the impact responses of the variables in the VAR to four identified shocks are summarized in Table 1. For a contractionary *monetary policy shock* (ε_t^m) we assume that output and inflation do not respond within the same quarter. This assumption has featured strongly in the literature on identifying monetary policy shocks and mirrors the restrictions implied in the Cholesky decomposition (cf. Christiano et al., 2005)

[12] All random vectors ε_t, η_t, ν_t and ω_t are assumed to be independent of one another. This restriction reduces the number of parameters that need to be estimated and allows a structural analysis of the shocks ε_t which would be precluded if block elements in the covariance matrix of the vector $[\varepsilon_t, \eta_t, \nu_t, \omega_t]'$ were non-zero (Primiceri, 2005).

Table 1: Identifying restrictions

	Shock			
Variable	ε_t^d	ε_t^s	ε_t^m	ε_t^p
y_t	+	−	0	0
π_t	+	+	0	0
d_t^e	?	?	−	?
r_t^e	?	?	+	?
i_t	+	?	+	?
p_t	+	?	?	+

The table shows the restricted sign of the impact responses of the variables in the benchmark VAR to a monetary policy shock ε_t^m, a stock price shock ε_t^p, as well as to a demand (ε_t^d) and a supply (ε_t^s) shock. The monetary policy shock is further restricted not to affect the real variables y_t and p_t in the long-run. Entries denoted with by a "?" are left unconstrained.

which have been largely motivated by the perception that the transmission of monetary policy interventions to the real economy is only effective with a considerable lag (Friedman, 1968).[13] In contrast, all financial variables are allowed to respond immediately. The imposed signs are motivated by the theoretical predictions developed in section 2: Excess dividends decrease on impact due to the positive response of the risk-free bond rate while the expected equity premium increases. Stock prices are allowed to respond as well, yet the sign of the response is ambiguous, allowing for a positive response of the mispricing component.

Following Bjørnland & Leitemo (2009), we interpret a *stock price shock* (ε_t^p) either as a non-fundamental, idiosyncratic shock motivated by speculative behavior, or as news about future real economic fundamentals. Therefore, financial variables may respond immediately to the arrival of new fundamental information or simply due to portfolio re-balancing in view of higher realized capital gains. The sign of their responses is left unconstrained with the obvious exception of stock prices. Similar to the case of the monetary policy shock, we assume that a stock price shock has no immediate effect on the slow moving variables output and inflation. This identification, therefore, distinguishes idiosyncratic stock price shocks from general demand or supply shocks. This is at the heart of interest to the discussion how central banks should react to stock price shocks that are not immediately related to their primary targets of inflation and output, but may only affect those variables in the longer run. Yet, this leaves us with the simultaneity problem in distinguishing stock price and monetary policy shocks, as they are not uniquely identified so far. We solve this by imposing additional long-run restrictions on the monetary policy shock following Bjørnland & Leitemo (2009).

[13] As a robustness, we have relaxed the zero impact restrictions and replaced them with sign restrictions allowing the contractionary monetary policy shock (both conventional and unconventional) to lower both output and inflation on impact (Baumeister & Benati, 2013). The detected recession in this case is stronger, while the responses of stock prices and its components remain unaffected.

In specific, we assume that by the long-run neutrality of money, monetary policy does not have any permanent effect on the real variables output and stock prices.

Finally, we attempt to identify general aggregate *demand* (ε_t^d) and *supply shocks* (ε_t^s). Even though we are not primarily interested in those shocks, imposing as many restrictions as possible helps to close in on the shocks of interest (cf. Canova & Gambetti, 2009 and Kilian & Murphy, 2012). The imposed impact restrictions displayed in the table are standard and follow Baumeister & Benati (2013). Following the previous discussion on the nature of a stock price shock, a general demand or supply shock is hence characterized by immediate responses of output and inflation.

4 Data

Our analysis builds on sample information from 1962Q1 to 2014Q4. We do not exclude the financial crisis period but rely on our TVP model to account for possible structural breaks and smooth structural changes. The variables directly included in the VAR are real GDP, the GDP deflator (both in log-growth rates), the effective federal funds rate[14] and the growth rate of the real S&P500 index. We then augment this VAR by our measure for excess dividends, which is computed from real quarterly dividends less the quarterly real interest rate on 10-year U.S. government bonds. Stock prices and dividends are obtained from Shiller (2005).[15] All series are deflated by the U.S. Consumer Price Index for All Urban Consumers. Finally, the last variable included in the VAR is the expected excess return on stocks $E_t\left[r_{t+k}^e\right]$ (the expected equity risk premium). This variable is, however, not observable.

To obtain a proxy for the expected excess return on stocks, we therefore follow a broad literature initiated by Campbell (1991) and use an auxiliary VAR model to forecast the objective expectations of r_{t+k}^e at each margin t. The forecast $\hat{r}_{t+k}^e$ from the VAR can then be interpreted as the objective expectations $E_t\left[r_{t+k}^e\right]$ consistent with the rational processing of data in line with our model framework. The variables included in the auxiliary VAR are the *realized* quarterly excess equity return r_t^e, the log price-earnings ratio $p_t - e_t$, and the BAA-AAA corporate bond spread r_t^b.[16] The corporate bond spread serves as an exogenous measure for expected default risk in the economy, which is likely to be correlated with the expected equity risk premium (Campbell et al., 2013).[17] The lag length of the VAR is set

[14] These variables are obtained from Federal Reserve Economic Data (FRED) of the Federal Reserve Bank of St. Louis, available at `http://research.stlouisfed.org/fred2/`.

[15] Available at `http://www.econ.yale.edu/~shiller/data.htm`.

[16] Earnings e_t are the 10-year moving average of quarterly earnings from Shiller (2005).

[17] The forecasts are robust to additional variables frequently used in the literature such as the term spread (the difference between the 10-year U.S. treasury bond and the 3-month treasury bill yield (Campbell et al., 2010)) and a measure for expected market volatility (obtained from the quarterly variance of daily returns (Campbell et al., 2012)). The proxy for expected excess returns is smaller in magnitude around the global

to one in line with the literature and the forecasts are obtained from a VAR estimated on the full sample. Finally, the forecast horizon is set to ten years to relate expected excess equity returns to the yields on the long-maturity government bond. Forecasts are obtained sequentially for each quarter and are then cumulated.

Figure 1 shows the cumulated, ten-year forecasts of the expected excess equity returns over time. In line with evidence in Claus & Thomas (2001), we find an expected equity premium of around three percent, which fluctuates, however, quite substantially over time. We find an increase in the expected premium simultaneously to the rise in real interest rates during the Volcker-disinflation period until about 1984. Subsequently, the expected premium has decreased back to the level of the early 1960's during the Great Moderation. From 1995 onwards, the expected equity risk premium declined rapidly further, which is consistent with the sharp run-up in stock prices during the dot-com bubble. As soon as the bubble collapsed in the early 2000's, the expected premium jumped up again. In fact, the initial rise in the expected equity premium precedes the dot-com crash in 2000Q1. Finally, the expected equity premium spiked once more, but this time subsequently to the collapse of the housing bubble. The period shortly preceding and following the global financial crises may be peculiar though and largely driven by strong fluctuations in the price-earnings ratio. We have therefore run all following analyses also on a shorter sample up to 2007Q4 excluding the global financial crisis and find that our results are robust to the shorter sample period.

[Figure 1 about here.]

As a robustness check, we further compare our measure of the expected equity risk premium to two alternative proxies of expected default or equity risk commonly used in the literature. The first is the BAA-AAA spread, which measures the expected default risk premium in the corporate bond market and should therefore be correlated with expected risks on equity. The second measure is derived from the Gordon (1962) dividend discount model (DDM) which suggests to infer the implied required rate of return on stocks directly from the asset pricing equation (2) (Claus & Thomas, 2001). This model is, however, not consistent with our framework as it excludes the possibility of asset mispricing and assumes that the transversality condition holds at all times.[18] Therefore, we only employ it as a robustness

financial crisis when a measure of inflation is included in the VAR as suggested by Campbell & Vuolteenaho (2004).

[18] With a measure of the expectations about future real cash flows and under the additional assumption that the time t required return remains constant in the future, one can infer $E_t[R_{t+1}] = E_t[R_{t+2}] = \dots$ from (2). Along those lines, we obtain annual estimates of the DDM implied equity premium from Damodaran (2015). These estimates are then transformed to the quarterly frequency using the BAA-AAA default spread. In specific, we compute the ratio of the DDM equity premium and the annual average of the default spread. Assuming that this ratio remains constant over one year, the spread-adjusted DDM equity premium can then be obtained as the average quarterly BAA-AAA spread multiplied by that ratio.

check of our proxy of the expected equity premium, and presume a positive correlation between the two measures in case mispricing is only weak or restricted to some periods.

We find that our measure of the expected equity premium derived from the auxiliary VAR model is strongly correlated with both the BAA-AAA spread (correlation of 0.64) and the measure derived from the DDM (correlation of 0.49). Figure 2 plots the three (standardized) measures for expected risk premia. The figure shows that the trend in all proxies is similar, with rising expected premia until about 1985, a following downward trend, and a strong spike around the global financial crisis. However, the downward trend of the expected equity premium obtained from our auxiliary VAR is more pronounced during the dot-com bubble and the rise during the financial crisis is less strong compared to the other two measures. Also, our measure appears less erratic overall. The frequent sharp rises and falls in the DDM premium may reflect the fact that it is potentially distorted by the presence of stock mispricing. Since the DDM assumes that the transversality condition holds, any stock mispricing enters directly into the measure of the expected equity premium.

[Figure 2 about here.]

Given our measure for the expected equity premium and the observations for excess dividends and total stock prices, we can evaluate the implied mispricing component contained in the S&P500. For this, we first discount at each margin $t = 1, ..., T - h$ the next h realizations of excess dividends and our measure for the expected equity premium. From equation (7), we can then obtain $\psi_t = p_t - \left(E_t\left[\sum_{i=1}^{\infty} \rho^{i-1} d^e_{t+i}\right] - E_t\left[\sum_{i=1}^{\infty} \rho^{i-1} r^e_{t+i}\right]\right)$, where we approximate the infinite sum by the next $h = 20$ realizations.[19] The approximated mispricing component is displayed alongside the log real S&P500 and the implied risk-adjusted fundamental component (the sum of future discounted excess dividends less the sum of future discounted expected equity premia) in Figure 3.

[Figure 3 about here.]

Importantly, the level of mispricing is indeterminate due to the omitted constant in equation (7). Nonetheless, the figure allows to evaluate the evolution of the mispricing component relative to the dynamics of the log real S&P500 index. Thus, the figure reveals some time variation in the contributions of the risk-adjusted fundamental and the mispricing components to the overall stock price. Up to 1975, the size of the risk-adjusted fundamental component was relatively stable, such that most of the short-run dynamics of the stock price index can be attributed to a fluctuating mispricing component. Between 1975 and 1982, the

[19] The implied mispricing is robust to extending the approximation of the infinite sum to $h > 20$ observations.

risk-adjusted fundamental value of the S&P500 decreased along with the estimated increase in the expected equity risk premium. In this period, the dynamics of the mispricing component and the stock index diverge. From 1982, both the fundamental and the mispricing increase and explain the pronounced increase in the stock index. Yet, around 1986 – prior to the 1987 stock market crash – the trend growth in the S&P500 decouples from the relatively stable evolution of the fundamental component and is thus largely attributed to a strong increase in the mispricing component. This is particularly the case during the run-up to and the crash of the dot-com bubble in the second half of the 1990's and the early 2000's. Thus, our measure of the mispricing component matches well with anecdotal evidence of excessive stock price periods. We conclude from this that that we obtain a reasonable estimate for the expected equity premium from our auxiliary VAR forecasts.

In the following, we, however, refrain from using the estimated mispricing component directly in our VAR model and instead follow Galí & Gambetti (2015) and infer the response of the mispricing component to a monetary policy shock from the responses of the observed stock price index, excess dividends and the expected equity risk premium. However, our results show to be robust to including the estimated mispricing component in the VAR instead of the observed stock price index.

5 Results

We first present the estimated responses of the stock price and its components to a contractionary monetary policy shock in the framework of a constant coefficient VAR (C-VAR), which can be estimated more efficiently than the TVP-VAR. Later, we will move to TVP-VAR estimations and show that there is some evidence for time-variation in the response of stock prices and equity premia to monetary shocks. The TVP-VAR, however, supports the general findings from the C-VAR. The monetary policy shock is calibrated to raise the policy rate by 100 basis points (BPS). The individual stock price components are calculated as suggested by our stock price equation (7), where we approximate the infinite sum of discounted excess dividends and expected equity premia by the sum over the next 20 periods.

5.1 Evidence from a constant coefficient VAR

Figure 4 shows the cumulative impulse responses of the financial variables and the inferred responses of the individual stock price components. In specific, panel 1-3 show the responses of the variables that enter our VAR model, i.e. excess dividends, the proxy for the risk premium and the real S&P500 price index. In panel 4-6, we display the response of the individual stock price components. Thus, we look at the impulse responses of the fundamental component, measured as the sum of future discounted excess dividends, the fundamental

component adjusted for the sum of future discounted expected equity premium (labeled risk-adjusted fundamental component), and, finally, the mispricing component that is obtained by subtracting the response of the risk-adjusted fundamental component from the observed total response of stock prices.[20]

We find that excess dividends decrease on impact by about 0.2% and the equity risk premium increases by about five BPS. Both responses are persistent and significant for at least two years. Importantly, and in contrast to Galí & Gambetti (2015), we find a strong negative response of the real S&P500 index of about five percent on impact which is significant for about two years. This finding is robust to various specifications of the VAR and is also obtained when including the same set of variables in the model as Galí & Gambetti (2015). Hence, we argue that this can be attributed to the different identification frameworks, where ours is less restrictive. Our estimated immediate decrease in the S&P500 is only slightly smaller in absolute terms compared to the findings of Bjørnland & Leitemo (2009), who only apply long-run restrictions on the monetary shock on a shorter sample.

[Figure 4 about here.]

To assess which factors drive the negative response of the S&P500 index to a contractionary monetary policy shock, we evaluate the individual components of the stock prices in panels 4-6. Similarly to Galí & Gambetti (2015), we find that the fundamental component inferred from the response of excess dividends decreases significantly by almost two percent on impact. This decline is persistent and significant up to two years. This implies that the fundamental factor explains less than half of the immediate decrease in the S&P500. When we add the implied response of the risk premium we find that the explanatory content increases further and that the responses in excess dividends and the expected risk premium together account for slightly more than a two percent fall in stock prices (panel 5). Thus, this leaves about half of the observed five percent impact drop in the S&P500 index unexplained. From equation (7) this unexplained part can hence be attributed to the response of the mispricing component as displayed in the lower right panel. All in all, we therefore conclude that a contractionary monetary policy shock lowers stock prices over and beyond what is implied by fundamental factors. Hence a central bank could use such a policy to lean against the wind of stock price bubbles if it perceives stock prices to be excessively high.[21]

[20] For the median response, 100,000 candidate impact response matrices are checked and median-targeting was applied to obtain a unique model from the set of accepted models. 68% credible sets are obtained from a bootstrap with 1,000 repetitions. For each bootstrap repetition, 100 candidate impact response matrices were evaluated.

[21] It is important to note that our results are subject to the Lucas' critique. If monetary policy were to exploit these findings in a systematical manner, investors will take this into account, which may already reduce the frequency of excessive stock price periods.

We find our results to be robust to employing the BAA-AAA spread or the DDM implied equity return as alternative measures for expected excess returns. The results are displayed in Figures 5 and 6. We find a somewhat larger response compared to the VAR-forecast measure of eight BPS for the BAA-AAA spread and 15 BPS for the DDM-implied premium. However, the responses of all other variables are largely robust with the exception of the total response of the S&P500 when we use the BAA-AAA spread. In this case the stock price response is somewhat weaker at around four percent, and hence the explanatory power of the mispricing component is smaller and only significant at a few horizons.

[Figures 5 and 6 about here.]

Thus, our findings suggest that central banks *could* attenuate excessive stock developments by raising the policy rate. Yet, in order to assess whether central banks also *should* make use of such a LATW policy, we need to trade off the benefits of such a policy against its real economic costs. Figure 7 shows the cumulative responses of output and inflation to the exogenous 100 BPS increase in the policy rate (in the top panels). The figure reveals that a leaning against the wind policy lowers output significantly by up to 0.5% after one year. Thus, deflating excessively high stock prices through conventional interest rate policy puts considerable downward pressures on real economic activity. This obvious conflict between financial and output stability feeds into the debate whether monetary policy is too blunt an instrument to stabilize asset prices and if not other policy instruments, i.e. macroprudential policies, are more suitable.[22]

[Figure 7 about here.]

Finally, we also address the question how the U.S. Fed has responded to stock price surprises which is the key identifying assumption in Galí & Gambetti (2015). These results are presented in Figure 8. Letting the data speak on the response of the central bank to exogenous stock price shocks that raise the S&P500 by one percent, we find a positive and significant response of the federal funds rate within the same quarter by about twelve BPS which is with line to the findings of e.g. Rigobon & Sack (2003) who find an impact reaction of about 20 BPS. Output and inflation, however, do not respond significantly to the stock price shock.

[Figure 8 about here.]

[22] For a concluding statement on the cost-benefits-analysis of such a policy, one would need to consider a general equilibrium model with a loss function of the monetary authority.

5.2 Evidence from the TVP-VAR

Figures 9 to 13 show the responses of excess dividends, the equity premium, stock prices and its decompositions to the monetary policy shock over time. In general, the TVP-VAR confirms the main findings from our constant coefficient VAR model, but we nevertheless find some time-variation in the impulse responses, which helps to shed light on the question, whether a LATW policy is particularly effective during specific periods of time, especially in times of stronger mispricing.

Figure 9 shows that the negative response of excess dividends was quite stable over time and increased in absolute terms only towards the end of the sample. For the expected equity risk premium, time variation in the response is more pronounced. Figure 10 shows that up until around 1985, the positive response of the expected equity premium was very modest and around five BPS. Thereafter, the response increased considerably and became more volatile. Similarly, the impulse response of the stock price index shown in Figure 11 shows quite a substantial degree of time variation. Until the mid-1980s, the S&P500 decreased by around five percent following a monetary tightening of 100 BPS. Thereafter, however, the response increased in absolute value to around 15 percent during the dot-com bubble in the late 1990's and the last quarters in 2014.

[Figures 9, 10 and 11 about here.]

Correspondingly, also the individual components respond stronger during the latter part of the sample. As shown in Figure 12, the impact of the implied risk-adjusted fundamental component continuously became stronger in explaining the decline in stock prices from around three percent in 1980 to around six percent at the end of the sample. Yet, as also the stock price responds more strongly towards the end of the sample, the risk-adjusted fundamental component accounts for a larger share of the overall stock price decrease in the early part of the sample until about 1985. This is also confirmed by Figure 13 which shows the mispricing component over time. Over the whole sample period, we confirm the negative response of the mispricing component to a contractionary monetary policy, providing strong evidence that the central bank could lower excessive price movements in stocks by raising its policy rate. Yet, we observe that the response has increased sharply in absolute value around 1990 and is particularly strong between 1995 and 2001, the period that is associated with the stock price boom during the dot-com bubble. Our evidence thus suggests, that a tighter monetary policy stance during this period could have reduced mispricing by about ten percent.[23]

[23] In contrast to the time-variation in responses of financial variables, the response of output to monetary policy shocks is relatively stable across time and corresponds to the responses estimated using the C-VAR.

[Figures 12 and 13 about here.]

To summarize, the results of the TVP-VAR offer support to the proponents of a LATW policy and indicate that a monetary tightening lowers the excessive stock prices. To give an indication of the significance of these findings over time, Figure 14 displays the probability of a negative cumulative response of the mispricing component over time at selected horizons from the credible set of accepted impulse responses. For all times and all horizons, this probability is larger than 50%. For short horizons of up to one year, this probability is considerably larger and takes values of up to 85% for the one quarter horizon and the time period of 1990 to 2000. At the impact horizon the probability of a negative response shows the largest time-variation. Accordingly, during the period 1990 to 2001 when the S&P500 was most likely overpriced, a monetary policy contraction would have been most likely effective in attenuating mispricing.

[Figure 14 about here.]

5.3 Robustness test: Monetary policy at the zero lower bound

In response to the global financial crisis, the Federal Reserve Bank has gradually lowered its target range for the federal funds rate until it has reached the zero-lower bound (ZLB) in December 2008. From this time onwards, the federal funds rate could not been used anymore as an instrument to further stimulate the economy. To evaluate whether the estimated time-variation in the effects of monetary policy over time was affected by this constraint, we repeat our estimations using the Wu & Xia (2014) shadow rate instead of the federal funds rate in our VAR. The shadow rate accounts for monetary policy effects on the term structure of interest rates in a ZLB environment and is used a measure of the federal funds rate that would prevail in the absence of the ZLB.

Figures 15 to 19 show the impulse responses of excess dividends, the equity premium, stock prices, the risk-adjusted fundamental and the speculative component over time. We find that the main results are confirmed. However, the impact responses are somewhat smaller than in the benchmark model. Moreover, we find that the time-variation in the response of the mispricing component is now less pronounced (Figure 19). In particular, while the response still increases in absolute value over time, the dot-com bubble episode does not stand out anymore. Nonetheless, from 2000 onwards, monetary policy seems to have worked more strongly on stock prices through the mispricing component than through fundamental factors.

[Figures 15, 16, 17, 18 and 19 about here.]

6 Conclusion

In this paper, we address the question whether central banks could implement a leaning against the wind monetary policy to attenuate excessive stock price developments. For this, we develop a partial equilibrium asset pricing model that allows us to decompose the observed stock price into a fundamental component, a required risk premium and a mispricing component. In our framework, mispricing may occur due to wrong subjective believes of irrational investors about the future development of fundamental determinants of stock prices or due to a violation of the transversality condition. We then evaluate how monetary policy affects stock prices through these three components. While the theory provides unique predictions for the response of the fundamental component and the expected risk premium, the response of the mispricing component is ambiguous. Hence, we attempt to answer this question empirically.

Earlier literature has shown that one obtains diametrically opposing results on the response of stock prices and a possible mispricing component depending on whether one assumes that monetary policy reacts contemporaneously or only with a delay to news in stock prices. By adopting a flexible identification scheme of combining zero impact and long run restrictions augmented by sign restrictions, we show that the data in fact suggests a significant countercyclical response of the U.S. Federal Reserve to stock price shocks.

Moreover, we find that stock prices decrease significantly and persistently in response to a monetary policy tightening. We then carry out an accounting exercise to distinguish the different channels of how monetary policy affects stock prices. Here, we find that fundamental factors such as a decrease in dividends and an increase in the discount factor, as well as an increase in the expected equity premium can account for about half of the immediate five percent fall in stock prices. Hence, we conclude that the other half of the decrease in stock prices can be attributed to a negative response of the mispricing component. By this, we provide tentative support to the claims of proponents of a more active, leaning against the wind monetary policy. If stocks are overpriced, contractionary monetary policy can be used to lower this mispricing. However, this comes at the cost of considerable downward pressure on real economic activity.

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A Derivation of Equation (3)

Under the assumption that the price-dividend ratio is stationary, the log-linear approximation of equation (1) is given by:

$$\begin{aligned} r_{t+1} &= \log(P_{t+1} + D_{t+1}) - \log(P_t) \\ &= p_{t+1} - p_t + \log\left(1 + \exp(d_{t+1} - p_{t+1})\right), \end{aligned} \tag{17}$$

where logs of variables are denoted by lowercase letters and $r_{t+1} = \log(1 + R_{t+1})$. Log-linearizing equation (17) around the steady state using a first-order Taylor expansion, we obtain:

$$r_{t+1} = k + \rho p_{t+1} + (1 - \rho) d_{t+1} - p_t, \tag{18}$$

where ρ and k are parameters of linearization defined as $\rho \equiv 1/\left(1 + \exp(\overline{d - p})\right)$, where $\left(\overline{d - p}\right)$ is the average log dividend-price ratio (such that $0 < \rho < 1$), and $k \equiv -\log(\rho) - (1 - \rho)\log(1/\rho - 1)$.

Solving equation (18) for p_t and iterating forward, the stock price can be written (disregarding a the constant term k) as a linear combination of future dividends, future stock returns, and a terminal value:

$$p_t = \sum_{i=1}^{\infty} \rho^{i-1} \left[(1 - \rho) d_{t+i} - r_{t+i}\right] + \lim_{T \to \infty} \rho^T p_{t+T}. \tag{19}$$

B Priors and estimation

We follow Primiceri (2005) and Galí & Gambetti (2015) and assume that the initial states for the coefficients θ_t, the covariances α_t, the log volatilities σ_t and the hyperparameters Q, V and W are independent of each other. The priors for the initial states of the coefficients, the covariances and the log standard errors are assumed to be normally distributed. The priors of the hyperparameters are assumed to be distributed as independent inverse-Wishart. All these assumptions are standard in the literature as described in Primiceri (2005). In specific,

the priors take the forms:

$$
\begin{aligned}
\theta_0 &\sim N(\hat{\theta}, 4 * \widehat{Cov}(\theta)) \\
\alpha_{i0} &\sim N(\hat{\alpha}, \widehat{Cov}(\alpha_i)) \\
ln(\sigma_0) &\sim N(ln(\hat{\sigma}), I_K) \\
Q^{-1} &\sim IW(k_Q(K+1)\widehat{Cov}(\theta), K+1) \\
V_i^{-1} &\sim IW(k_V(i+1)\widehat{Cov}(\alpha_i), i+1) \\
W^{-1} &\sim IW(k_W(K+1)I_K, K+1)
\end{aligned}
$$

where the parameters with hat indicate OLS-estimates from a constant VAR for a training sample with $T_0 = 40$ observations and with $k_Q = 0.005$, $k_V = 0.01$, $k_W = 0.01$ so that the priors are not flat but diffuse and uninformative. Note that the prior V is an inverse-Wishart with degrees of freedom and scale parameter adjusted to the number of variables in the respective equation $i = 2, \ldots, n$.

The model is estimated using the Gibbs sampling algorithm described in Del Negro & Primiceri (2013). A summary is available in the online appendix of Galí & Gambetti (2015).

C Figures

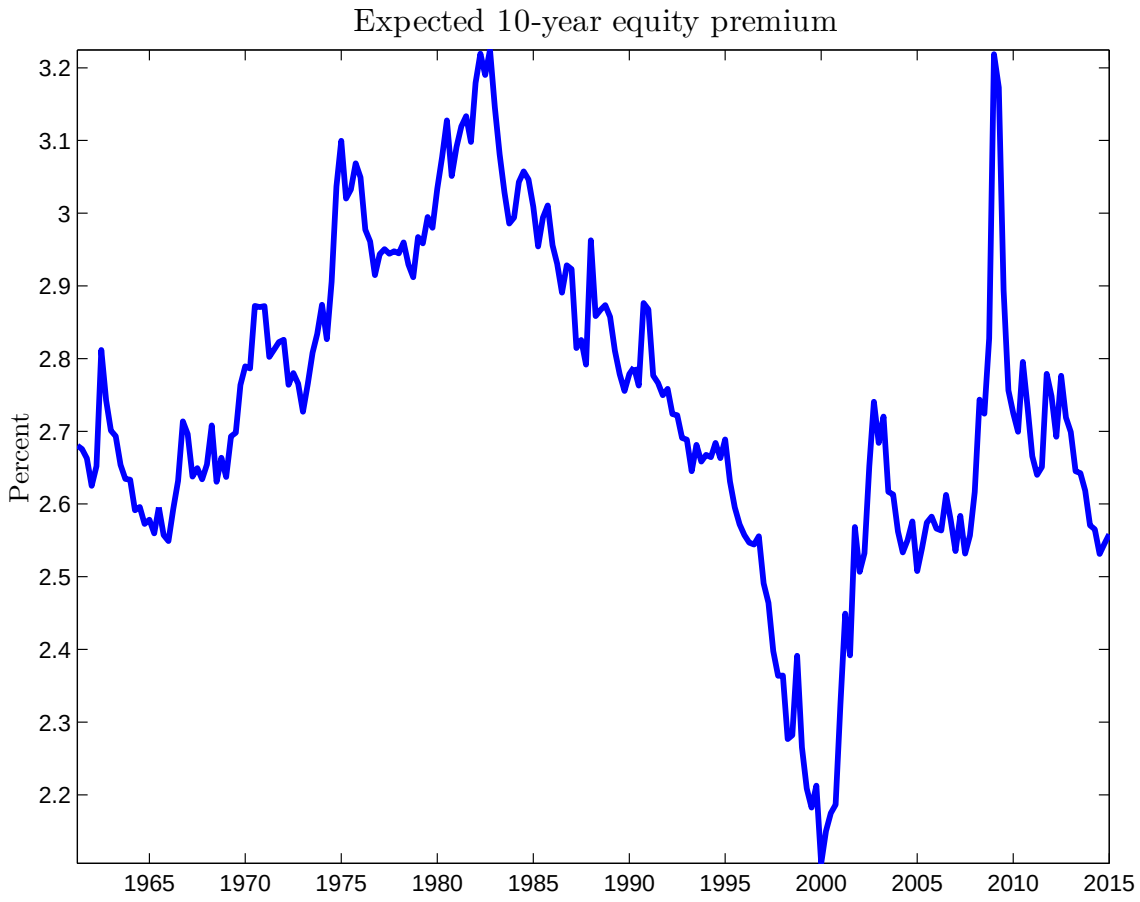

Figure 1: Estimated expected 10-year equity premium as obtained as forecasts from the auxiliary VAR.

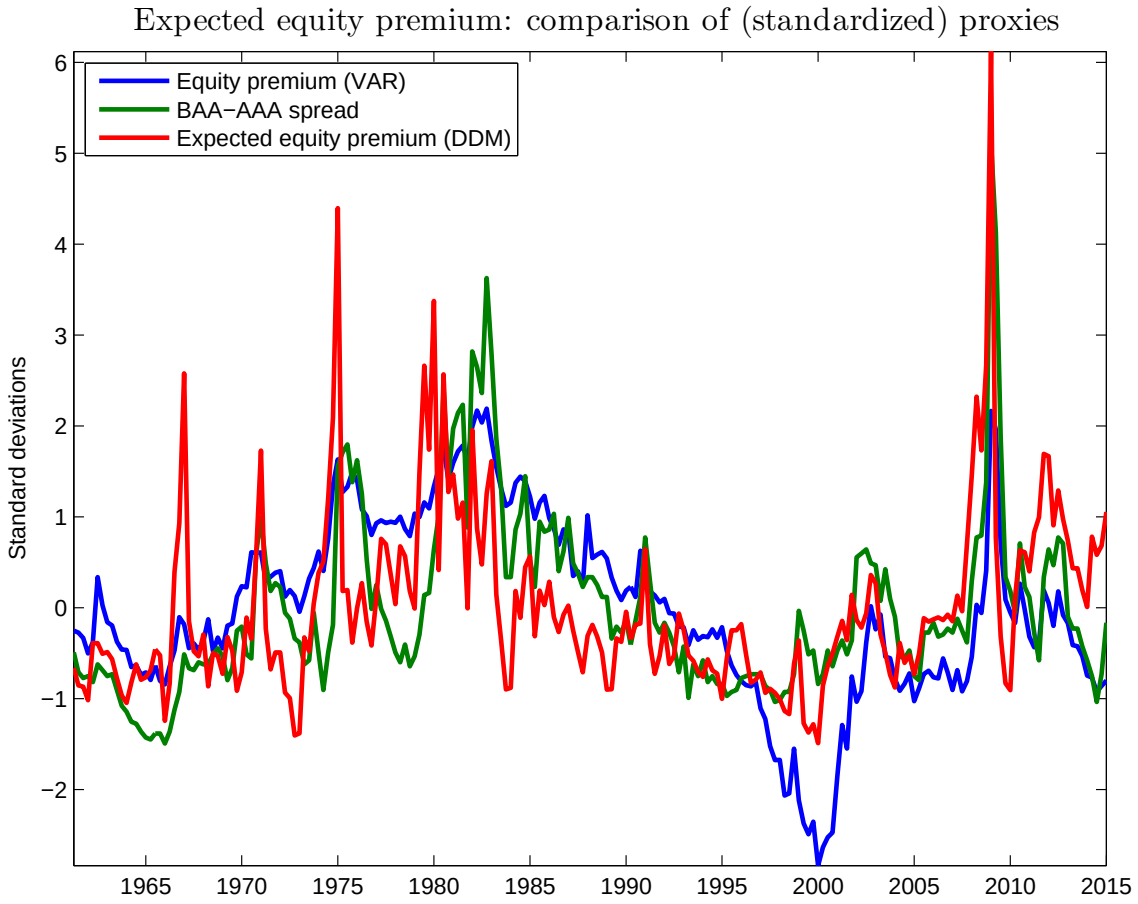

Figure 2: Comparison of standardized proxies for the expected 10-year equity premium.

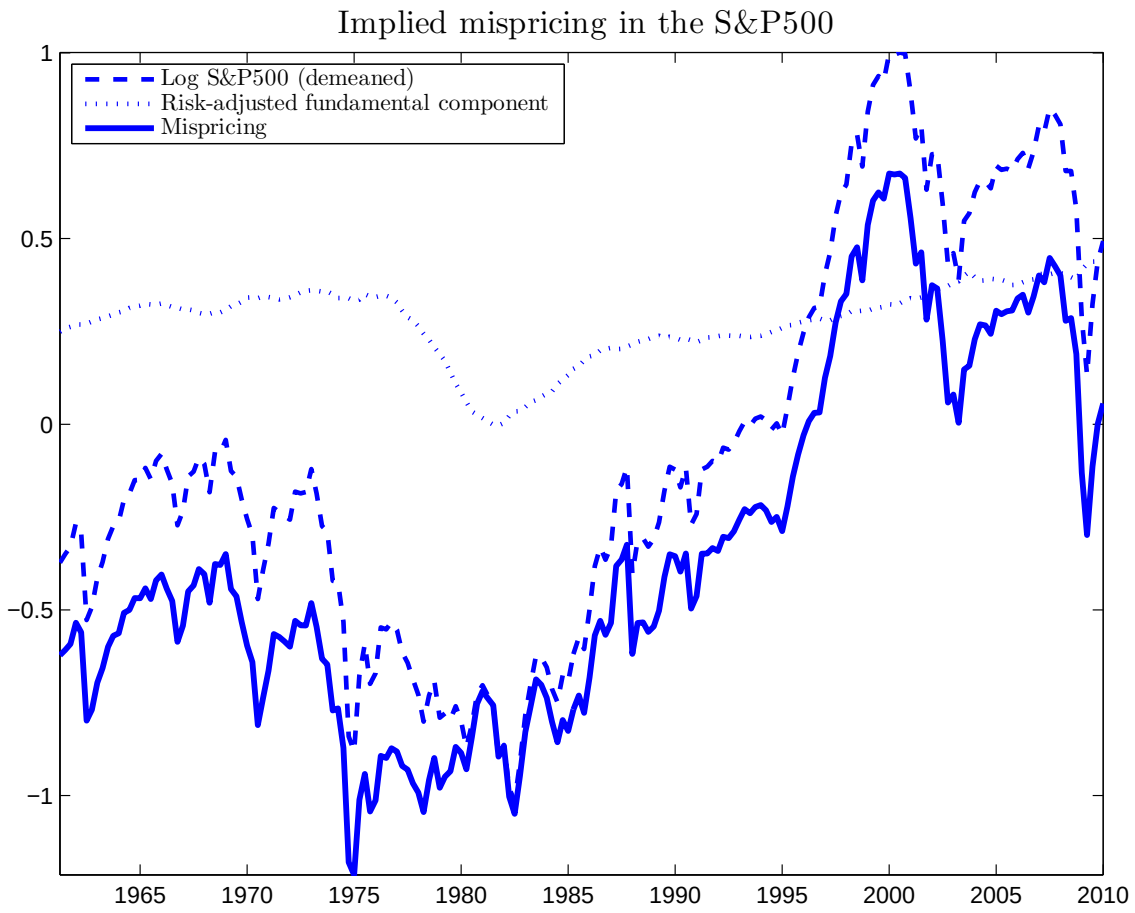

Figure 3: Log real S&P500 index (demeaned) and implied risk-adjusted fundamental and mispricing components from (7).

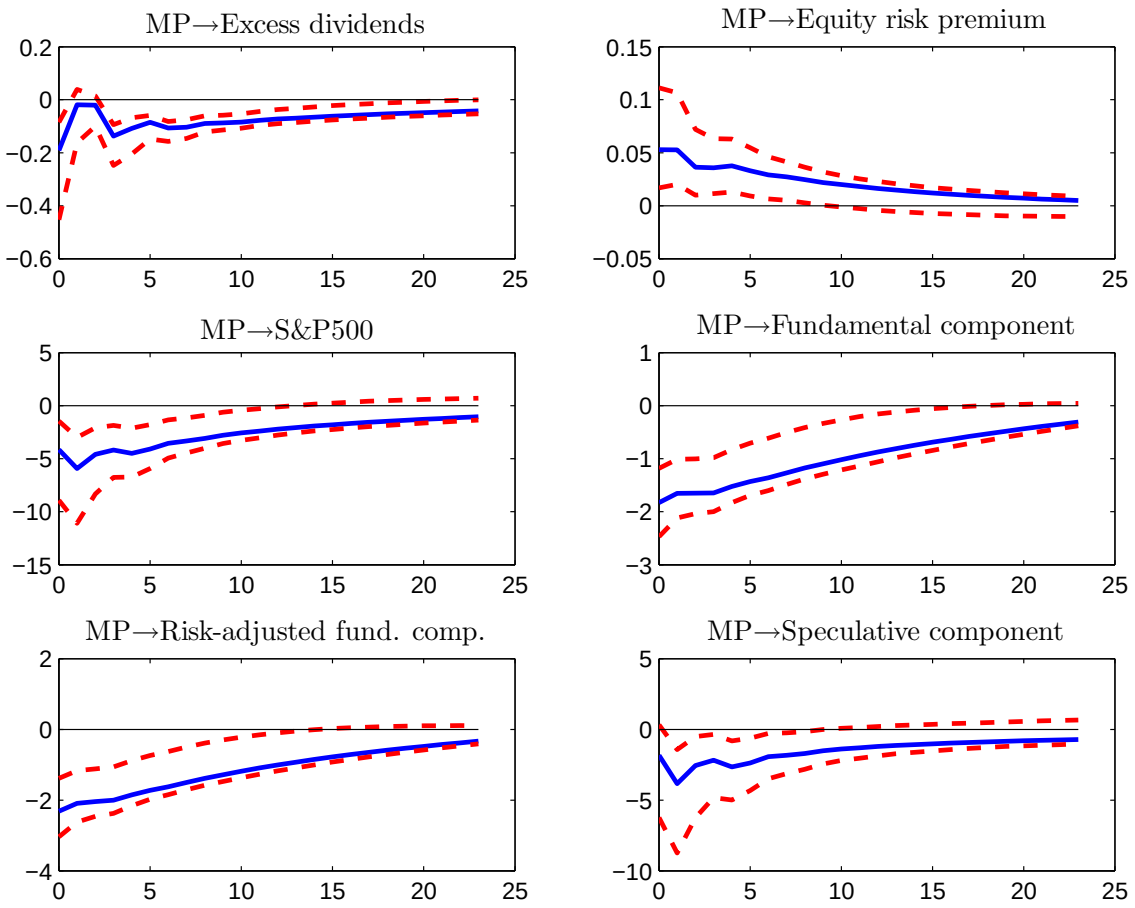

Figure 4: Cumulative responses (in percent) of excess dividends, the equity premium, the S&P500 price and its implied components to a 100 BPS increase in the federal funds rate (median and 68% credible set).

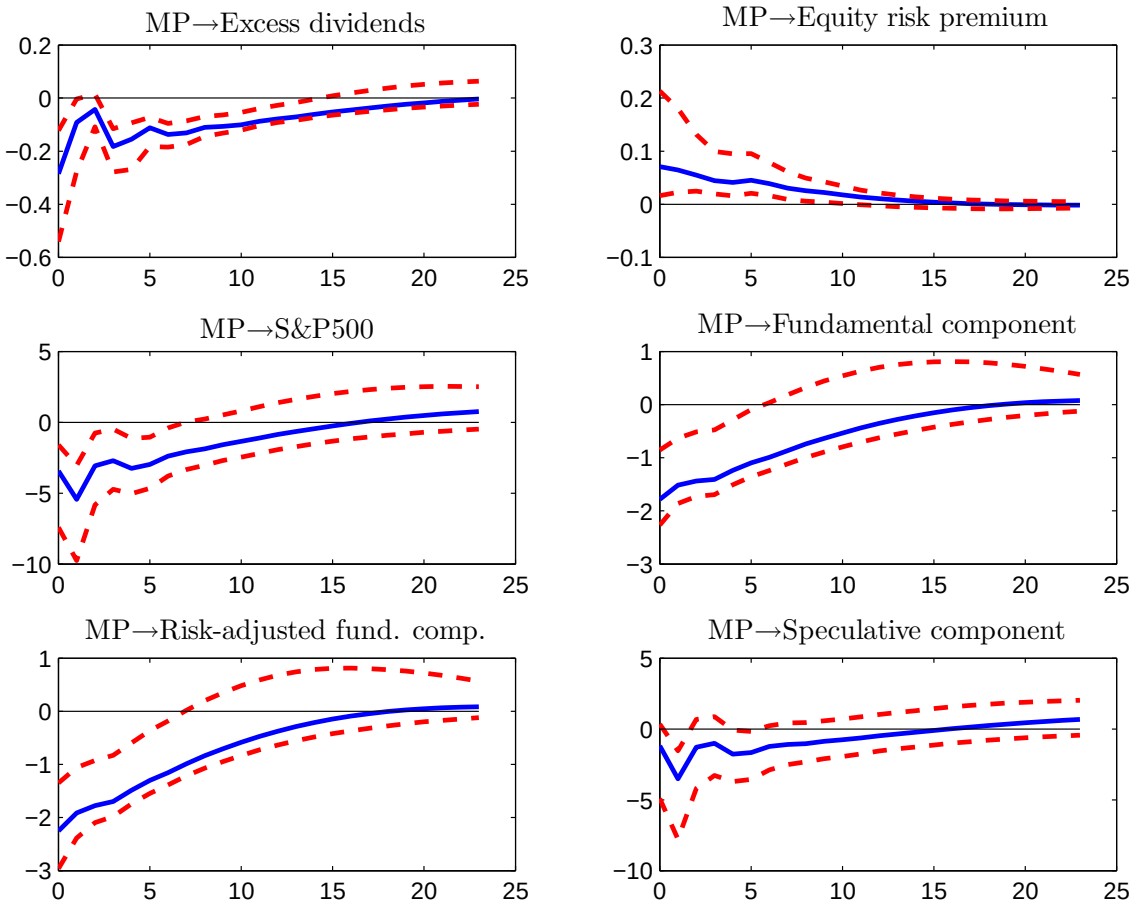

Figure 5: Cumulative responses (in percent) of excess dividends, the equity premium, the S&P500 price and its implied components to a 100 BPS increase in the federal funds rate (median and 68% credible set), where the equity risk premium is measured as the BAA-AAA spread.

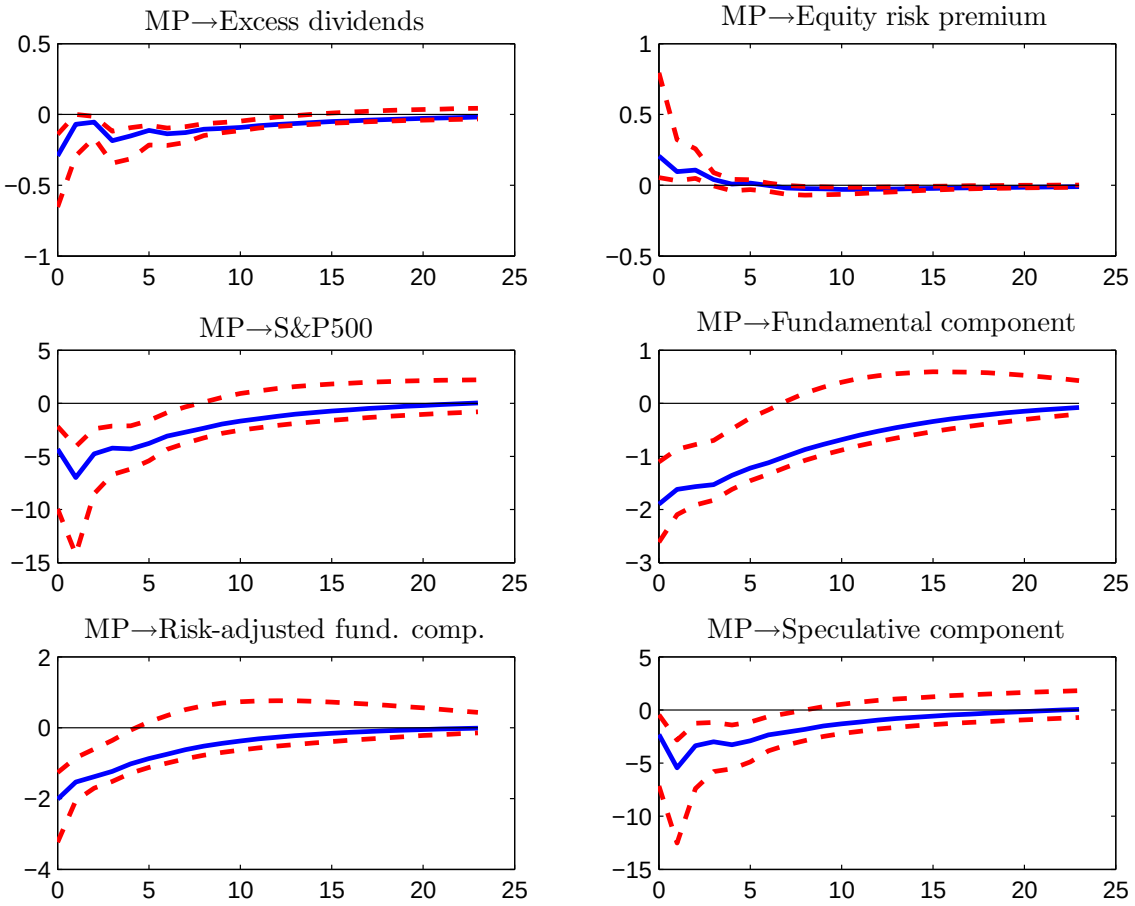

Figure 6: Cumulative responses (in percent) of excess dividends, the equity premium, the S&P500 price and its implied components to a 100 BPS increase in the federal funds rate (median and 68% credible set), where the equity risk premium is obtained from the dividend discount model (DDM).

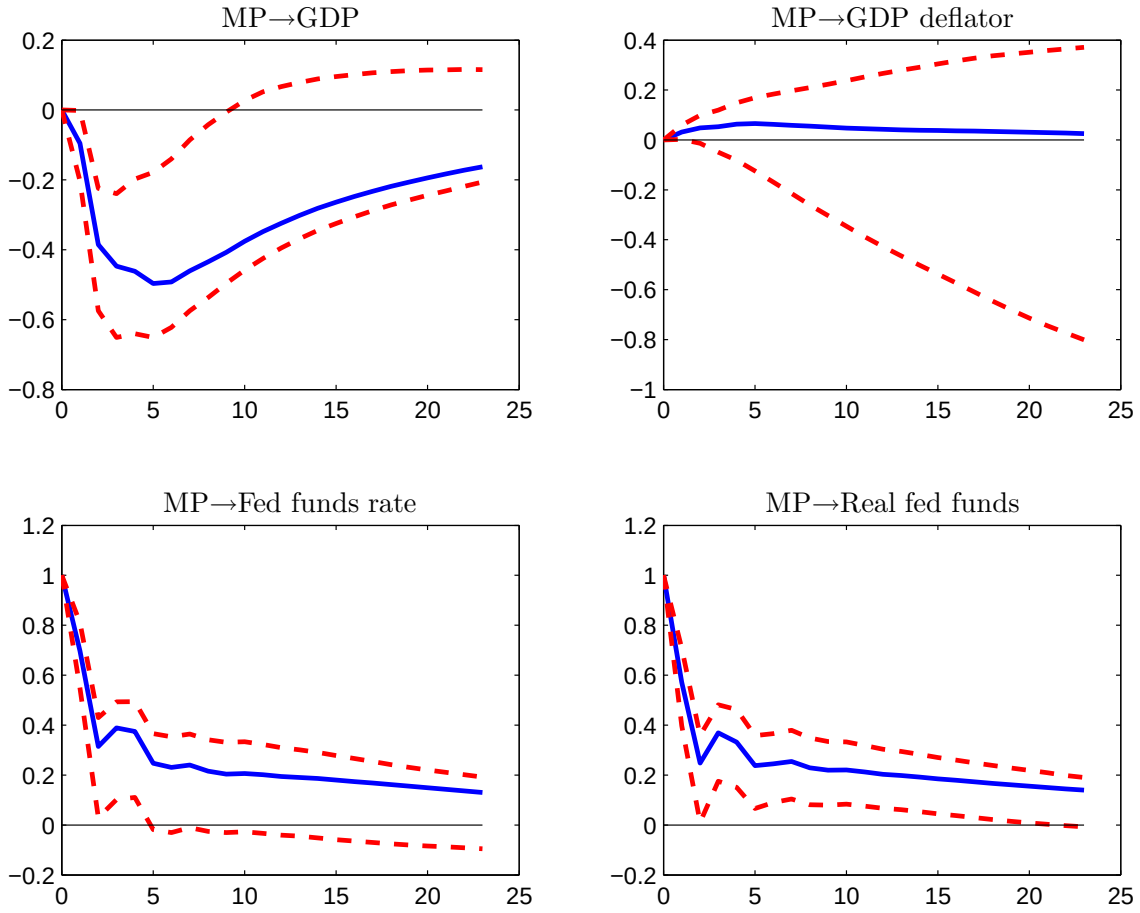

Figure 7: Cumulative responses (in percent) of real economic variables to a 100 BPS increase in the federal funds rate.

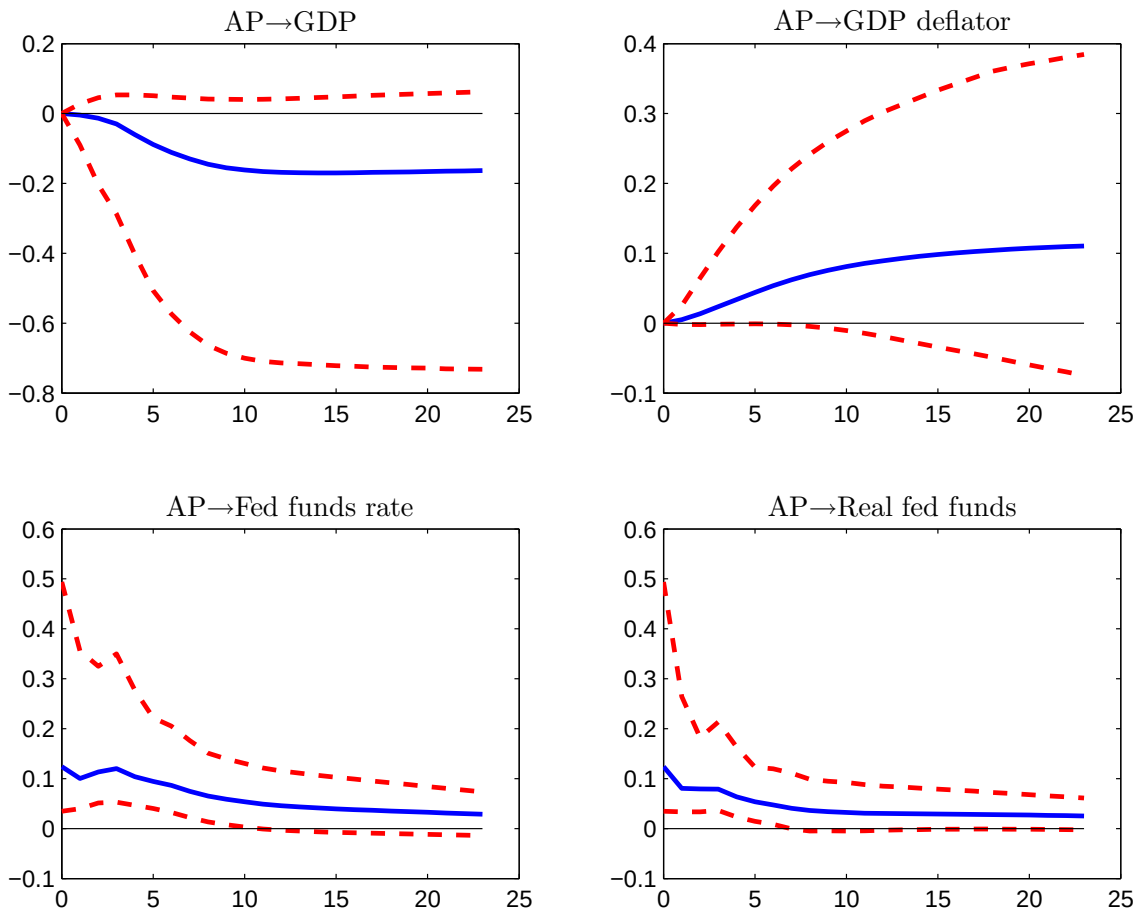

Figure 8: Cumulative responses (in percent) of real economic variables and the nominal and real policy rates to an exogenous one percent stock price increase.

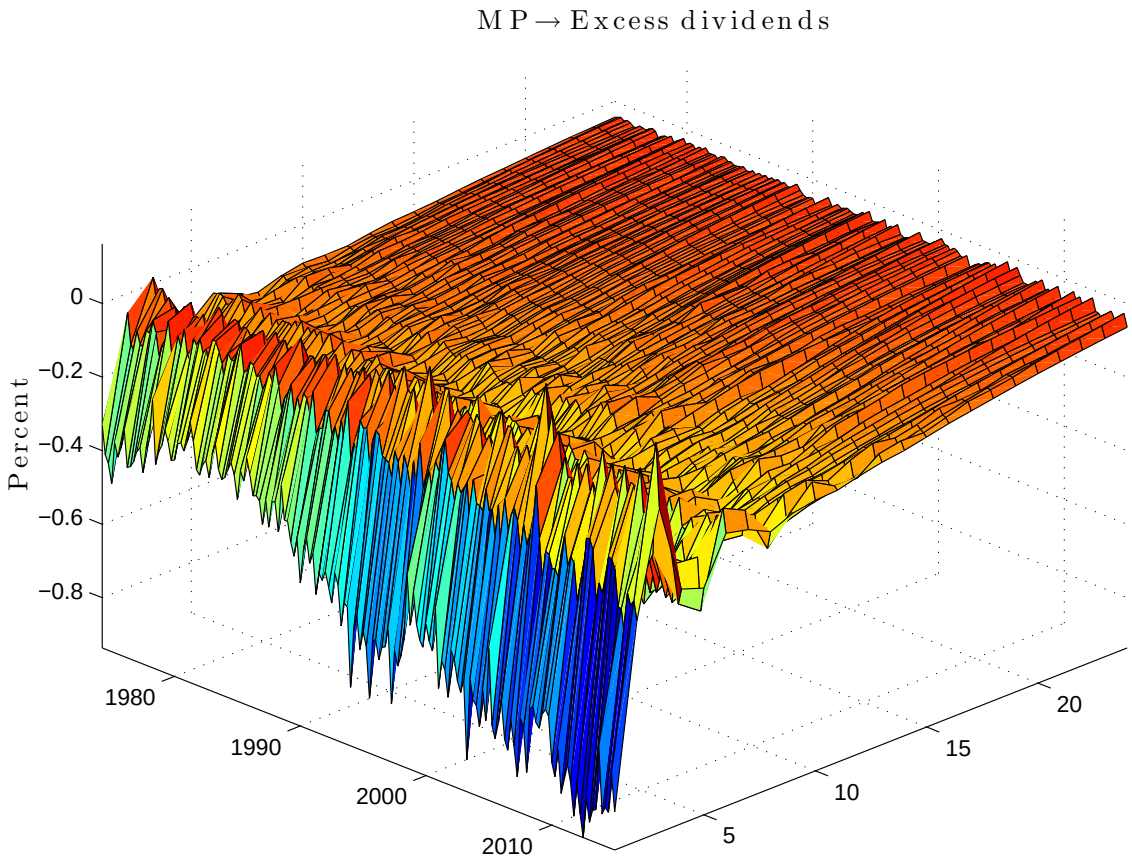

Figure 9: Cumulative, time-varying response of excess dividends to a 100 BPS increase in the federal funds rate.

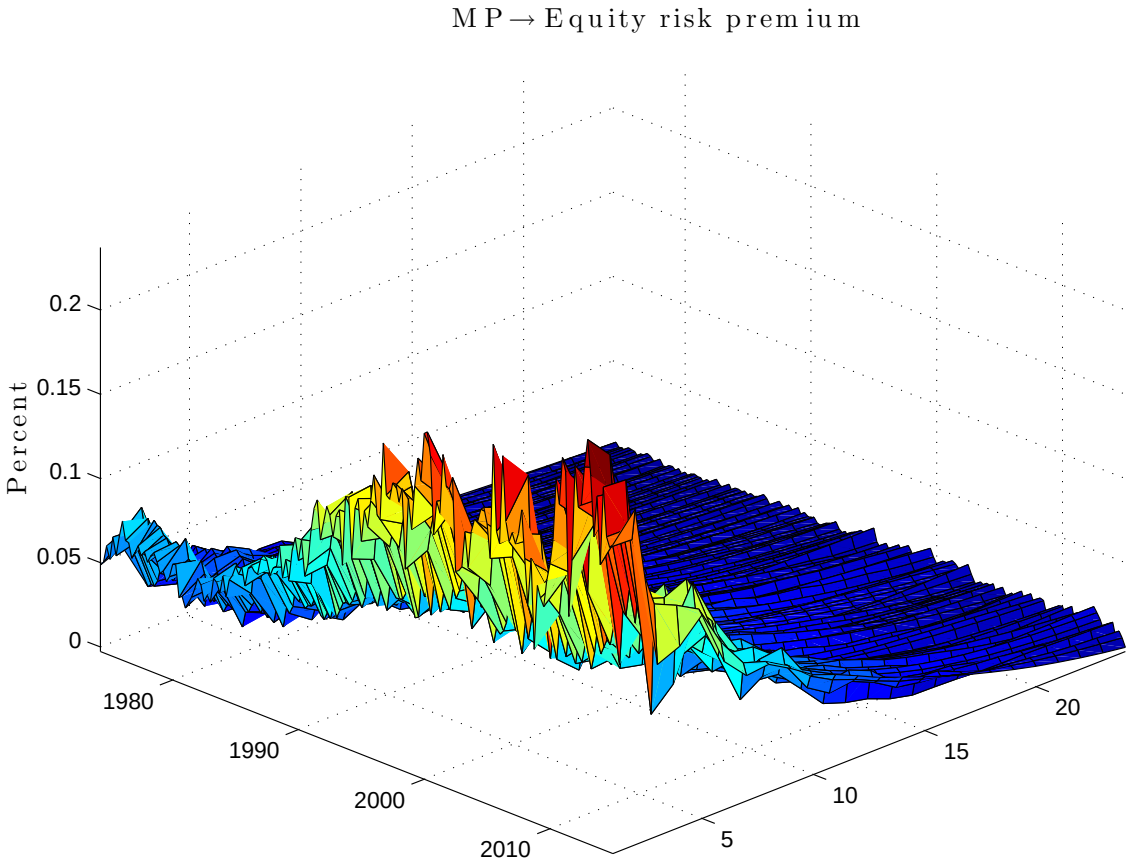

Figure 10: Cumulative, time-varying response of the equity risk premium to a 100 BPS increase in the federal funds rate.

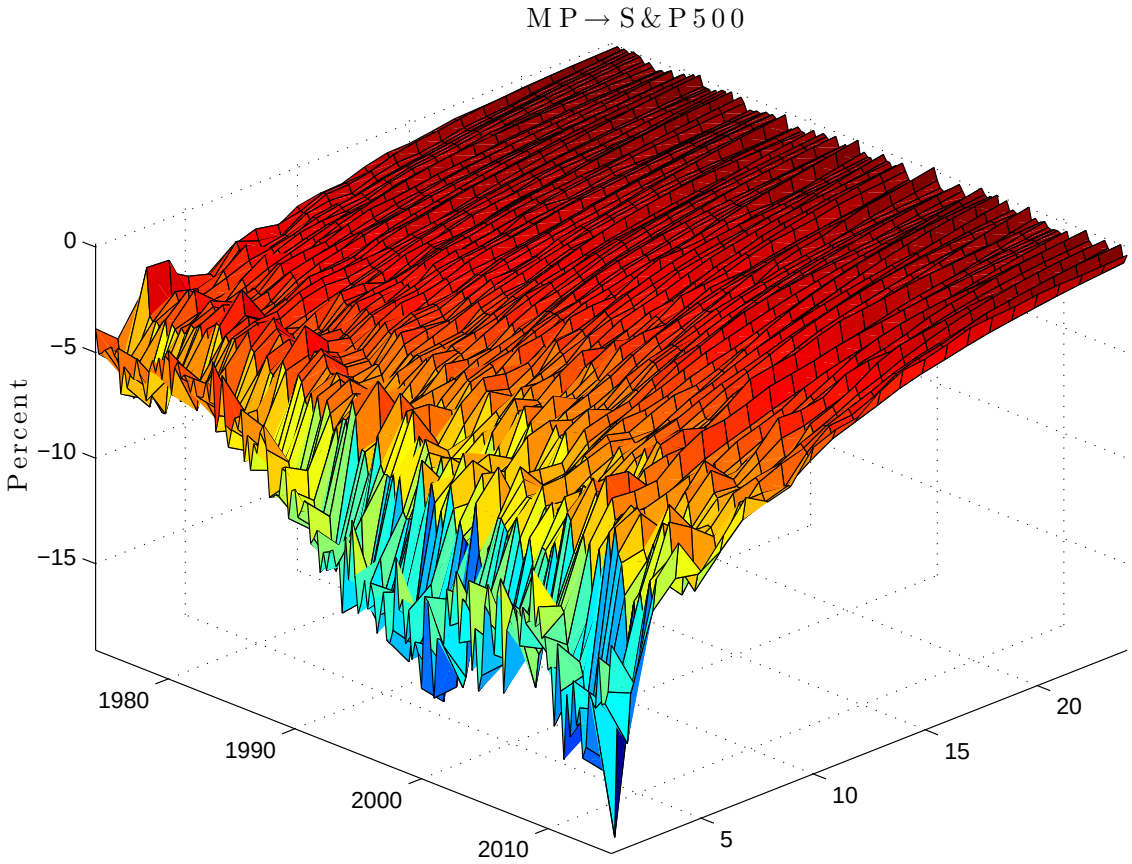

Figure 11: Cumulative, time-varying response of the S&P500 index to a 100 BPS increase in the federal funds rate.

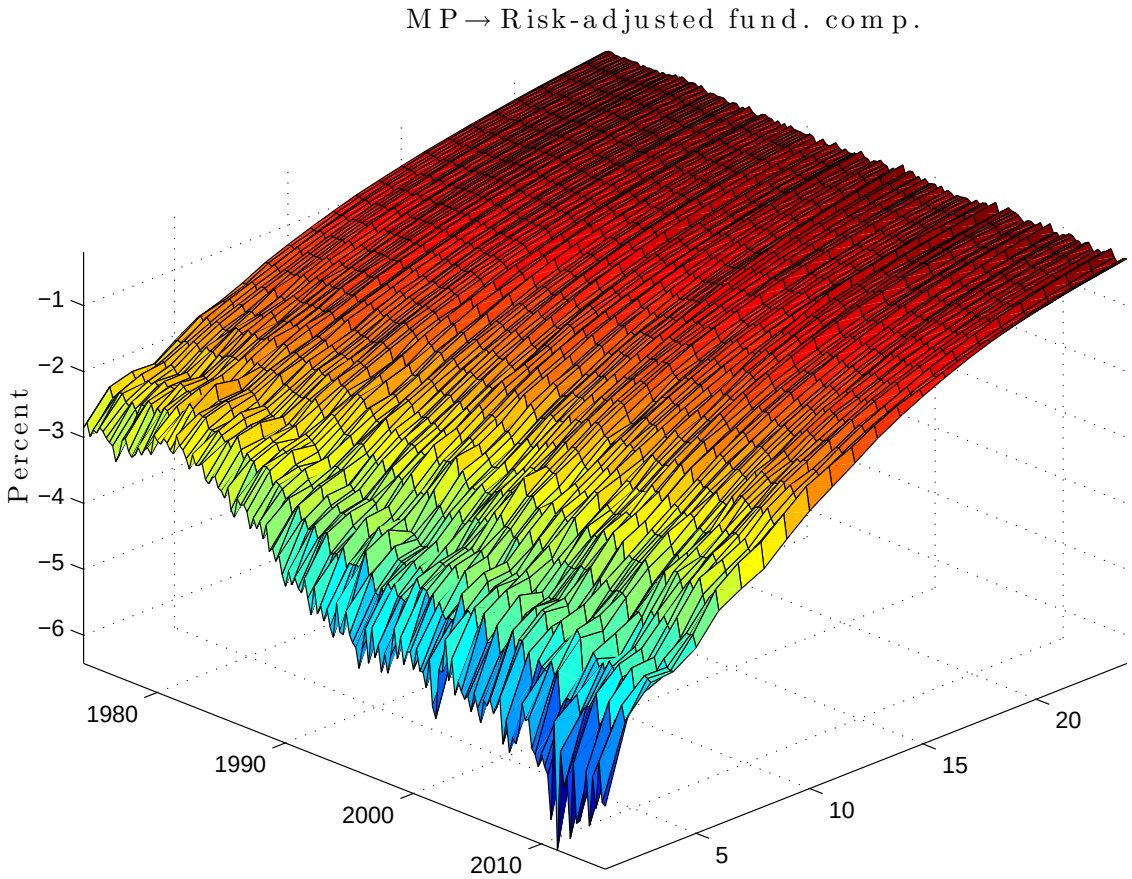

Figure 12: Cumulative, time-varying response of the risk-adjusted fundamental component to a 100 BPS increase in the federal funds rate.

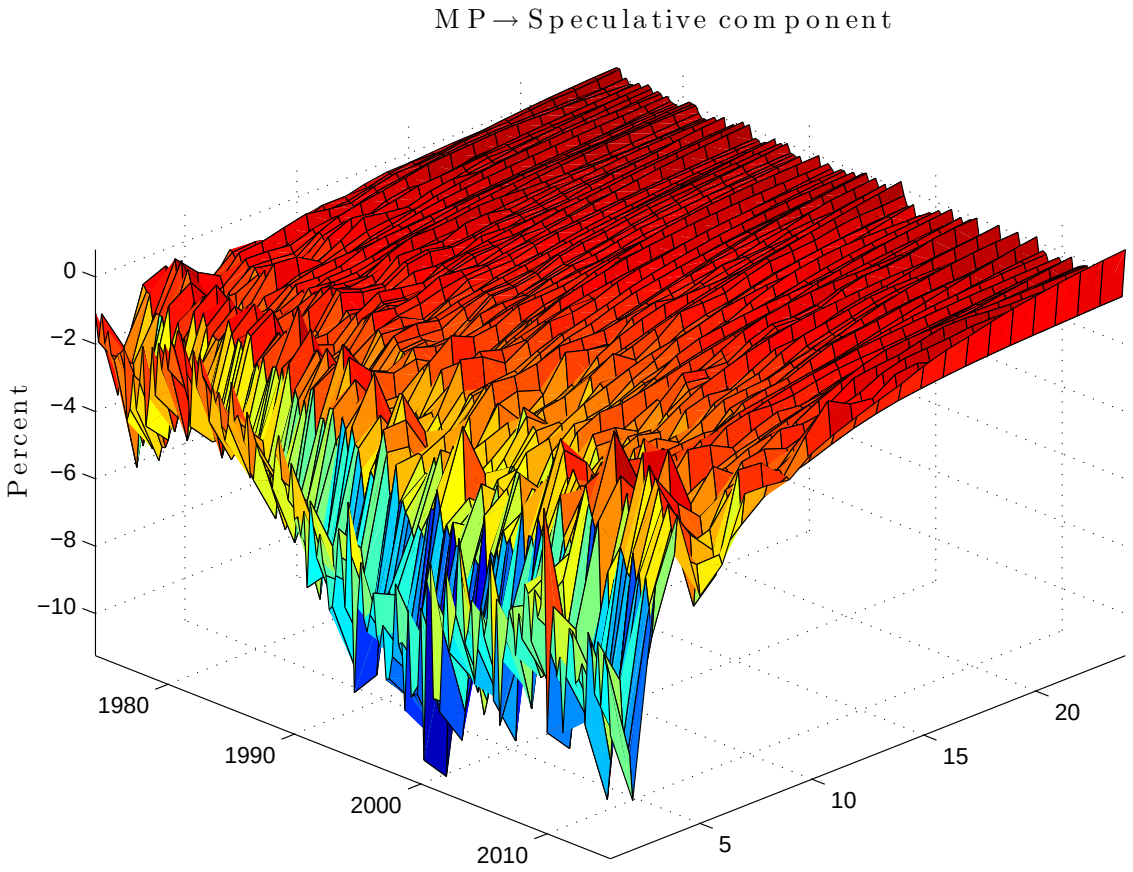

Figure 13: Cumulative, time-varying response of the mispricing component to a 100 BPS increase in the federal funds rate.

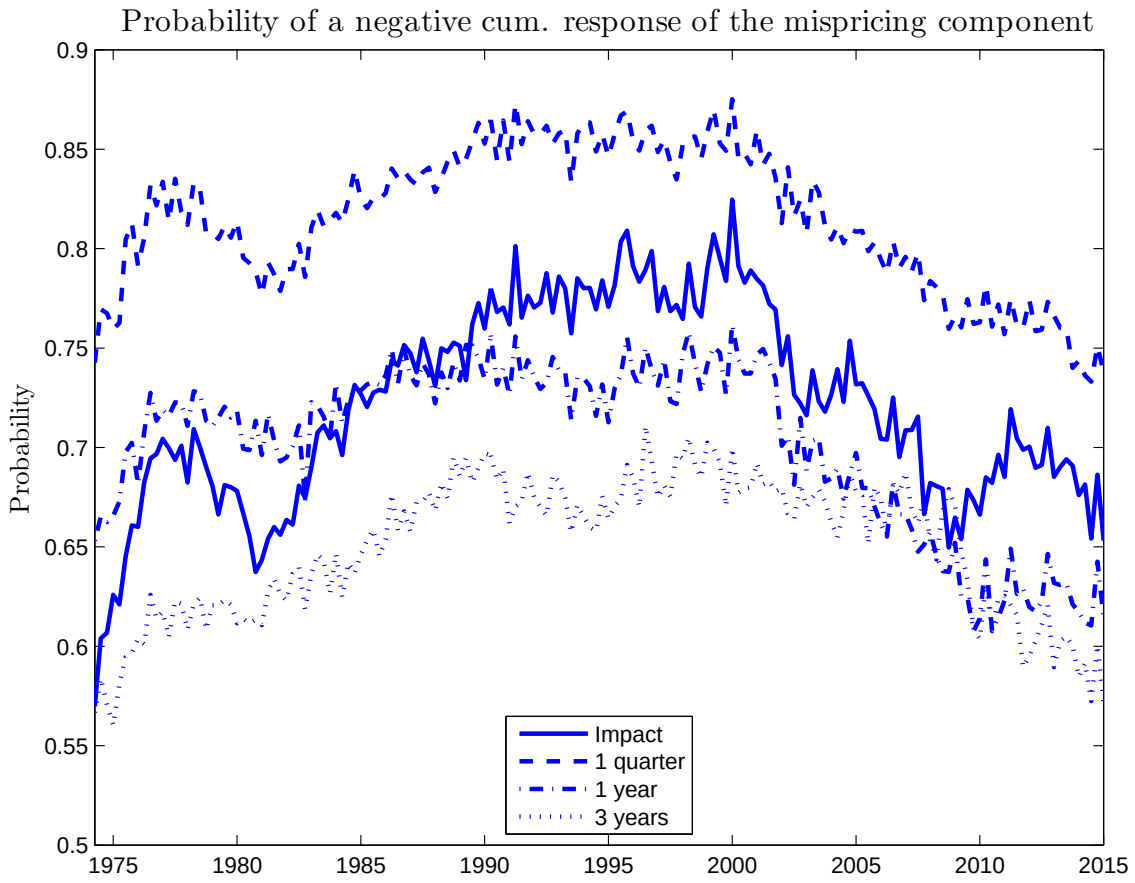

Figure 14: Probability of a negative cumulative response of the mispricing component to a 100 BPS increase in the federal funds rate over time at selected horizons.

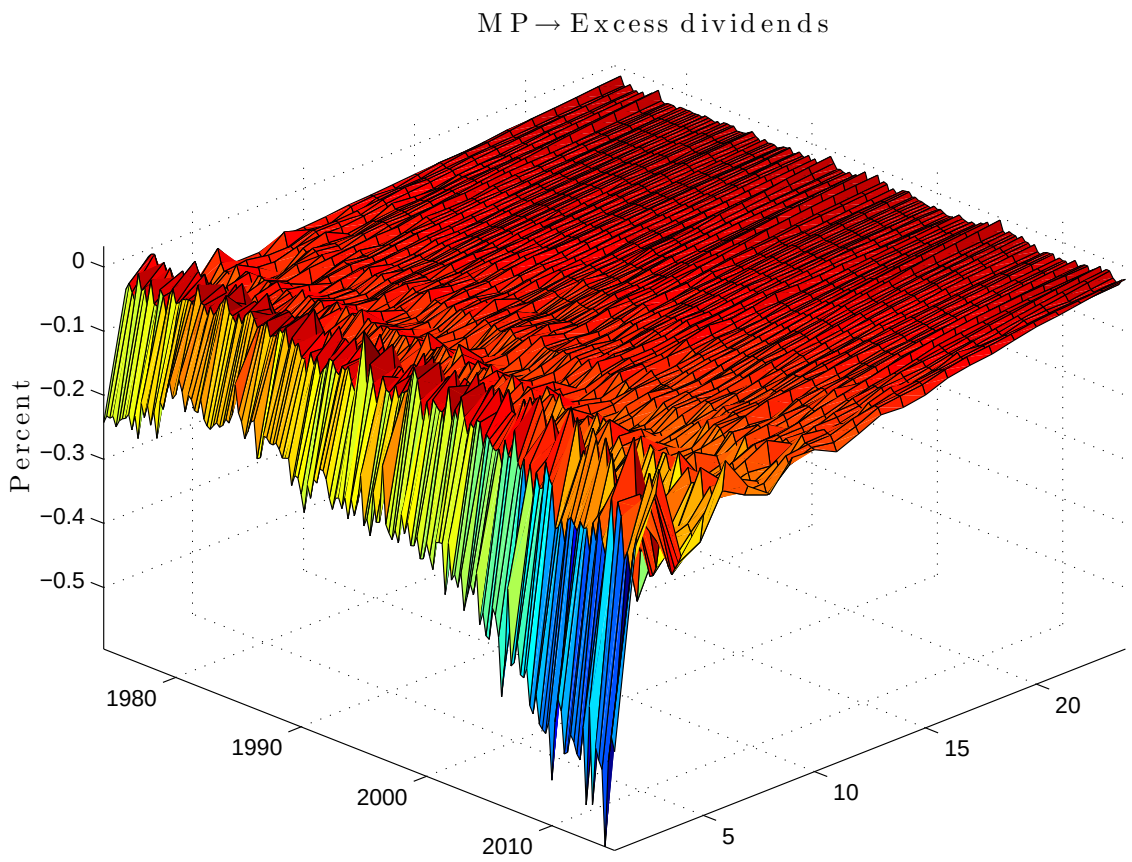

Figure 15: Cumulative, time-varying response of excess dividends to a 100 BPS increase in the Wu & Xia (2014) shadow rate.

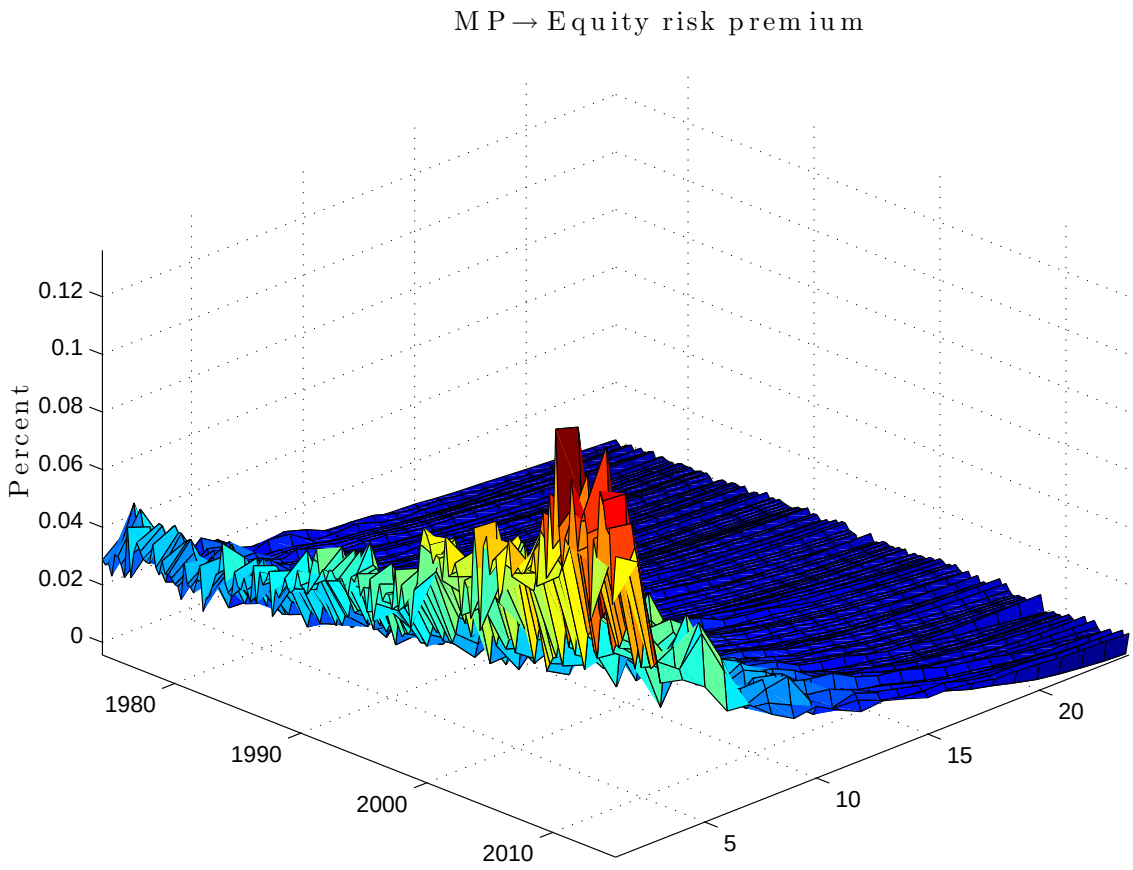

Figure 16: Cumulative, time-varying response of the equity risk premium to a 100 BPS increase in the Wu & Xia (2014) shadow rate.

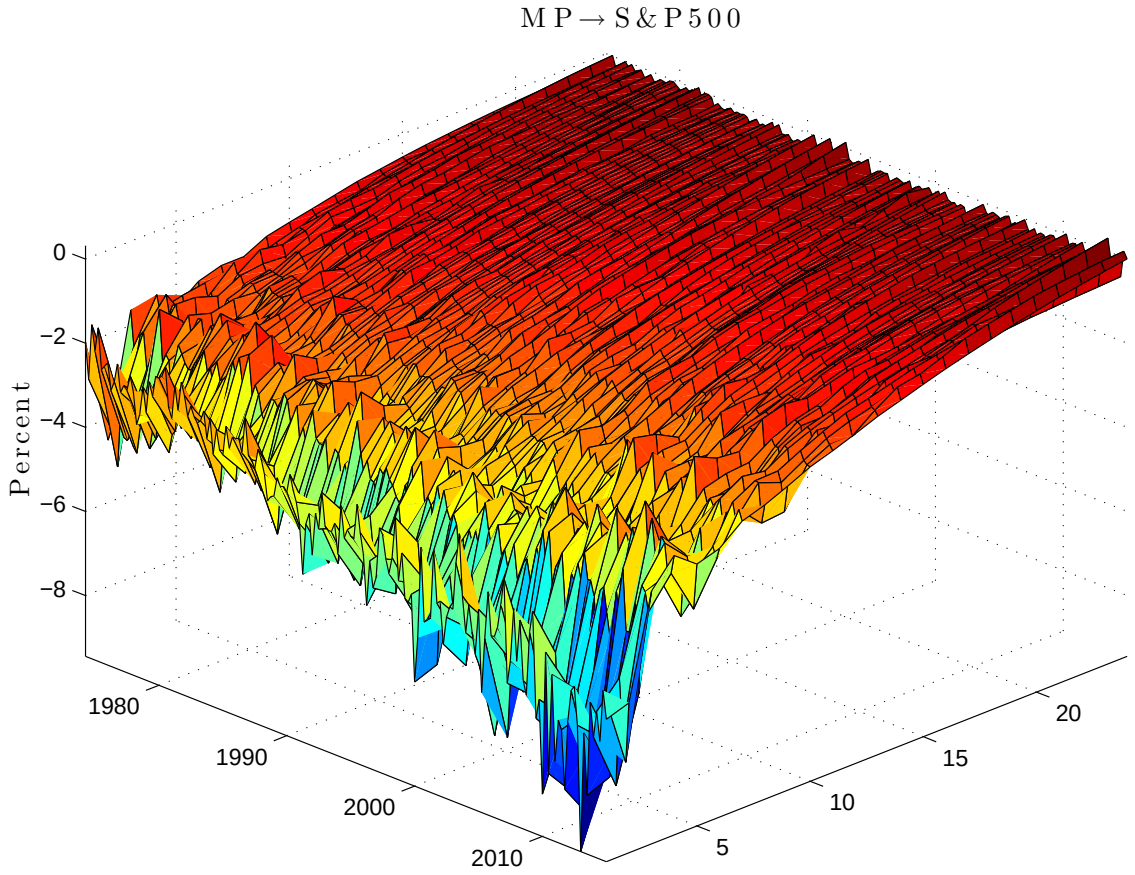

Figure 17: Cumulative, time-varying response of the S&P500 index to a 100 BPS increase in the Wu & Xia (2014) shadow rate.

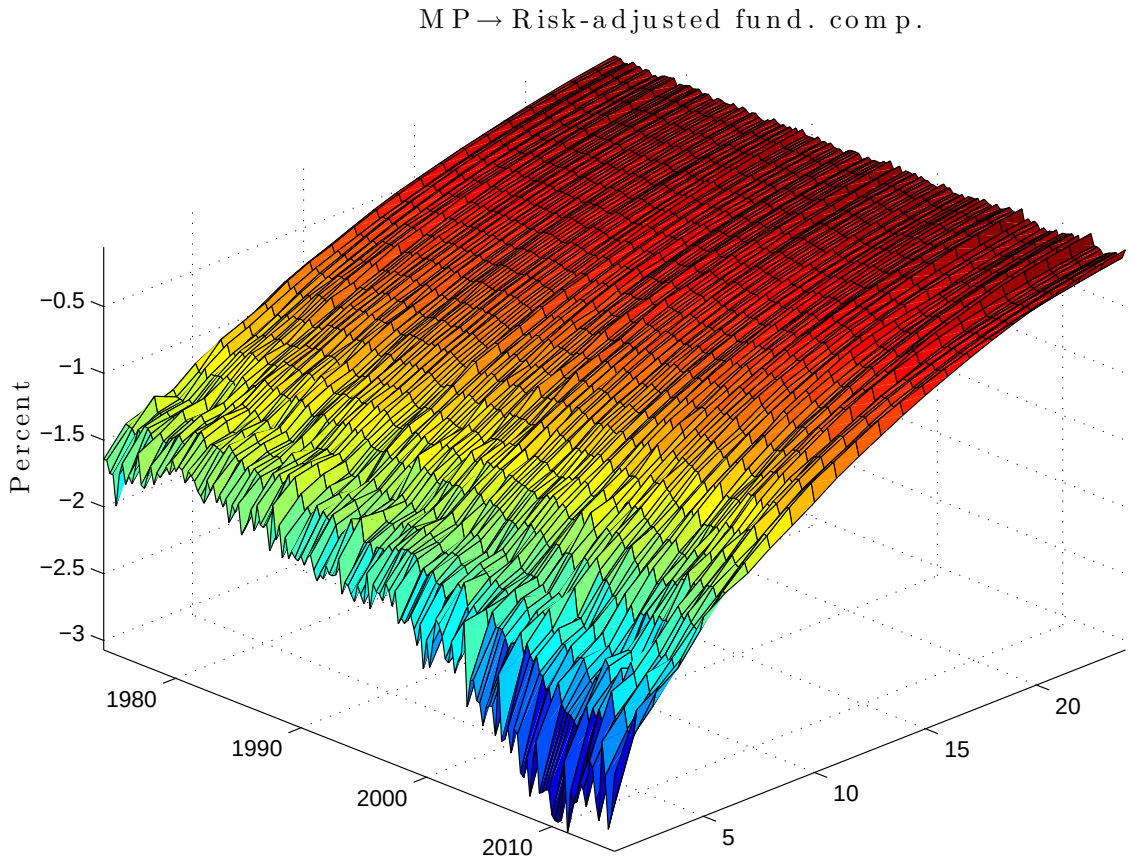

Figure 18: Cumulative, time-varying response of the risk-adjusted fundamental component to a 100 BPS increase in the Wu & Xia (2014) shadow rate.

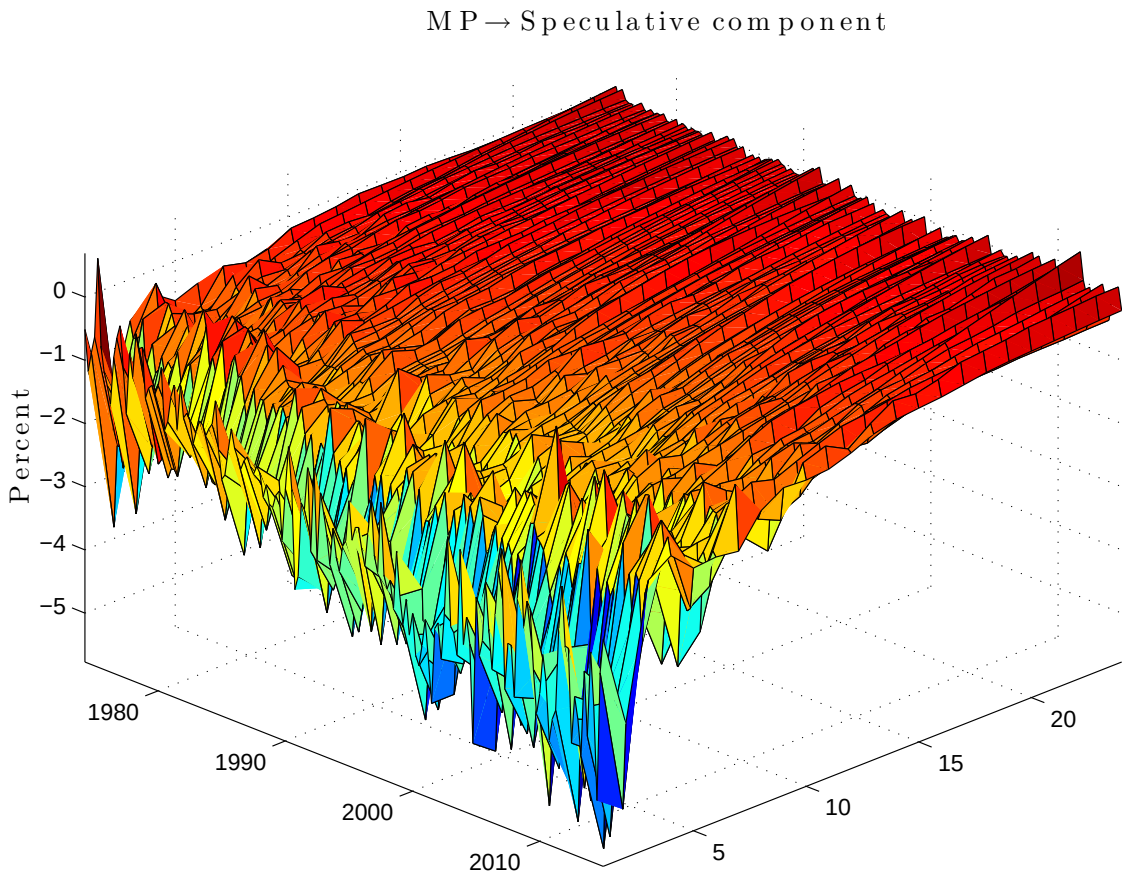

Figure 19: Cumulative, time-varying response of the mispricing component to a 100 BPS increase in the Wu & Xia (2014) shadow rate.